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Land Use Change and Sustainability

Edited by Seth Appiah-Opoku

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Meet the editor

Dr. Appiah-Opoku is a professor of geography at the University of Alabama, Tuscaloosa, AL, USA. He teaches world regional geography, regional geography of Africa, environmental management, land use regulation, principles of planning, regional planning and analysis, and a summer abroad course. He is also a member of the American Institute of Certified Planners and the author of two books. He has edited three other books. His research focuses on environmental assessment, ecotourism, transportation planning, international development issues, and regional planning. He has served on the international editorial board of the *Journal of Environmental Impact Assessment Review* since 2003 and has published scholarly articles in several renowned journals including *Habitat International*, *Transport Research Part A: Policy and Practice*, *Journal of Urban Planning and Development*, *Journal of Transport and Health*, *Environmental Management*, *Journal of Cultural Geography*, and *Plan Canada*. He was a member of the Technical Advisory Team that advised the government of Ghana on the preparation of a 40-year development plan for the country in 2015.

Contents

Preface

The concept of "land use" refers to humanity's manipulation of the natural environment in the quest for survival. It encompasses socioeconomic, political, and technological activities or decisions that affect the use of land. In this endeavor, several factors have contributed to land use changes that threaten the earth's environment and the survival of humanity. The factors include demographic pressures that lead to overuse and misuse of land resources including urban sprawl and destruction of watersheds; ignorance of the workings of nature that manifest in global warming, air pollution, and ozone layer depletion; tragedy of the commons, which results in overuse and misuse of land resources that are communally owned; humanity's misapprehension of being above rather than part of nature resulting in poor valuation and misuse of land resources; consumerism culture that drives rich nations to overuse or misuse land resources; and poverty that results in irrational exploitation or use of land resources in developing countries. In response, the concept of sustainable development is seen as the antidote to this trend. It involves the application of thoughtful intervention strategies to meet the land resource needs of humanity both in the short and long term without placing life on earth in jeopardy.

Against this background, this book discusses aspects of land use change and sustainability in ways that may generate research ideas. It brings together discussions from leading researchers and scholars in the field of land use change and sustainability from five different countries including the USA, Ethiopia, Guyana, Taiwan, and Indonesia. Based on empirical research and case studies, the book is divided into two sections. The first section is subdivided into four chapters and discusses such issues as land use sustainability in the Northern Great Plains of the USA; effects of rural land use and tenure on sustainable management of mangroves in Corentyne, Guyana; the property formation process in peri-urban areas of Ethiopia; and the effects of green energy production on farmlands in the Yulin County of Taiwan. The second section of the book is divided into two chapters and discusses cases pertaining to land use mapping and sustainability including land cover/land use mapping using soft computing techniques with optimized features; and applying systems analysis to evaluate Jelutung as an option for sustainable use of peat lands in Central Kalimantan, Indonesia.

As noted in previous volumes, this book must be seen as a wide brush stroke pointing the way to matters regarding land use change and sustainability because it does not cover every important issue in the discipline. Its strength lies in the fact that it is insightful, thought provoking, concise, and easy to understand. It serves as an important reference material on land use change and sustainability.

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Section 1

Land Use Change and Sustainability

Chapter 1

Soil and Land-Use Change Sustainability in the Northern Great Plains of the USA

Deepak R. Joshi, David E. Clay, Alexander Smart, Sharon A. Clay, Tulsi P. Kharel and Umakanta Mishra

Abstract

In the Northern Great Plains (NGP), the combined impacts of land-use and climate variability have the potential to place many soils on the tipping point of sustainability. The objectives of this study were to assess if the conversion of grassland to croplands occurred on fragile landscapes in the North America Northern Great Plains. South Dakota and Nebraska were selected for this study because they are located in a climate transition zone. We visually classified 43,200 and 38,400 points in South Dakota and Nebraska, respectively, from high-resolution imagery in 2006, 2012, and 2014 into five different categories (cropland, grassland, habitat, NonAg, and water). The sustainability risk of the land-use changes was assessed based on the land capability class (LCC) scores at the selected sites. Sites with LCC scores ≤ 4 are considered sustainable for crop production if appropriate management practices are followed. Scores ≥ 6 are not considered suitable for row crop production. From 2006 to 2014, 910,000 and 360,000 ha of land were converted from grassland to cropland in South Dakota and Nebraska, respectively. Approximately 92 and 80% of the grassland conversion to croplands occurred on land suitable for crop production (land capability class, LCC ≤ 4) in South Dakota and Nebraska, respectively.

Keywords: land-use change, sustainability, land capability class, Northern Great Plain, South Dakota, Nebraska

1. Introduction

The conversion of grasslands and forest to croplands is not sustainable if conversion occurs on land not suitable for crop production and if the soil loss rates exceed the rates of soil formation. In semiarid regions, soil erosion is one of the critical factors leading to soil degradation [1]. Erosion is increased when the vegetation cover is destroyed by cultivation [1, 2]. The resulting erosion can reduce the productivity by soil structural degradation as well as by reducing water holding capacity, water and nutrient runoff, and changing other soil properties [3, 4].

The Northern Great Plains (NGP) has undergone extensive management changes since homesteading in the 1880s. These management changes are the result of markets, technologies, and climate variation over time. Climate and market variability results in boom and bust cycles [2]. For example, during World

War I, farmers optimized their profits by plowing and planting grasslands with annual crops. The period of high yields was followed by drought during the 1930s which resulted in the dust bowl and bust. A recent boom occurred between 2006 and 2012 due to increase in maize and soybean price. During this time-period, Reitsma et al. [4] reported that 730,000 ha of grassland was converted to cropland.

During rapid land conversion periods, grasslands are often converted to cropland. This conversion can strengthen the financial resources of individual farms while simultaneously reducing wildlife habitat [5]. Thus, land conversion from grasslands to croplands creates the classical dilemma of balancing economic development with environmental impacts. Between 2008 and 2011, all across the USA, 23.7 million acres of grassland, shrub, and wetland were converted to agricultural land, and 3.2 million acres of wildlife habitat disappeared in North and South Dakotas alone [6]. Grasslands are one of the most threatened and least protected ecosystems.

Worldwide, the NGP ecoregion in North America is considered one of best remaining opportunities for grassland maintenance [7]. Similarly, other adverse side effects of land-use change are increased greenhouse gas emissions [8, 9], reduced water quality [10], and higher soil erosion [11, 12]. In the NGP, the adoption of management practices that improve soil health and minimize soil degradation is critical to insure long-term sustainability [13–19]. We believe that increasing the adoption of sustainable management practices requires a clear understanding of factors driving the land-use change. Reitsma et al. [4] reported that land-use change most likely resulted from many factors including recent technological improvements, land ownership structure changes, climatevariability, various governmental policies, crop prices, and aging workforce [4, 14, 20, 21].

Technology improvements, such as the development of new planting equipment and the wide-scale adoption of transgenic crops, have provided the opportunity to seed annual crops in areas that previously were considered unsuitable for crop production [14]. Moreover, complex interaction of various factors like climatic variability, soil quality, topography, and socioeconomic factors may influence individual decisions [22, 23]. In the NGP, higher rainfall and temperatures linked to climate change were important [7, 24].

From soil erosion perspective, the conversion of grasslands to cropland may be sustainable if conversion occurs on suitable land type [4]. One approach to assess suitability is the land capability classification (LCC) approach. In this approach, soils with LCC values ≤ 4 are generally considered sustainable for annual crops if appropriate management practices are followed. Soils with LCC values ≥ 6 are not considered suitable for annual crops. Soils with a LCC value of 5 may be prone to flooding. The number of restrictions increases as the LCC value increases from 1 to 4 and from 6 to 8. However, Rashford et al. [25] found that between 1978 and 2008, 0.4 million hectare of cropland increased and most conversions occurred on land are considered suitable for crop production (LCC ≤s 1–4). Rashford et al. [25] also reported that grassland with LCC ≤ 2 has a 30–50% greater probability of being converted to cropland than grassland with LCC values of 3 and 4.

In light of current pressure on land and various forces driving land-use change, it is essential to examine the dynamics of land changes. The objectives of this study were to calculate the rate of land-use change from 2006 to 2012 and from 2012 to 2014 in South Dakota and Nebraska and assess if land-use changes were sustainable. This region was selected as a model system because it is located in a climate transition zone and it has a humid continental climate on the eastern border and semiarid climate on the western border [26, 27].

2. Materials and methods

South Dakota and Nebraska were selected as model systems because these states contain a wide range of soil, crops, and climate which are representative of other larger areas; both states have a large production capacity for livestock and annual crops; most of the soils were developed in tall and mixed grass prairies; they are located in climate transition zone; and the two states have different access to irrigation water. This region receives most of its precipitation in the spring and fall [14].

The most common annual crops in South Dakota include maize (*Zea mays* L.), soybean [(*Glycine max* (L.) Merr.], and wheat (*Triticum aestivum* L.). In South Dakota, rainfall decreases from east to west, and temperatures decrease from South to North. Additional information on characteristics of South Dakota soils is available in Reitsma et al. [4] and Clay et al. [13]. Farmers in this region use crop rotations that include maize, soybean, wheat, sunflower, canola (*Brassica napus* L.), barley (*Hordeum vulgare* L.), lentil (*Lens culinaris* Medik.), flax (*Linum usitatissimum* L.), and pea (*Pisum sativum* L.).

Eastern Nebraska has a humid continental climate, whereas the western region has a semiarid climate [26, 27]. Eastern part of Nebraska has fertile, moist, and warm soil making it well suited for maize and soybean production. It consists of

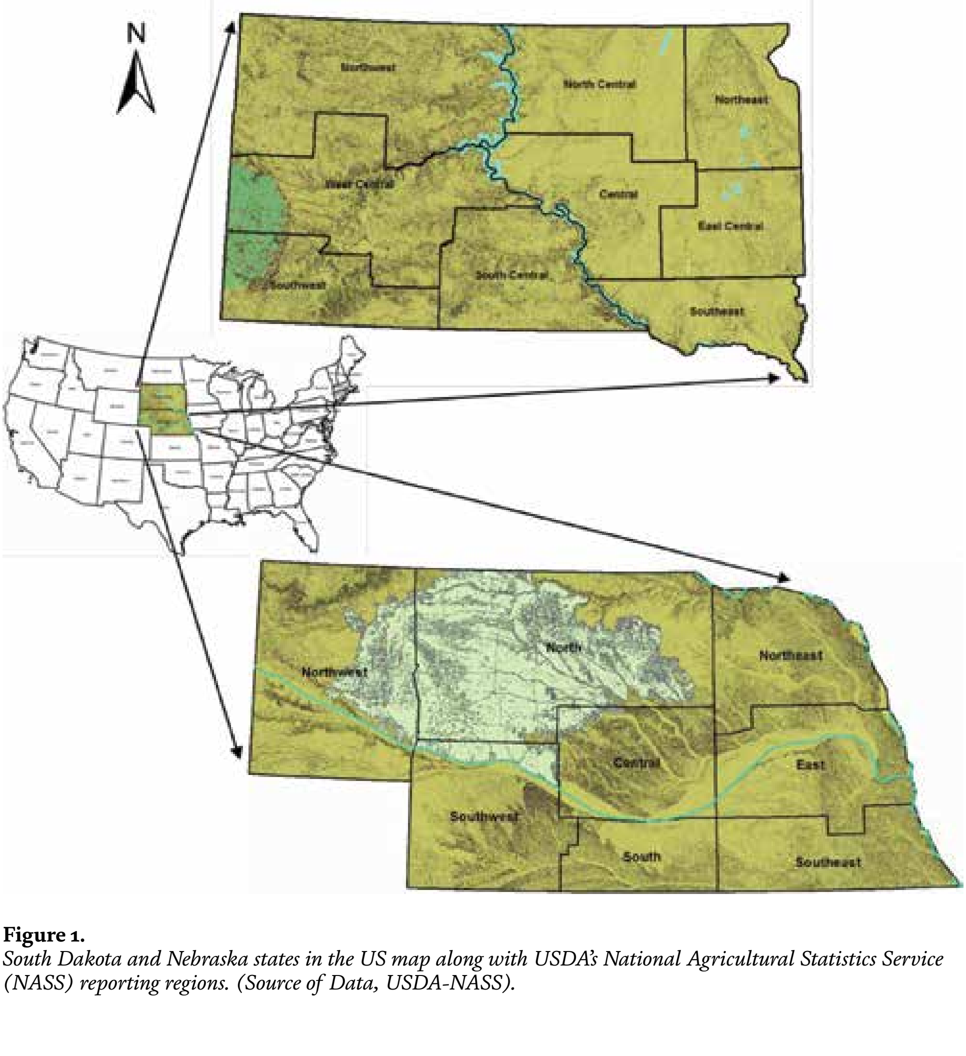

Figure 1.
South Dakota and Nebraska states in the US map along with USDA's National Agricultural Statistics Service (NASS) reporting regions. (Source of Data, USDA-NASS).

loess and glaciated till soils. The Nebraska Sand Hills are contained almost entirely within the Nebraska North NASS region, and it represents one of the most unique and homogenous ecoregions in North America. The Sand Hills are one of the largest areas of semiarid grass-stabilized sand dunes in the world [28].

2.1 Assessing land-use change

The method to assess land use was previously discussed in Reitsma et al. [4] and summarized below. South Dakota has nine National Agricultural Statistics Service (NASS) regions (USDA-NASS, 2015) that include the northeast (NE), south east (SE), north central (NC), east central (EC), central (C), south central (SC), northwest (NW), west central (WC), and south west (SW). Similarly Nebraska has eight NASS regions that include the northwest (NW), north (N), northeast (NE), central (C), east (E), south west (SW), south (S), and south east (SE) (**Figure 1**). Stratified random sampling approach was used for sampling and within each of 17 USDA-NASS reporting districts. In each NASS region, 1600 sampling points were randomly identified using ESRI® ArcMap 10.2.2. These points were laid over high-resolution imagery, obtained from the US Department of Agriculture (USDA), Farm Service Agency (FSA), National Agricultural Imaging Program (NIAP) (USDA-FSA, 2013). The NAIP imagery for 2006 had a 2 m resolution, and the 2012 and 2014 imagery had a 1 m resolution. At each point (8 by 8 m), the dominant land use (cropland, grassland, habitat, non-Ag, and water) was visually identified (for 2006, 2012, and 2014). In South Dakota, 43,200 points in total were visually classified (14,400 points each year), whereas in Nebraska, 38,400 points were classified (12,800 points each year). For validation of our visual assessment and classification system, we randomly selected 100 sampling points from 17 different counties in South Dakota. The predicted management based on the remote sensing data (visual classification) was identical to the known management at these points 100% of the time.

2.2 Assessing changes in soil quality

Land capability class (LCC) and dominant subclass were obtained from the Soil Survey Geographic (SSURGO) data set by superimposing the sampling points over SSURGO [29]. At these points, the LCC value was determined [24]. LCC subclasses are used to help define the limitation. The most common subclass limitations are erosion hazard (e), wetness (w), rooting-zone limitations (s), and climate (c). However this was different than Reitsma et al. [4] where the LCC value was the sum of the component soils within a mapping percent multiplied by its numeric LCC value. This change in classification approach may result in slightly different percentages of soils within a LCC category as reported by Reistma et al. [4].

3. Results and discussion

3.1 Land-use changes in Nebraska from 2006 to 2012

In Nebraska, 43% of the land was in croplands, and the other 45% remained in grasslands in 2006 and 2012. Between 2006 and 2012, 250,000 ha of grassland were converted to cropland at the rate of 41,670 ha $year^{-1}$ (**Table 1**). At the grassland- to cropland-converted sites, 92% had land capability classes that were of 4 or less. These data suggest that based on LCC scores, land-use change occurred primarily on suitable land and therefore based on the soil characteristics should be considered sustainable if appropriate practices are followed.

Change category	Land capability class (LCC) within a category with confidence interval for each proportion in parentheses							
	LCC 1	LCC 2	LCC 3	LCC 4	LCC 5	LCC 6	LCC 7	Estimated land
2006–2012				%				ha × 1000
Nebraska								
Crop-crop	7.42 (0.35)	47.95 (0.67)	24.66 (0.58)	12.02 (0.44)	0.15 (0.05)	7.71 (0.36)	0.04 (0.03)	7130
Crop-grass	9.09 (8.67)	54.55 (15.01)	0	36.36 (14.20)	0	0	0	15
Grass-crop	2.72 (1.20)	21.74 (3.04)	24.46 (3.17)	27.17 (3.28)	1.09 (0.76)	22.83 (3.09)	0	250
Grass-grass	0.37 (0.08)	7.58 (0.35)	10.61 (0.41)	13.59 (0.45)	1.41 (0.16)	60.75 (0.64)	5.02 (0.29)	10750
East								
Crop-crop	11.80 (1.18)	41.11 (1.79)	30.35 (1.68)	13.49 (1.25)	0.10 (0.12)	2.98 (0.62)	0	3580
Crop-grass	14.29 (25.92)	57.14 (36.66)	0	28.57 (33.47)	0	0	0	9
Grass-crop	4.63 (3.96)	25 (8.17)	27.78 (8.45)	32.41 (8.83)	0.93 (1.81)	9.26 (5.47)	0	130
Grass-grass	1.67 (0.76)	18.87 (2.33)	30.71 (2.75)	26.46 (2.63)	1.11 (0.62)	20.26 (2.40)	0.46 (0.40)	1310
West								
Crop-crop	2.59 (0.61)	55.49 (1.90)	18.29 (1.48)	10.40 (1.17)	0.19 (0.17)	12.92 (1.28)	0.08 (0.11)	3550
Crop-grass	0	50 (49)	0	50 (49)	0	0	0	6
Grass-crop	0	17.11 (8.47)	19.74 (8.95)	19.74 (8.95)	1.32 (2.56)	42.11 (11.10)	0	120
Grass-grass	0.06 (0.07)	4.96 (0.62)	5.95 (0.68)	10.60 (0.88)	1.48 (0.35)	70.14 (1.31)	6.07 (0.69)	9440

Table 1.
Land-use change in different land capability classes of Nebraska from 2006 to 2012.

In Nebraska, the state was separated into eastern and western portions. The eastern portion contained three NASS regions (northeast, east, and southeast), whereas the western region contained five regions (northwest, southwest, north, central, and south). In eastern Nebraska, 130,000 ha grassland, at a rate of 21,670 ha year^{-1}, were converted to cropland between 2006 and 2012. At these converted sites, 89.8% had LCC values ≤ 4.

In western Nebraska, 120,000 ha grassland at an annual rate of 20,000 ha year^{-1} were estimated to change from grassland to cropland category. At these converted sites, 56.6% occurred on soils with LCC values ≤ 4.

3.2 Land-use changes in Nebraska from 2012 to 2014

Between 2012 and 2014, 110,000 ha, at a rate of 55,000 ha of grassland year^{-1}, were converted to cropland. At these sites, 83.8% had LCC values ≤ 4 (**Table 2**). This rate of change represents an increase from the 41,670 ha year^{-1} that was observed from 2006 to 2012.

Change category	Land capability class (LCC) within a category with confidence interval for each proportion in parentheses							
	LCC 1	LCC 2	LCC 3	LCC 4	LCC 5	LCC 6	LCC 7	Estimated land
2012–2014				**%**				**ha × 1000**
Nebraska								
Crop-crop	7.27 (0.67)	47.09 (47.09)	24.65 (1.12)	12.52 (0.86)	0.18 (0.11)	8.20 (0.17)	0.04 (0.05)	7370
Crop-grass	0	37.5 (33.5)	37.5 (33.5)	12.5 (22.92)	0	12.5 (22.92)	0	12
Grass-crop	1.35 (2.63)	25.68 (9.95)	32.43 (10.67)	24.32 (9.78)	0	16.22 (8.40)	0	110
Grass-grass	0.37 (0.16)	7.40 (0.68)	10.27 (0.79)	13.51 (0.89)	1.44 (0.31)	61.24 (1.27)	5.07 (0.57)	10670
East								
Crop-crop	11.55 (1.14)	40.52 (1.76)	30.34 (1.65)	14.19 (1.25)	0.13 (0.13)	3.20 (0.63)	0	3710
Crop-grass	0	25 (42.44)	50 (49.0)	25 (42.44)	0	0	0	5
Grass-crop	2.04 (3.96)	30.61 (12.90)	30.61 (12.90)	24.49 (12.04)	0	12.24 (9.18)	0	60
Grass-grass	1.73 (0.79)	18.40 (2.36)	30.44 (2.80)	26.59 (2.69)	1.16 (0.65)	20.71 (2.47)	0.48 (0.42)	1260
West								
Crop-crop	2.58 (0.61)	55.80 (1.90)	18.81 (1.49)	10.95 (1.19)	0.23 (0.18)	14.10 (1.33)	0.08 (0.11)	3660
Crop-grass	0	50 (49)	25 (42.44)	0	0	25 (42.44)	0	7
Grass-crop	0	16 (14.37)	36 (18.82)	24 (16.74)	0	24 (16.74)	0	50
Grass-grass	0.06 (0.07)	4.93 (0.62)	5.75 (0.67)	10.58 (0.88)	1.51 (0.35)	70.31 (1.31)	6.10 (0.69)	9410

Table 2.
Land-use change in different soil types of Nebraska from 2012 to 2014.

In eastern Nebraska, 60,000 ha, at a rate of 30,000 ha year^{-1}, of grassland were changed to cropland. At these sites, 87.8% occurred on soils with LCC values ≤ 4. The rate of change between 2012 and 2014 represents an increase, relative to change that occurred between 2006 and 2012. In western Nebraska, 50,000 ha, at an annual rate of 25,000 ha of grassland year^{-1}, was converted to cropland between 2012 and 2014. At these sites, 76% of changes occurred in soils with LCC values that were ≤ 4.

3.3 Land-use changes in South Dakota from 2006 to 2012

Between 2006 and 2012, 5.78% (700,000 ha) of the state grassland (12,120,000 ha) were converted to croplands at an annual rate of 116,700 year^{-1}. Most (92.9%) of the converted grasslands were lands considered suitable for annual crops (LCC ≤ 4) (**Table 3**).

In eastern South Dakota, 480,000 ha of grasslands, at an annual rate of 66,670 ha year^{-1}, were converted to cropland between 2006 and 2012. In this region, 94.5% occurred in soils with LCC values of 4 or less. In western South

Change category	Land capability class (LCC) within a category with confidence interval for each proportion in parentheses							
	LCC 1	LCC 2	LCC 3	LCC 4	LCC 5	LCC 6	LCC 7	Estimated land
2006–2012				%				ha × 1000
South Dakota								
Crop-crop	7.82 (0.41)	63.35 (0.74)	14.89 (0.54)	10.16 (0.46)	0.61 (0.12)	2.88 (0.26)	0.23 (0.07)	5130
Crop-grass	4.76 (1.55)	54.5 (3.62)	17.46 (2.76)	12.17 (2.38)	4.23 (1.46)	5.29 (1.63)	1.59 (0.91)	230
Grass-crop	2.6 (0.69)	50.93 (2.16)	24.72 (1.86)	14.31 (1.51)	0.56 (0.32)	6.13 (1.03)	0.74 (0.37)	700
Grass-grass	0.45 (0.08)	16.79 (0.44)	15.11 (0.42)	16.95 (0.44)	1.02 (0.12)	30.24 (0.53)	17.3 (0.44)	11420
East								
Crop-crop	8.94 (0.92)	67.60 (1.50)	11.30 (1.02)	9.35 (0.93)	0.67 (0.26)	2.04 (0.45)	0.08 (0.09)	4210
Crop-grass	5.96 (3.78)	62.91 (7.70)	9.27 (4.63)	11.26 (5.04)	5.30 (3.57)	3.97 (3.12)	1.32 (1.82)	160
Grass-crop	3.48 (1.79)	59.45 (4.80)	19.40 (3.87)	12.19 (3.20)	0.75 (0.84)	3.98 (1.91)	0.75 (0.84)	480
Grass-grass	1.38 (0.47)	38.48 (1.95)	14.81 (1.42)	17.82 (1.53)	2.47 (0.62)	15.77 (1.46)	8.20 (1.10)	2890
West								
Crop-crop	0	33.77 (4)	39.93 (4.15)	15.86 (3.09)	0.19 (0.37)	8.77 (2.39)	1.31 (0.96)	920
Crop-grass	0	21.05 (12.96)	50 (15.90)	15.79 (11.59)	0	10.53 (9.76)	2.63 (5.09)	70
Grass-crop	0	25.74 (7.35)	40.44 (8.25)	20.59 (6.80)	0	12.50 (5.56)	0.74 (1.44)	220
Grass-grass	0	6.39 (0.68)	15.25 (1)	16.53 (1.03)	0.32 (0.16)	37.17 (1.34)	21.66 (1.14)	8530

Table 3.
Land-use change in different soil types of South Dakota from 2006 to 2012.

Dakota, 220,000 ha at an annual rate of 36,700 ha $year^{-1}$ of grassland were converted to cropland. In western South Dakota, 86.8% of the sites have LCC values of 4 or less.

3.4 Changes in South Dakota from 2012 to 2014

From 2012 to 2014, 1.79% of South Dakota's grasslands were converted to cropland at the rate of 105,000 ha $year^{-1}$ which was slightly lower (116,700 ha/year) than the rate between 2006 and 2012. At these sites, 91.7% occurred in soils with LCC values of 4 or less (**Table 4**). Most of this conversion occurred in eastern South Dakota where 92.5% of the changes occurred on soils characterized as LCC 4 or less, and less than 5% of the change occurred on soils characterized as 6 or 7. In western South Dakota, 85.7% of the grassland-converted sites had LCC values of 4 or less, and <15% of the change occurred in soils with LCC classes that were 6 or greater.

Change category	Land capability class (LCC) within a category with confidence interval for each proportion in parentheses							
	LCC 1	LCC 2	LCC 3	LCC 4	LCC 5	LCC 6	LCC 7	Estimated land
2012–2014				%				ha × 1000
South Dakota								
Crop-crop	7.42 (0.74)	62.37 (1.37)	15.59 (1.02)	10.42 (0.86)	0.66 (0.23)	3.14 (0.49)	0.37 (0.17)	5810
Crop-grass	0.94 (1.84)	47.17 (9.50)	22.64 (7.97)	18.87 (7.45)	1.87 (2.59)	7.55 (5.03)	7.55 (5.03)	150
Grass-crop	2.38 (2.31)	61.90 (7.34)	10.71 (4.68)	16.67 (5.64)	2.38 (2.31)	5.95 (3.58)	0	210
Grass-grass	0.56 (0.17)	17.58 (0.86)	15.10 (0.81)	16.78 (0.84)	1.07 (0.23)	29.82 (1.03)	17.01 (0.85)	11540
East								
Crop-crop	8.56 (0.85)	66.89 (1.42)	11.86 (0.98)	9.47 (0.89)	0.74 (0.26)	2.17 (0.44)	0.24 (0.15)	4720
Crop-grass	1.23 (2.40)	58.02 (10.75)	14.81 (7.74)	17.28 (8.23)	2.47 (3.38)	6.17 (5.24)	0	100
Grass-crop	2.72 (2.63)	67.35 (7.58)	7.48 (4.25)	14.97 (5.77)	2.72 (2.63)	4.76 (3.44)	0	170
Grass-grass	1.66 (0.29)	39.57 (1.90)	14.39 (1.37)	17.26 (1.47)	2.60 (0.62)	15.53 (1.41)	8.08 (1.06)	3000
West								
Crop-crop	0	32.92 (3.62)	39.72 (3.77)	16.54 (2.86)	0.15 (0.30)	9.43 (2.25)	1.24 (0.85)	1090
Crop-grass	0	12 (12.74)	48 (19.58)	24 (16.74)	0	12 (12.74)	0	50
Grass-crop	0	23.81 (18.22)	33.33 (20.16)	28.57 (19.32)	0	14.29 (14.97)	0	40
Grass-grass	0	6.42 (0.68)	15.47 (1)	16.53 (1.03)	0.30 (0.15)	37.07 (1.34)	21.55 (1.14)	8540

Table 4.
Land-use change in different types of soil in South Dakota from 2012 to 2014.

4. Soil and environmental sustainability

One purpose of the LCC system is to provide guidance on sustainability. An implication of LCC system is that land-use changes are not sustainable if soil losses exceed the rate of soil production. However, since the development of the LCC system, during the 1940s, agricultural technologies have improved [30]. These improvements have resulted in (1) the adoption of no-tillage or conservation tillage and cover crops across the NGP, (2) higher yields, (3) increasing soil organic matter contents, and (4) reduced erosion [11, 12, 16].

Given that technologies have changed since the 1940s, it is likely that classification approach based on the technologies of the 1940s may not be appropriate today. For example, Schuller et al. [31] reported that in Chile, adoption of no-tillage reduced erosion by 94% when compared with conventional tillage. Similarly, in South Dakota decreasing tillage intensity and increasing yields contributed to soil organic carbon levels that increased 24% from 1985 t0 2012 [11].

The conversion of grasslands to croplands may reduce methane sink, pest suppression, flood mitigation, pollination, and protection of grassland birds [32]. Land conversion is also likely to increase soil erosion if suitable management practices are not adopted [13, 33] and reduce the amount of carbon stored in the soil [34].

Land-use changes may be driven by a desire to stabilize economic returns in a region with a variable climate. In the NGP, increasing rainfall and temperatures provide an opportunity to grow annual crops [7]. Precipitation variability is projected to increase in Northern Great Plains [7, 14], while increasing atmospheric CO_2 level may help by improving water-use efficiency and crop productivity [35]. Similarly, droughts result in losses in crop yield, grazing capacity, ground water, and plant composition and hydrologic condition of rangeland.

As discussed earlier, one of the primary factors influencing land-use change is economics. Farm economics is influenced by revenues received by farmers and yield and crop production costs [36]. These potential returns and cost vary in time and space. For example, during the period of 2006–2012, maize prices doubled from \$119.68 to \$271.26 Mg^{-1}. However, the maize cost of production was lowest in 2000 (\$395 ha^{-1}) and peaked in 2012 (\$1192.5 ha^{-1}) and then decreased to \$1002.5 ha^{-1} in 2015. Similarly, soybean had similar changes in production cost and selling prices. Marketing year average soybeans price received double from \$236.24 Mg^{-1} in 2006 to \$529.06 Mg^{-1} in 2012. However, during the period between 2012 and 2014, the soybean price decreased to \$371.07 Mg^{-1}, and maize prices decreased to \$135.94 Mg^{-1} [37].

5. Agricultural land market trend and environmental sustainability

From 2011 to 2014, the average value of all agricultural land in South Dakota increased from \$3350 to \$6175 ha^{-1} [36]. The largest gains were observed in highly productive eastern South Dakota. For example, in the southeast and east central NASS regions, non-irrigated cropland had value of \$17,785 and \$15,827.5 ha^{-1}, respectively, in 2014. Slightly lower values were observed in the northeast where land values increased from \$7295 ha^{-1} in 2011 to \$13,227 ha^{-1} in 2014. Similar increases were observed in the north central and central regions. In north western South Dakota, land value increases were much lower, and from 2011 to 2014, it increased from \$1562 ha^{-1} to \$2050 ha^{-1}.

Native rangelands are highly concentrated in the western and central regions of South Dakota, whereas managed pastures are scattered without any particular region of state. Rangeland and pasture land values also tend to cluster in three different groups. East central and southeast regions had the highest rangeland values of \$7152 and \$6745 ha^{-1}, respectively. When compared with 2011, these values represent a 60.82 and 69.79% increase in value. In the second cluster that consists of northeast, north central, and central NASS regions, the per hectare land values are 1859, 1600, and 1828 dollars, respectively. These regions had value increases of 52.75, 68.42, and 80.81% changes from 2011 to 2014. The regions with lowest range value were located in the western part of state and were \$1187 in the south central, \$571 in the southwest, and \$436 in northwest in 2014. The south central (SC), south west (SW), and north east (NE) regions had 87.2, 39.6, and 41.1% increases in rangeland value from 2011 to 2014.

Like South Dakota, Nebraska regional cropland values were clustered into the northeast, central, and western regions. From 2006 to 2014, the value of dry land cropland with irrigation potential in the northeast increased from \$4102 to 16,075 per hectare [38]. Similar increases were observed in the east and southeast areas. In the central region, land value increased from \$3625 ha^{-1} in 2006 to \$12,275 ha^{-1} in 2014. Similar gains were observed in the southern region. Western regions of the state had the lowest price per hectare acre and value increases. For example, in the northwest, land value increased from $1137 to $2337 ha^{-1} from 2006 to 2014.

Thus, the record land market value gain observed in South Dakota and Nebraska varied by region. These gains in land market value could be fueled by various factors such as better agricultural input and equipment supplies, increasing ethanol demand, spiking crop prices, and boosted US agricultural export opportunities [39, 40]. Maize-producing regions, which are the main input source for ethanol plants, had the greatest land value gain. For example, in Nebraska and South Dakota, market value increased within 50 miles of ethanol plants where ethanol production was highly concentrated [41].

However the climbing land values, on the other hand, could raise the farmer debt to buy new farm land. To repay debt from increased land purchase prices, farmers could be forced to intensify crop and livestock production for higher returns, regardless of long-term consequences to land use sustainability. But it is very important to note if such extensive agricultural expansion would be conducive to cropping system and environment. Especially in Northern Great Plains, where periodic patterns of drought persist, such agricultural practices may not be appropriate if expansions are not in more suitable climatic and soil conditions.

6. Summary

Along with economic opportunities to local families, recent technological improvements, land ownership structure changes, climate variability, various governmental policies, and aging workforce are major driving factors for changing grasslands to croplands. Along with these factors, it may also be driven by a desire to increase the value of the land. For example, irrigated cropland had a higher value than grazing lands.

Higher temperature, changing precipitation pattern, increasing CO_2 levels, and extreme climatic events like drought directly affect food production and land use in the NGP. For example, ranchers who faced severe drought during 2012 may have sold their livestock and may have plowed their grassland in order to produce an economic return.

Our study shows that South Dakota had higher grassland conversion rates than Nebraska. During the first 6-year period, 700,000 ha grassland was changed to cropland in South Dakota compared with only 250,000 ha in Nebraska. Similarly, 210,000 ha newly expanded cropland was estimated during the later 2-year period in South Dakota. Contrarily, Nebraska had only 110,000 ha of new cropland. The higher conversion rates in South Dakota than Nebraska are attributed to the type of land available for conversion. In Nebraska, between 2006 and 2012 and between 2012 and 2014, 76.1% and 83.8% of the change occurred on soil are considered suitable for cropland (LCC $\leq$ 4), respectively. However, in South Dakota, over 90% of the land that was converted was considered suitable for croplands. Again, soil types with higher LCC values are not considered suitable and can be less sustainable.

In conclusion, the majority of grasslands converted to the crop land during study period can be managed for sustainable food production with the recommended farming practices. However appropriate soil and crop management research is needed for the portion of converted land that is at higher risk to prevent degradation.

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References

[1] Oldeman L. The global extent of soil degradation. In: Greenland DJ, Szabolcs I, editors. Soil Resilience and Sustainable Land Use. Wallingford: CAB International; 1994. pp. 99-1181

[2] Gregorich EG, Greer KJ, Anderson DW, Liang BC. Carbon distribution and losses: Erosion and deposition effects. Soil and Tillage Research. 1998;**47**(3):291-302

[3] Pimentel D, Harvey C, Resosudarmo P, Sinclair K, Kurz D, McNair M, et al. Environmental and economic costs of soil erosion and conservation benefits. Science. 1995;**267**(5201):1117-1123

[4] Reitsma KD, Dunn BH, Mishra U, Clay SA, DeSutter T, Clay DE. Land-use change impact on soil sustainability in a climate and vegetation transition zone. Agronomy Journal. 2015;**107**(6):2363-2372

[5] Mushet DM, Neau JL, Euliss NH Jr. Modeling effects of conservation grassland losses on amphibian habitat. Biological Conservation. 2014;**174**:93-100

[6] Faber S, Rundquist S, Male T. Plowed Under: How Crop Subsidies Contribute to Massive Habitat Losses. Environmental Working Group; 2012

[7] Schrag A. Climate change impacts and adaptation strategies. Addendum in Ocean of grass: A conservation assessment for the Northern Great Plains. In: Forrest SC, Strand H, Haskins WH, Freese C, Proctor J, Dinerstein E, editors. Northern Plains Conservation Network and Northern Great Plains Ecoregion. US, Bozeman, Montana: World Wildlife Fund; 2011

[8] Searchinger T, Heimlich R, Houghton RA, Dong F, Elobeid A, Fabiosa J, et al. Use of US croplands for biofuels increases greenhouse gases through emissions from land-use change. Science. 2008;**319**(5867):1238-1240

[9] Tilman D, Hill J, Lehman C. Carbon-negative biofuels from low-input high-diversity grassland biomass. Science. 2006;**314**(5805):1598-1600

[10] Moss B. Water pollution by agriculture. Philosophical Transactions of the Royal Society B: Biological Sciences. 2008;**363**(1491):659-666

[11] Montgomery DR. Soil erosion and agricultural sustainability. Proceedings of the National Academy of Sciences. 2007;**104**(33):13268-13272

[12] Acharya BS, Blanco-Canqui H. Lignocellulosic-based bioenergy and water quality parameters: A review. GCB Bioenergy. 2018;**10**(8):504-533

[13] Clay DE, Chang J, Clay SA, Stone J, Gelderman RH, Carlson GC, et al. Corn yields and no-tillage affects carbon sequestration and carbon footprints. Agronomy Journal. 2012;**104**:763-770

[14] Clay DE, Clay SA, Reitsma KD, Dunn BH, Smart AJ, Carlson GG, et al. Does the conversion of grasslands to row crop production in semi-arid areas threaten global food supplies? Global Food Security. 2014;**3**(1):22-30

[15] Clay DE, Reicks G, Carlson CG, Moriles-Miller J, Stone JJ, Clay SA. Tillage and corn residue harvesting impact surface and subsurface carbon sequestration. Journal of Environmental Quality. 2015;**44**(3):803-809

[16] Cook BI, Ault TR, Smerdon JE. Unprecedented 21st century drought risk in the American Southwest and Central Plains. Science Advances. 2015;**1**(1):e1400082

[17] He Y, DeSutter TM, Clay DE. Dispersion of pure clay minerals as

influenced by calcium/magnesium ratios, sodium adsorption ratio, and electrical conductivity. Soil Science Society of America Journal. 2013;**77**(6):2014-2019

[18] He Y, DeSutter TM, Hopkins DG, Wysocki DA, Clay DE. Relationship between 1: 5 soil/water and saturated paste extract sodium adsorption ratios by three extraction methods. Soil Science Society of America Journal. 2015;**79**(2):681-687

[19] Dahal S, Dorcas F, Cabrera M, Hancock D, Stewart L, Mahmud K, et al. Spatial distribution of inorganic nitrogen in pasture: As affected by management and landscape, and cattle locus. Journal of Environmental Quality. 2018;**47**(6):1468-1477

[20] Lee S, Clay D, Clay S, Songstad D, Hatfield J, Tomes D. Conservation tillage and genetically modified herbicide tolerant corn (Zea mays), soybean (Glycine max), and cotton (Gossypium hirsutum): Adoption linked impacts on the environment and economic returns. In: Convergence of Food Security, Energy Security and Sustainable Agriculture. Berlin: Springer-Verlag; 2014. pp. 211-236

[21] Mamani-Pati F, Clay DE, Smeltekop H. Modern landscape management using andean technology developed by the Inca Empire. In: G.J. Churcham, and E.R. Landa, editors, The Soil Underfoot: Infinite Possibilities for a Finite Resource. CRC Press, Boca Raton, FL. 2014. p. 247

[22] Rindfuss RR, Walsh SJ, Turner BL, Fox J, Mishra V. Developing a science of land change: Challenges and methodological issues. Proceedings of the National Academy of Sciences. 2004;**101**(39):13976-13981

[23] Turner BL, Lambin EF, Reenberg A. The emergence of land change science for global environmental change and sustainability. Proceedings of the National Academy of Sciences. 2007;**104**(52):20666-20671

[24] Hatfield JL, Boote KJ, Kimball B, Ziska L, Izaurralde RC, Ort D, et al. Climate impacts on agriculture: Implications for crop production. Agronomy Journal. 2011;**103**(2):351-370

[25] Rashford BS, Walker JA, Bastian CT. Economics of grassland conversion to cropland in the Prairie Pothole region. Conservation Biology. 2011;**25**(2):276-284

[26] Elder JA. Soils of Nebraska. Conserv and Survey Div Resource Rept 2. University of Nebraska, Lincoln.1969

[27] McKnight T, Hess D. Physical Geography; A Landscape Appreciation. Prentice Hall, Upper Saddle River. 2000

[28] Boody G, Vondracek B, Andow DA, Krinke M, Westra J, Zimmerman J, et al. Multifunctional agriculture in the United States. AIBS Bulletin. 2005;**55**(1):27-38

[29] Soil Survey Staff. Web soil survey. Natl. Soil Surv. Ctr., Lincoln, NE. 2016. Available from: http://websoilsurvey.nrcs.usda.gov/

[30] Hockensmith RD, Steele J. Recent trends in the use of the land-capability classification. Proceedings of the Soil Science Society of America. 1949;**1950**(14):383-388

[31] Schuller P, Walling DE, Sepúlveda A, Castillo A, Pino I. Changes in soil erosion associated with the shift from conventional tillage to a no-tillage system, documented using 137Cs measurements. Soil and Tillage Research. 2007;**94**(1):183-192

[32] Werling BP, Dickson TL, Isaacs R, Gaines H, Gratton C, Gross KL, et al. Perennial grasslands enhance biodiversity and multiple ecosystem

services in bioenergy landscapes. Proceedings of the National Academy of Sciences. 2014;**111**(4):1652-1657

[33] Lindstrom M, Schumacher T, Blecha M. Management considerations for returning CRP lands to crop production. Journal of Soil and Water Conservation. 1994;**49**(5):420-425

[34] Zhang H, Thompson ML, Sandor JA. Compositional differences in organic matter among cultivated and uncultivated Argiudolls and Hapludalfs derived from loess. Soil Science Society of America Journal. 1988;**52**(1):216-222

[35] Van Der Sleen P, Groenendijk P, Vlam M, Anten NP, Boom A, Bongers F, et al. No growth stimulation of tropical trees by 150 years of CO_2 fertilization but water-use efficiency increased. Nature Geoscience. 2015;**8**(1):24

[36] Janssen L, Pflueger B, McMurty B. South Dakota Agricultural Land Values and Cash Rental Rates. 2013

[37] National Agricultural Statistics Service (NASS). 2015

[38] Jansen J. Nebraska Farm Real Estate Market Highlights, 2016-2017. 2017

[39] Henderson J. Will farmland values keep booming? Economic Review. 2008;**93**:81-104

[40] Henderson J, Briggeman B. What are the risks in today's farmland market? Ag Decision Maker Newsletter. 2015;**15**:8-1

[41] Henderson J, Gloy BA. The impact of ethanol plants on cropland values in the great plains. Agricultural Finance Review. 2009;**69**(1):36-48

Chapter 2

Urban Built-Up Property Formation Process in the Peri-Urban Areas of Ethiopia

Achamyeleh Gashu Adam

Abstract

Peri-urban areas in Ethiopia, like that of other African countries, are places where much of urban growth is taking place and new urban built-up properties have been formed rapidly. They are geographic places where the competition for land between agriculture and non-agriculture (urban built-up property) is intense leading to the vanishing of rural agricultural land rights. In this chapter an attempt has made to assess and create an understanding of the process of new urban built-up property formation in the transitional peri-urban areas of Ethiopia. Case study and desk review approaches were employed. The findings of this study show that formal and informal actors play a significant role in the process of converting peri-urban agricultural lands into urban built-up non-agricultural properties. Finally, this study also shows that urban built-up properties in the peri-urban areas are the results of land use conversion through the informal and formal channels.

Keywords: built-up, land tenure, formal, informal, Ethiopia, peri-urban, peri-urbanization

1. Introduction

Peri-urban land is conceptualized as a third space between the urban and rural hinterlands where urban land development processes meet, mix and interact on edge of the cities [1]. It has ever changing characteristics of land uses and land ownership with time and investments changes [2]. It is also a zone where peri-urban dwellers and other actors are confronted with both urban and rural laws and institutions [3]. It is a space crying out for attention [4].

Peri-urban land is of capital importance in any society. It is place where transformations resulting from the dynamics of rapid urbanization are concentrated [5]. Much of the current urban growth is taking place at the peri-urban areas. Similarly, the competition for land between agriculture and non-agriculture (urban housing) is intense in the peri-urban areas [6]. Thus, peri-urban areas are centers for almost all new land developments and changes in property right systems both formally and informally [7].

From property rights perspective, peri-urban areas are places where new urban property rights emerge to replace traditional or customary rights [8, 9]. As urbanization is penetrating into the countryside, agricultural lands are increasingly converted into non-agricultural uses or urban built-up properties. Moreover, urbanization in sub-Saharan Africa is often accompanied by the termination of existing local land rights in the peri-urban areas and the birth of new and urbanized form of land/property rights [10].

In the transitional peri-urban areas, competition for land between local rural settlers engaged in agricultural practices and urban actors interested in this land for residential purposes is fierce. The competitions for land during transition could instigate institutional changes need to regulate the emerging land rights. It is obvious that peri-urban areas are largely characterized by a wide range coexistence of formal and informal land transaction practices. Consequently, they serve as a breeding ground for new types of land tenure systems (which can be either semi-legal such as occupation of state land or non-legitimated totally) and land transaction processes which exist side by side with formal and customary systems [5].

Peri-urban land from the Ethiopian context involves an agricultural rural land adjacent to municipal boundaries, often held by local peri-urban farming communities. It is also a land under constant threat of expropriation of by the government agents and with a very high possibility of being converted into urban built-up property [11]. Peri-urban areas in Ethiopia can also be described as mushrooming place for new unauthorized/informal settlement without basic utilities. Therefore, peri-urban land in Ethiopia is a fascinating arena displaying complementary and conflicting interests.

Moreover, land in the peri-urban areas in Ethiopia is in a rapid process of change from rural agricultural land to urban built up [11]. New urban built-up properties and associated rights are being evolved at the expense of rural agricultural land rights [12]. The process of new property and property right formation in Ethiopia is not well studied and explored. This book chapter primarily explores the process of new urban built-up property formation in the peri-urban areas of Ethiopia. Details on the peri-urbanization process are discussed in this chapter under six sections. The first section details with the conceptualization of peri-urban land. The second section discusses the property right system of Ethiopia focusing on the strength and limitations. The third section focuses on how the research was conducted. The fourth section covers about urban built-up property formation based on empirical analysis and debates. The reason for why the formal and informal channel of land development co-existence in the peri-urban areas is also explored in the fifth section of the book chapter. The final section covers the conclusion of the study.

2. Property system in Ethiopia: overview of features and its deficits

As it is clearly defined in the federal constitution of Ethiopia, land is the property of state the peoples of Ethiopia and accordingly sale and as a means of exchange is prohibited [13]. Under the umbrella of exclusive state ownership of all land, the property system is bifurcated into rural and urban landholding systems due to the bifurcation of legal and institutional frameworks for rural and urban land (see **Figure 1**). Land located in the rural territory is governed by a rural land holding system by which rural landholders are allowed to exercise usufruct right only without the right to permanent transfer through sale or without the right to convert it into non-agricultural use by themselves [14]. On the other hand, land in the urban jurisdiction is governed by a leasehold system by which allocation of urban land is carried out through auction and government allotment on the basis of annual rent for a specified lease period and allows development rights according to a land use plan [15].

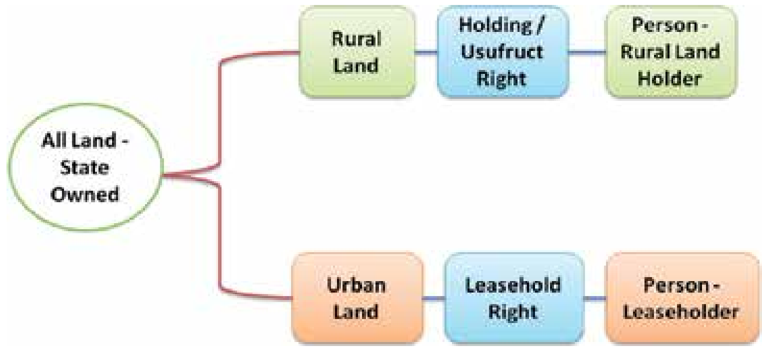

Figure 1.
The bifurcated property rights system in Ethiopia. Source: author produced.

State as sole supplier and owner of land is responsible to allocate all types of land use rights to the citizens. In the process of land allocation different requirements and procedures are being employed to allocate rural and urban land use rights. According to both federal and regional legislations, rural land can be granted to the people with usufruct right free of charge without time limit for those citizens who want to engage in agricultural activities for their livelihood [13, 14]. These two legal frameworks allow every citizen from 18 years of age whose main residence is in rural areas and who wants to make a living from agriculture to be accorded free access to rural land and permitted to exercise usufruct/holding rights for an indefinite period (FDRE, Proc. No. 456/2005, Art.5). Rural land in Ethiopia can be acquired by reallocation of communal or other unoccupied lands [16]. The land-holders of rural land in Ethiopia have the authority to use and harvest on it, to rent it, to donate it, to bequeath and sharecropping except selling and mortgaging it.

On the other hand, the land within the administrative boundary of urban areas in Ethiopia is governed by the urban lease holding system. The lease system is proclaimed as a sole means of accessing urban land in the country since the 1990s. The system allows that all land in urban areas to be transferred in to lease system and calls for conversion of old possessions to leasehold [15]. The current lease law recognizes tender (auction) and allotment as the basic means of lease transfer from government to citizens. As a matter of principle, land needed for residential, commercial (urban agriculture, industry, or service), and other uses are transferred by competitive tender. As an exception, city municipality may give land by allotment to selected areas of paramount importance to government institutions, religious institutions, public residential housing programs, diplomatic mission, displaced persons for urban renewal. The lease system serves as a hot political and legal agenda and has been criticized for a number of reasons including rent seeking, corruption, inefficiency, price hike, etc. that made the system unable to satisfy the growing demand of the urban poor and investors [17].

Land governance and institutional setup is derived from the constitutional provision and are a reflection of the property system of the country. The responsible authorities managing land are divided into municipal and rural land administration for urban and rural land respectively both at federal government and regional government level. The division of land governance institutions into urban and rural has been creating confusion in the transitional peri-urban areas where the land is highly demanded for urbanization and being converted into urban built-up property rapidly. The authority and the land tenure system in the transitional peri-urban areas lack clarity. Sometimes this transitional area may also fall under neither rural nor urban jurisdictions.

Moreover, the urban boundaries are always expanding into the surrounding peri-urban agricultural and rural areas and this in turn has been affecting the rural jurisdiction. As urban growth strategy, the government has been implementing expropriation of land from peri-urban areas as a response to the growing demand of land for rapid urbanization and the need for modernized infrastructures.

3. Research methods and materials

The primary objective of this study was to create an understanding of the process of new urban property and property right formation in the transitional peri-urban areas of Ethiopia. To attain the objective a mixture of desk review and case study research approaches were employed. As a case study area, Bahir Dar city located in the north western part of Ethiopia was chosen (see **Figure 2**). Bahir Dar city is one of the fastest growing metropolitan areas in Ethiopia where a lot of rural

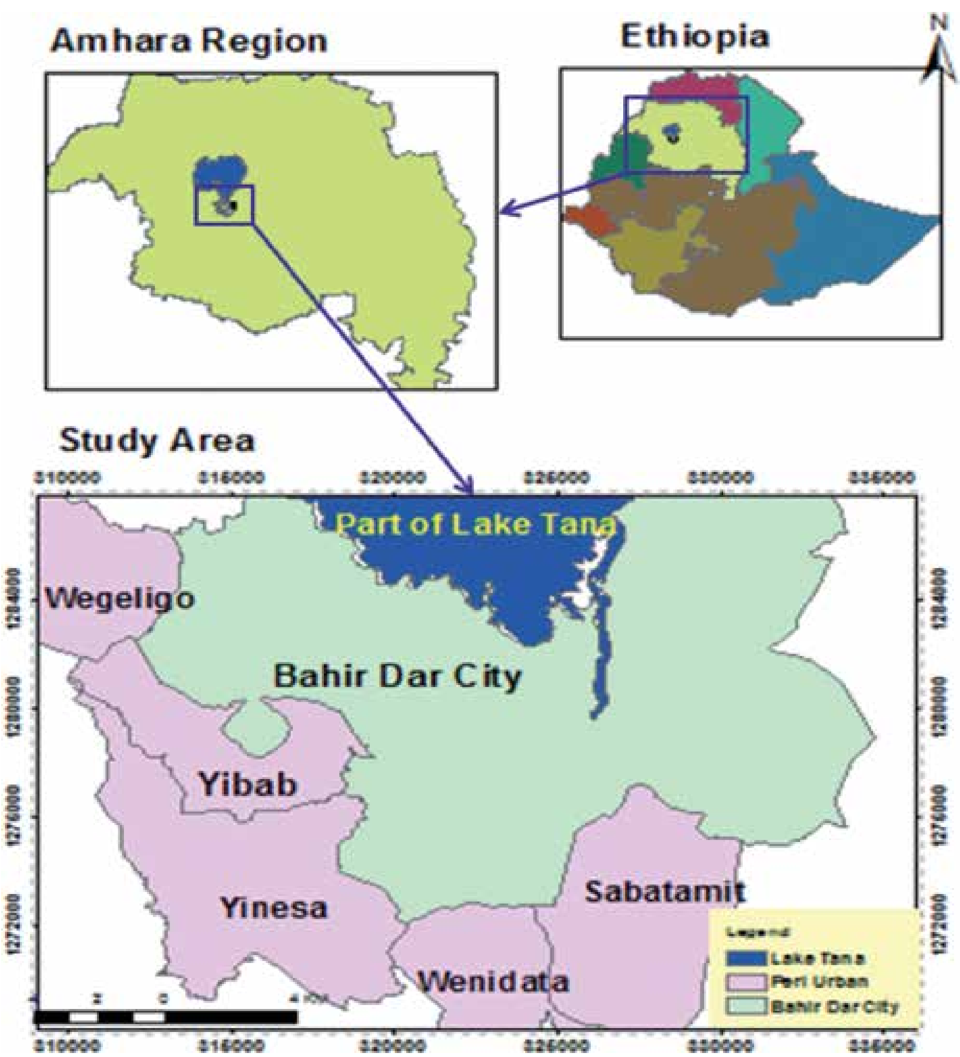

Figure 2.
Location map of Bahir Dar city. Source: author produced.

agricultural land has already been converted into urban built-up properties. It is also the area where there is a huge land demand for urban development purposes.

Focus group discussion (FGD) was undertaken with urban and rural land agency officials and experts. The officials and experts shared their views on how new urban built-up properties and property rights are being evolving. In addition, the discussants shared their views on how rural land rights are disappearing in the process of urban expansion. The focus group discussion was complemented by key informant interviews and site observations in the peri-urban areas. Key informant interview was held with key stakeholder such as planners, academia, local and regional government officials and the community leaders in the peri-urban areas. In addition to primary sources of data, an intensive desk review was conducted with a purpose to get a clear picture on the process of peri-urbanization. In addition, reviews on legal and policy frameworks and urban development strategies been conducted.

4. Results and findings

Urban areas in Ethiopia are growing and over spilling into the peri-urban areas in terms of space and population [12]. Peri-urban areas located adjacent to the municipal boundaries have become the most dynamic areas in Ethiopia. They are places where all forms of lively competitions for land are fierce. Due to the rural-urban dichotomy of land holding systems in Ethiopia, urbanization and urban development in peri-urban areas involves land holding right acquisition and transfer issues. In the process of urban expansion and development in Ethiopia, peri-urban landholders or farmers' land rights are forcibly taken by the state and thereafter reallocated to urban residents and private developers through lease agreement. At the same time the informal acquisition and development of land is a commonly seen phenomenon in the transitional peri-urban areas of Ethiopia. This section deals with the formal and informal ways of built-up property formation process in the peri-urban areas of Ethiopia.

4.1 Formal channel of urban built-up property formation

The formal urban development strategy of Ethiopia is solely dependent on compulsory expropriation and re-allocation of land. Expropriation measures as a mechanism to supply urban land are largely implemented in the transitional peri-urban areas and it is the single formal way of trading between the dichotomized rural and urban tenure systems where by the output would be the formation of urban built-up property. The formal urban built-up property formation process by expropriation decisions of the government involves a three step process of land acquisition and delivery [11]. First, the peri-urban area must be included within the city's master plan; in the second step, expropriation decisions should have to be made; and third, the expropriated land need to be reallocated to different private and public users through lease contract on the basis of annual ground rent for the period specified in lease contract. As soon as previously peri-urban and rural territory is planned for urban expansion, its inhabitants become the subject of "default" expropriation, with compensation only in cases where they have legal rights to the land, and at prices that are many times lower than those farmers can fetch on the informal market.

The process of urban built-up property formation through the formal channel also reveals that the mechanism to convert peri-urban/rural land rights into urban rights is non-existent. The use right of the local peri-urban landholders supposed to be exercised for lifetime can be terminated at any time by expropriation decisions of the government. As urban boundary approaches to the peri-urban territory, local landholders at this territory are assumed to be subjects of expropriation. As a consequence, sense of land tenure insecurity is very high in the transitional peri-urban areas than any other places in Ethiopia and about 94% of the local peri-urban landholders in one way or the other feel insecure for their land right [11]. The local landholders in the peri-urban areas expect that their land shall be taken by the municipality at any time when the land is needed for urban expansion programs.

Another deficit of the urban built-up property formation through expropriation in Ethiopia is related to the wrong interpretation and assumption that all land belongs to the state which has resulted in unjustifiable disregard of land value in the amount of compensation paid to those people expropriated form their land. In this regard, the practice shows that local peri-urban landholders can be paid compensation only for improvements on land, i.e., buildings and structures on the land [18], without taking into consideration the land value itself. The practice also shows that there is a considerable variation in the rate and amount of compensation paid to the expropriated landholders [19, 20]. For example, if the land is taken for a federal purpose, landholders would be compensated at a rate determined by the federal government; if the land is taken by regional or local authorities, the rate would be determined by regional or local authorities. Therefore, the amount of compensation paid by the federal government is much higher than local or regional government. As a result landholders in the peri-urban areas prefer their land to be taken by federal government.

Moreover, the urban land development process and a new built-up property formation process in particular is not built on participatory approaches. The stakeholders inability to make a direct involvement and negotiation due to the wrong assumption that land is the exclusive property of the state and can never be definitely negotiated by any one has created uncertainty on peri-urban landholders located adjacent to the cities [11]. Experiences show that expropriation decisions made by municipal authorities are most commonly top-down without considering the interests of the peri-urban communities including the preferences in the type of compensation. For instance, the great majority of the local landholders (91%) in the peri-urban areas prefer to have either land-to-land compensation from other areas or preserving reasonable portion of land within the urban boundary [21]. Therefore, the landholders in the area would like to preserve their land use rights and stay in farming activities. In addition they want to transfer their agricultural land to their sons and daughters as they have received it from their parents. The practice shows that reaching consensus and agreement with the affected local landholders before the final decision of land acquisition is most often non-existent. As a result objection and resistance against government's expropriation measure is a common phenomenon in the peri-urban areas of Ethiopia. The overall reflection from sample respondents and previous research results on the current urban development process in Ethiopia seems to be ignoring the land rights and livelihoods of the local peri-urban communities and skewed to the urban people [22].

4.2 Informal built-up property formation process in the peri-urban areas

Informal developments and settlements mushroom in the peri-urban areas than any other geographic place. Informal acquisition and transaction is the second mechanism for new built-up property formation in the peri-urban areas The expectation of peri-urban local landholders that their land shall be taken by urban administration compulsorily, on the one hand, and the inefficiency to provide affordable houses to the low income people in the inner-city have created an increasing pressure upon peri-urban land to be sold in the informal market [11]. In the following sub-sections an emphasis is to given explain how new urban built-up property be formed through the informal channel of land subdivision, transaction and development in the peri-urban areas.

4.2.1 Profile of actors interested in informal plot from peri-urban areas

The profile of actors involved in acquiring a plot of land through the informal channel from the peri-urban areas is examined with a purpose to provide a clear structure and insight about the characteristics of actors and institutional arrangements governing informal transaction and development of land in the peri-urban areas. The actors interested in acquiring a plot of land from peri-urban areas have multifaceted and engaged in various occupations to earn income for their livelihood (see **Table 1**). Self-employed households engaged in small scale commerce and daily laborers working mainly in the construction sector account more than 75% of the informal settlers in the case study area. The role of government employees and local residents in the process of new built-up property is significant as well [23]. Again, from the income perspective, the great majority of actors interested in the informal acquisition of land and formation of new built-up property earn very low monthly income.

In this study, an attempt was also made to track where the informal settlers are coming form. The largest proportion respondents which account about 92% of informal settlers used to live in the inner-city in rental houses. They informal settlers justify why they preferred to come to the inaccessible and unplanned peri-urban areas to live. According to their views unregulated rising of housing rent and inability to buy a condominium flat in the inner city are the most significant pushing factors that expelled them to the peri-urban areas in search of shelter. On the other hand, availability of informally subdivided parcels in cheap prices relatively attracted them to leave their original place of residence. Some of the housing units are also constructed by local residents themselves whose prior residence is from the same locality. Local residents or local informal settlers are those actors who built muddy house either on their own farm land or on a plot received as a gift, or on a plot bought from other local peri-urban landholder. The housing units constructed by local residents account about 7% of the houses in the area. Thus, the analysis of actors involved in the formation of informal urban built-up properties (construction of informal housing units) and the nature of the houses built in the study area reveals the infancy stage of settlement and land development where the

Respondents' occupation	Monthly income				Total (%)
	<500 Eth. Birr (%)	501–1000 Eth. Birr (%)	1001–2500 Eth. Birr (%)	>2500 Eth. Birr (%)	
Low income government employees	0	9	7.00	0	16
Peri-urban local residents	1	6	0	1	8
Daily laborers	19	23	0		42
Small scale business	7	24	2	1	34
Total	27	62	9	2	100

Table 1.
Respondents' occupation and monthly income (n = 120).

area is inhabited mainly by low income households. Moreover, all house structures built in the area are sub-standard and temporary shelters constructed of muddy and wooden walls and roof of iron sheet scattered on the agricultural land and inhabited by low income households. Moreover, basic amenities such as school for children and other basic facilities such as electricity, road and sanitation services are not available.

4.2.2 Plot acquisition mechanisms in the informal channel

Peri-urban areas which used to be prime agricultural areas have also rapidly being converted into urban built-up property informally outside the official and the formal law. The actors in the informal settlement process use different modes of acquiring an informal plot of land from the informal market. The great majority of plots which is about 78% of the informal plats were bought illegally from the local peri-urban smallholding farmers who received the land for agricultural purposes. However, according to the land policy and legislations of Ethiopia, land is not salable property [13]. Some informal settlers also claim as if they have received the plot as a gift from relatives but in reality it was bought illegally. Speculators are also involving in the transaction and construction of informal houses with expectation of profit in the future and they involve in selling and buying of agricultural lands and then they convert into urban built-up property. So informal houses or urban built-up properties can also be built on plots bought from previous informal buyers with some profit. This study also shows that sub-standard houses or informal houses can be constructed by local peri-urban landholders themselves on their own agricultural field [23].

The analysis of the modes of acquisition of informal plots in the peri-urban areas shows that the largest proportion of the land occupied by informal settlers was previously held by local peri-urban farmers which destined to be used for agricultural purpose only. The action of local peri-urban landholders/farmers is against the constitutional provision that forbids land sale. As indicated above, the federal constitution of Ethiopia clearly states that all land is state property in which citizens enjoy only use rights without the right to sale [13]. Thus, peri-urban land holders play a double role in the informal urban built-up property formation process. On the one hand, they are primary suppliers of land to the informal market and on the other hand they are also playing a key role in the construction of unauthorized and sub-standard residential houses on agricultural fields without permission to do so. Their motive to construct unauthorized houses by the local landholders themselves on agricultural fields is partly due to their interest in capturing future land value increase resulted from the incorporation of the land into urban jurisdiction.

It is also important to see other factors that push local peri-urban landholders to involve in unauthorized subdivision of their agricultural fields into pieces of plots and later on to transfer it through sale and other mechanisms of transfer. The key pushing factor is their expectation that they would not be able to keep their land for long time in the future due to the rapid urban expansion into their area. The largest proportions of local peri-urban landholders feel that sooner or later the city administration would take their land for urban expansion programs through expropriation decisions. They have also a feeling that the compensation is not fair enough to cover what they loss and the whole process is not participatory. They have also a feeling that even the decided amount may not be paid on time. As a result, local peri-urban landholders on their side, by weighing the amount of compensation that they will be paid upon expropriation of the land and the sales price they are receiving by their own, prefer to sell the land.

The rural-urban dichotomy of land governance institutions is another favorable ground for the widespread practice of informal transaction of land in the transitional peri-urban areas. As a result of the urban rural dichotomy, the possibility of a power vacuum peri-urban zone to be formed is very high than any other geographic space. Most commonly power vacuum zone could be able to be formed when the municipalities adopt a revised master plan that includes the peri-urban areas into the urban center without expropriating and putting the land into its land bank. This power vacuum zone refers to a space neither under rural jurisdiction nor in the urban jurisdiction which in other words refers to a space under no one's jurisdiction. This is an excellent opportunity for local landholders to subdivide and sale their land informally and finally to convert it into a built-up property.

4.2.3 Key aspects of negotiation and documentation process

The negotiation process of plot acquisition from the peri-urban areas through the informal channel involves various step by step carefully studied activities and decisions made mainly by the informal buyer so as to make the transaction safe and free from fraud. For the buyer, having accurate and reliable information about plot availability for sale and reliability of the seller are the preconditions for initial negotiation to be started between seller and buyer in the informal market. Focus group discussion with the brokers shows that information about the potential land sellers like reputation for good behavior and reliability are among the important issues that buyers want to know. It is only after the informal buyer has developed trust on the behavior and reliability of the seller that the process of negotiation for transaction would start.

Local peri-urban residents play a key role as information center for the newcomers who want to buy a plot of land from the area and to build unauthorized residential houses. Local residents are either the rightful local landholders themselves or informal settlers who came to the area some time earlier. Local residents also act as sub-brokers who supply information to the main brokers. Evidences from previous study show that the majority of informal settlers which is about 72% gained information about plot availability for sale from local residents while the remaining 28% of the respondents got information from brokers [23]. Therefore, the role of brokers in the negotiation and information diffusion process is so significant in the informal land market. They are the main diffusers of information about availability of plot for sale. Once they obtained information, they disseminate it by talking to everyone they meet. Land brokers, in the area, have a wide range of social interactions through which they can get information about plot availability for sale.

After having sufficient information about plot availability by the buyer, the potential seller and the potential buyer come into a negotiation table by the support of mediators most commonly by brokers. Again after the potential seller and buyer are being introduced each other what follows is a process of bargaining by which each party tries to secure the best deal as much as possible. The central point of the negotiation is usually the price of the plot. In addition, plot size, location, and distance from public facilities like public road networks are some of the key issues considered in the price negotiation process.

When the parties reach an agreement on the price of the plot, they end up by concluding a written agreement signed by both parties as part of documentation process. Traditional letter of agreement (contract of sale), locally known as "yemender wule," would be concluded between the parties as evidence of transaction at the presence of three witnesses who are locally known as "shemagelewoch." Traditional letter of agreement could be either contract of sale or loan agreement. The amount of money stated in the contractual agreement is usually greater than the real purchase amount with an intention to capture future increase in land value. The content of agreement also states that if the borrower could not pay back the loan within the agreed time, he/she agreed to convey his/her piece of land to the lender in an exchange to the money borrowed. In addition, the content of the agreement contains a written description of the extent of the plot measured in meter or feet. Usually, elders of the village or leaders of traditional social institutions are often preferred as witnesses of transaction. The buyers and sellers receive copies of the agreement, and a third copy is made and kept by one of the witnesses of transaction.

However, the contractual agreements signed by buyers and sellers either in the form of sale or loan or mortgage transfers have no legal ground due to two main reasons. First of all it is not allowed to transfer land through sale in Ethiopia [13] and second of all, contracts of transaction should follow registration by public body as a formal requirement and recognition of transaction. But land transaction the peri-urban areas through the informal channel do not fulfill the requirements. The main purpose of documentation and contractual agreement in the informal market is to avoid conflicts in the future between buyer and seller. The transaction is mainly built on trust.

4.2.4 Plot demarcation and dispute resolution

Plot demarcation and documentation will follow after the parties have reached in agreement on the price of the plot. The spatial extent of the plot can be demarcated by using visible markers such as poles plants, stone marks and fence. The spatial extent of the plots are demarcated and delineated by different actors involved in the transaction most commonly at the presence of three witnesses. Social norms like trust and reciprocity play a prominent role in the land transaction and regulation of the behavior of transacting parties.

As mentioned above the transacting parties in the informal market have no legal grounds and could not be able to take their cases to courts to seek justice in the formal judiciary system when dispute arises between the two transacting parties. The conflicting parties rather prefer to take their cases to the socially respected elders and leaders of "*idir*" and "*iqub*" in the village and the elders and leaders social institutions are quite efficient in solving such conflicts. When conflict arises the affected parties will take their cases to the elders in the village and the elders try to solve the problem by urging the conflicting parties to be governed by their agreement. If the parties could not be able to reach into agreement, they may face problems like being excluded from participating in different social affairs with the community. Moreover, traditional social institutions like "*ider* and *iqub*" play a significant role in making negotiations with government bodies claiming for formalization and organizing resistance against forced eviction. These institutions also provide the members (residents) an identity of belongingness to the area. It is only through these associations that the residents in this settlement area are recognized and registered as residents of the village.

5. The co-existence of formal and informal built-up properties in the peri-urban areas

The formal and informal approaches of land transaction and development are the two contrasting ways built-up property formation ways that persist to exist in the peri-urban areas of Ethiopia (see **Figure 3**). The formal and informal channels of land transaction are being equally practiced side by side one

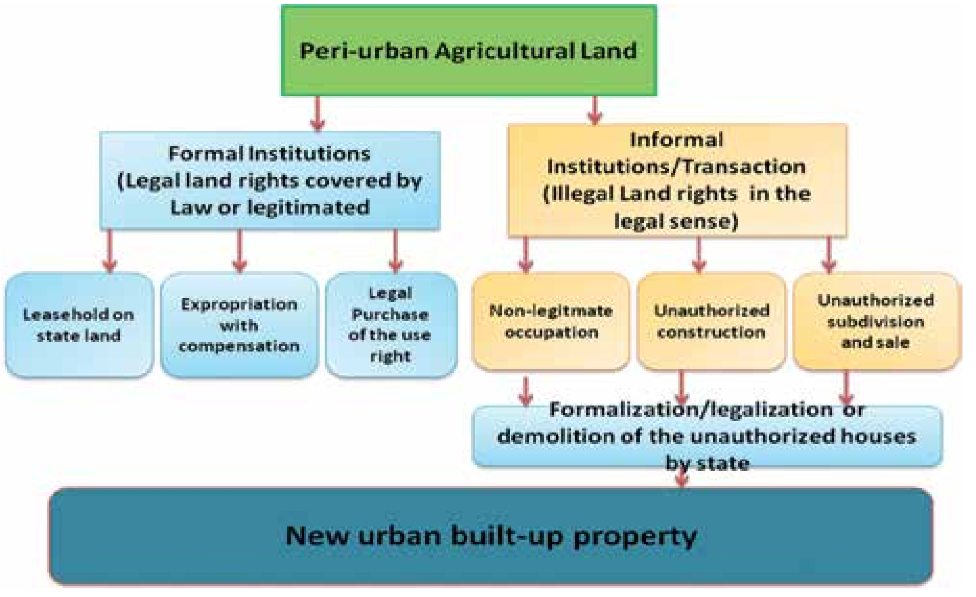

Figure 3.
Built-up property formation process in the peri-urban areas of Ethiopia. Source: author produced.

influencing the other. Peri-urban land which used to be agricultural land has been rapidly converted into urban built-up property both through formal and informal channels. Most commonly, the inability of the formal land acquisition and delivery system to meet the requirements is main reason for the emergence of informality. As it is elaborated in the earlier sections, all land including peri-urban in Ethiopia is state or public property and private property does not exist [13]. According to the formal law, urban land can be allocated to the individuals largely from peri-urban areas based on 99-year leasehold contracts for residential housing [15]. Individuals may also sale and transfer the leasehold right acquired from the state to the others. Therefore, compulsory and formal conversion of the individualized usufruct right of peri-urban landholders into leasehold right is persistently growing and the end result would also be continuous formation of new urban built-up property due to rapid urbanization process.

However, the administrative allocation of urban land through lease system after expropriation seems to be inefficient and not affordable to the urban poor and even to the middle class. On the other hand, rapid urban population growth has been intensifying a great demand for cheap and easily available urban residential land. This demand is partly indeed met by informal supply and acquisition of land from peri-urban areas. Informal supply and acquisition of land includes activities such as illegitimate occupation, unauthorized construction of substandard houses and unauthorized subdivision and sale of land. Peri-urban land holders/farmers are the key actors in the process. Peri-urban farmers fearing expropriation (revocation of their agricultural use rights/holding rights) by the state without adequate compensation prefer to subdivide their farm land into building pieces and transfer their land in the informal (black) market [23]. In addition, other different groups of actors such as brokers, speculators, corrupt government officials, peri-urban residents have been willing to involve in the process of informal transaction and development of land in the peri-urban areas. This trend result in a rapid development of an informal land market, based partly on extra-legal, partly on not-legitimated, and therefore criminal, land tenure regulations. To legitimatize the transaction the parties involved the informal transaction of land use different mechanisms such declaring the transaction as a gift, inheritance, repayment of debt and the like. Despite all illegality in the informal transaction of land, there is also an increasing trend and chance of formalization or legalization by the state. Therefore, this instance best explains the continuous breeding of informal land rights and then after the emergence of new formal property rights by means of formalization/legalization of informal land rights.

6. Conclusion and policy implications

The process of peri-urbanization and urban built-up property formation in the transitional peri-urban areas of Ethiopia is assessed in detail in this chapter. Existing contemporary literatures about peri-urbanization and the resulting emergence of new urban built-up property rights formation process both through the formal (legal) system and informally outside the legal framework are also reviewed. The finding in this chapter has shown that both formal and informal ways are equally important in the process of converting peri-urban agricultural lands into new urban built-up non-agricultural properties. In the process of urban expansion, the former peri-urban landholders are expected to surrender their land to the urbanities through expropriation measures. The expropriated land is expected to be allocated to private developers and business men through lease agreement with the purpose to facilitate urban-based economic growth. This is the general insight how individualized rural usufruct right has been converting into individualized lease holding right formally and the end result of the process would be the formation of new urban built-up property. This study also shows that the urban expansion and development programs of the government into the peri-urban areas seem to seem to favor the urbanities at the expense of the local peri-urban communities.

The inefficiency of the formal land acquisition and delivery system for urban development is found out to be the driving force for the emergence of new urban built-up properties in the peri-urban areas informally. One of the key indications of the inefficiency of the formal system is the termination of agricultural usufruct right held by local peri-urban communities and the replacement of the system by the urban lease system compulsorily by the government. The unparticipatory and top-down decision of the government to expropriate land and to transfer this land to the outsider users through lease system has been pushing the local peri-urban landholders to subdivide and sell their agricultural land illegally before the government expropriates and reallocates their land to the urban developers. This is also aggravated by the bifurcation of the rural and urban land tenure system for urban and rural areas which has resulted in ambiguities on by which system that the transitional peri-urban areas shall be governed.

Finally, this study has proven that the quantity of informal built-up properties will continue to grow unless the government has made accommodative measures are taken to all group of the society. In other words, the dichotomy between the existing "formal" and "informal" city will continue to exist and it will continue to influence one another. The practice shows that unauthorized and illegal houses constructed in the peri-urban areas likely to grow in number and it is accommodating the majority and indeed the poorer section of the population who have no other option. This means it can neither be ignored nor be left to continue to grow and take its own path of development. Therefore, this requires the government to set up a responsive institutional framework that narrows down the rural-urban land governance dichotomy which has been resulting in power vacuum zone in the transitional peri-urban areas. Moreover, the federal government or the local government needs to develop proactive and protective measures for regulating informal land subdivision, use and development in the peri-urban areas.

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References

[1] Narain V, Nischal S. The peri-urban interface in Shahpur Khurd and Karnera. India Journal of Environment and Urbanization. 2007;**19**:261-273

[2] Mbibaa B, Huchzermeyerb M. Contentious development: Peri-urban studies in sub-Saharan Africa. Progress in Development Studies. 2002;**2**(2):113-131

[3] Tacoli C. Changing rural–urban interactions in sub-Saharan Africa and their impact on livelihoods: A summery. In: Working Paper 7 in Rural–Urban Interactions and Livelihood Strategies Series. London: IIED; 2002

[4] Narain V. Growing city, shrinking hinterland: Land acquisition, transition and conflict in peri-urban Gurgaon. India Journal of Environment and Urbanization. 2009;**21**:501-512

[5] Wehrmann B. The dynamics of peri-urban land markets in sub-Saharan Africa: Adherence to the virtue of common property vs. quest for individual gain. Erdkunde. 2008;**62**(1):75-88

[6] Payne G. Urban Land Tenure and Property Rights in Developing Countries a Review. London: Intermediate Technology Publications; 1997

[7] Allen A. Environmental planning and management of the peri-urban interface. Environment & Urbanization. 2003;**15**:135-147

[8] Kasanga KJ, King R, Roth M. Land Markets and Legal Contradictions in the Periurban area of Accra, Ghana: Informant Interviews and Secondary Data Investigation. In: LTC Research Paper No. 127; 1996

[9] Maxwell D, Larbi WO, Lamptey GM, Zakariah S, Armar-Klemesu M. Farming in the Shadow of the City: Changes in Land Rights and Livelihoods in Peri-Urban Accra. In: Cities Feeding People Series Report 23. International Development Research Centre (IDRC); 1998

[10] Cotula L, Neve B. The drivers of change. In: Cotula L, editor. Changes in Customary Land Tenure Systems in Africa. Hertfordshire, UK: Russell Press; 2007

[11] Adam AG. Land tenure in the changing peri-urban areas of Ethiopia: The case of Bahir Dar city. International Journal of Urban and Regional Research. 2014b;**38**(6):1970-1984

[12] Adam AG. Peri-urban land rights in the era of urbanisation in Ethiopia: A property rights approach. African Review of Economics and Finance. 2014c;**6**(1):120-130

[13] FDRE. Constitution of the Federal Democratic Republic of Ethiopia (FDRE). In: Proc. No. 1/1995, Negarit Gazeta. Addis Abeba, Ethiopia; 1995

[14] FDRE. Rural Land Administration and Use Proclamation. In: Federal Democratice Republic of Ethiopia Proclamation No. 456/2005. Addis Abeba; 2005b

[15] FDRE. Urban Lands Lease Holding Proclamation. In: Federal Democratic Republic of Ethiopia Proclamation No. 721/2011, Negarit Gazeta. Addis Abeba, Ethiopia; 2011

[16] Alemu G. Rural Land Policy, Rural Transformation and Recent Trends in Large-Scale Rural Land Acquisitions in Ethiopia. In: European Report on Development: Confronting Scarcity: Managing water, energy and land for inclusive and sustainable growth; 2012

[17] Ambaye DW. Land Rights in Ethiopia: Ownership, equity, and

liberty in land use rights. In: Knowing to manage the territory, protect the environment, evaluate the cultural heritage; Rome, Italy; 2012. [Accessed: 6-10 May 2012]

[18] FDRE. Expropriation of Land Holdings for Public Purpose and Payment of Compensation Proclamation. In: Federal Democratic Republic of Ethiopia Proclamation No. 455/2005; Addis Abeba, Ethiopia; 2005a

[19] Alemu BY. Expropriation, valuation and compensation practice in Ethiopia the case of Bahir Dar city and surrounding. Property Management. 2013;**31**(2):132-158

[20] Anteneh A. The Assessment of Rural Land Valuation and Compensation Practices in Ethiopia. In: Ethiopia Land Tenure and Administration Program (ELTAP). Addis Abeba; 2007

[21] Adam AG. Introducing Land Readjustment as an Alternative Land Development Tool for Peri-Urban Areas of Ethiopia. In: 2016 World Bank Conference on Land and Poverty. Washington, DC: The World Bank; 2016. [Accessed: 14-18 March 2016]

[22] World-Bank. Options for Strengthening Land Administration in Federal Democratic Republic of Ethiopia. In: World Bank Report No: 61631-ET, Washington, DC; 2012

[23] Adam AG. Informal settlements in the peri-urban areas of Bahir Dar, Ethiopia: An institutional analysis. Habitat International. 2014a;**43**:90-97

Chapter 3

Effects of Rural Land Tenure System on Mangroves Management in Corentyne, Guyana

Linda Johnson-Bhola

Abstract

Mangrove forests in Guyana are recognized as the most important soft-engineering structure that protects the low-lying coastal areas against wave and wind actions. However, this vegetation has become severely degraded along some sections of the coast as a result of excessive exploitation and the dynamic nature of the coastline. In an attempt to protect and manage the mangrove ecosystem, the Government of Guyana has instituted a number of mechanisms, including the Guyana Mangrove Restoration Project (GMRP). However, the effectiveness of these instruments has been impaired by the different types of land tenure systems. The study aimed at exploring the inter-relationships between land use and tenure issues, and the sustainable management of mangroves in selected villages in Corentyne, Guyana with a view in determining plausible remedies. The study used a mixed-methods approach, involving Google Earth technology, observation, in-depth interviews, and questionnaire surveys. The results showed that while land use has not changed significantly over the past decade, the advancement and proliferation of mangroves on privately owned lands were quite noticeable. This has given rise to a new area of conflict between managers of coastal mangrove forests and land owners and small-scale traditional users, signifying an urgent need for policy reform.

Keywords: land use, land tenure, mangrove management

1. Introduction

Globally, mangroves occupy the upper tidal zones in the tropical and subtropical regions of Africa, Asia, Oceania, the Americas, and the Caribbean. Altogether, they account for about 15,642,673 hectares to 17,075,600 hectares of the earth's land [1]. The greatest diversity of species is found in South-east Asia where mangroves envelop more than one million hectares of land, representing about 7% of the global total land area coverage [2–4]. Mangrove forests perform a variety of functions and provide a wide array of services, ranging from ecological and protective to social and economic. They provide nursery ground for various marine species; create habitats for bees and other animals; [4] absorb pollutants;

stabilize sediments originating from sea-land interactions; and protect coastal communities from strong winds and waves [4, 5]. Their usefulness also includes the provision of food, medicine, fuels, and construction materials, as well as increasing biodiversity values for local communities [5].

However, while available data point to a variety uses of mangrove ecosystems, analysis of remotely sensed images shows that mangroves are recognized as the most important soft-engineering sea defense structure against erosion in low-lying coastal areas in Guyana [6, 7]. By virtue of more than 75% of the country's population residing along the coastal belt and within proximity of mangrove habitats, uncontrolled developments, economic activities [7–9], and erosion episodes [7, 9] have severely impacted the sustainability of mangrove ecosystems in some locations over the years. These trends, along with the prospect of sea-level rise [10–13], necessitate investigation of how changes in land use, land cover, and land tenure arrangements affect mangrove colony and distribution [6, 9, 12]. For close to a decade, there has been renewed interest in the protection and management of mangroves along Guyana's sea coast [12]. The establishment of the Guyana Mangrove Restoration Project (GRMP) in 2010 is one of the main responses initiated by the government to address these issues [14]. Also, at the policy level, mangrove restoration and management have been identified as two of Guyana's primary responses to the prospect of climate change and sea-level rise, and honoring of obligations to the United Nations Framework Convention on Climate Change (UNFCCC).

The primary objective—founded on three key principles adumbrated by the project document—of the GMRP is to promote the sustainable management of mangroves. These principles are ecological sustainability, economic sustainability, and social system sustainability. According to the GMRP, ecological sustainability suggests maintaining the ecological balance of mangrove ecosystems at its restoration sites while utilizing some resources. Economic sustainability identifies opportunities for satisfying some basic needs of the local communities by establishing mangrove reserves and producers cooperatives, for example; and sustainability of the social systems is directed to developing infrastructure, such as building common facilities for community activities, ensuring social justice, and sustaining local and national traditions that are enshrined in the national policy documents [6, 8, 15]. The different types of land tenure systems invariably have an influence on land use and mangrove management. The objectives of this study, therefore, were to determine the relationship between the dominant land uses and the extent of mangrove coverage in the study area, and to examine land tenure issues that impacted the conservation and sustainable management of mangroves using a case-study approach.

2. Study area, methods, and materials

2.1 Location

The study area is located on the Low Coastal Plain, which is a narrow strip of land on the north-eastern coast of Guyana, South America, and comprises nine villages in the East Berbice-Corentyne Administrative Region. These villages are Adventure, Limlair, Wellington Park, Kiltearn, Eversham, Java, Joppa, Good Hope, and No. 46 (See **Figure 1** for the location of the villages). They were randomly selected from a group of villages, where it was observed that mangroves have advanced on private land east of the public road.

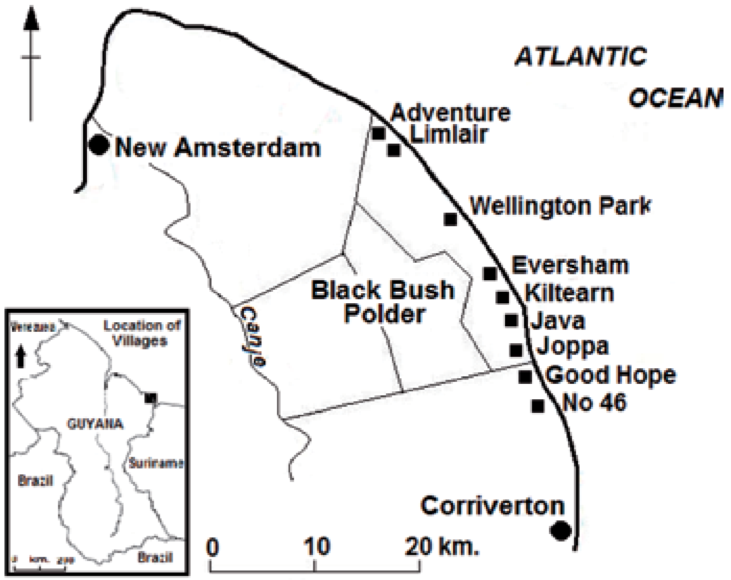

Figure 1.
Location of the study area. Courtesy: Claudette foo.

The study area is characterized by variable hydrological and meteorological conditions. Two wet (May–August and December–January) and two dry seasons (February–April and September–November) are experienced annually. Humidity is high all year round, and there is a narrow range of temperature (26–28°C). The ground surface to the south and east slopes gradually toward the Atlantic Ocean, which lies to the north. Due to the elaborate drainage network and mechanical drainage facilities, the area seldom floods from heavy and continuous rainfall. Although the area is periodically flooded as a result of saline water intrusion during above-normal spring tides, small-scale agricultural activities are carried out sporadically in the area. The relatively flat topography, fertile soils, and good accessibility facilitate agricultural activities. Soils found there originated from different types of parent materials, but they predominantly clays on the front lands and a type of tropical peat called pegasse—which occurs behind the coastal clays and along the river estuaries—in the backlands. The spongy nature of the peat soil allows for high moisture-retention capacity.

The study area consists of economically depressed communities that rely heavily on cash crop cultivation, fishing, and paddy rice farming (this is done on the leeward side of the public road and away from the mangroves). There was no marked change in land use over the past decade, except the expansion of residence in Eversham and surrounding villages, and some instances of the natural proliferation of mangrove on privately owned lands. The residential area is found on both sides—east and west—of the public road only, and it takes on the same linear arrangement as the neighboring communities.

2.2 Research design and approach

2.2.1 Selection of study sites

Three criteria were used in the selection of the study sites for data collection. These are:

a. Availability of data: the need to identify, for comparison purposes, sites for which information was readily available;

b. Socio-economic and ecological consideration: the need to identify sites with similar characteristics, such as employment and presence of mangroves; and

c. Accessibility of sites: the close proximity of the study areas to the main transport route and population allowed for relative ease of visits to the sites.

2.2.2 Land use data collection procedures

The study utilized four methods of data elicitation: Google Earth images for 2009, 2013, and 2016 to determine land use dynamics; observation of land use; in-depth interviews; and questionnaire survey. These methods were used to obtain and triangulate information on the type of land ownership, response to mangrove protection on private land, and strategies to address land tenure issues as it relates to mangrove management in the communities. The sample size consisted of forty-seven (47) households that exist in locations colonized by mangroves.

Various studies on land use or land cover mapping at large scale commonly used the low and medium spatial resolution imagery, such as NOAA, TERRA/MODIS, and Landsat TM or ETM+ [2], and some other global and regional land use or cover products such as FROM-GLC [16, 17] and GLC2000 [18] obtained from remotely sensed data. These advanced technologies have definitely improved our understanding of regional and global land cover distribution and their changes. Regrettably, the relatively low spatial resolution renders them inadequate for detailed land cover mapping in areas that have complex and high varied landscapes, such as cities that are usually featured by small-dimension elements, combined with intricate spatial patterns [18]. Changes in land use close to areas where mangroves exist are often reflected in the land use policy and tenure systems [19]. These changes, which can be determined using Google Earth (GE), are a basic indicator of mangrove coverage and extent [20].

The GE tool was applied to this study for a number of reasons. When used at small scales, it generates medium spatial resolution images. It is a free and open data source and it provides enormous support for the traditional land use/cover mapping [21, 22]. However, very few studies have been undertaken to use GE images as the direct data source for land use/cover mapping and opted for higher spatial resolution images, including QuickBird, IKONOS, and RapidEye [21–23]. If Google Earth images can achieve relatively satisfactory classification, they can provide some opportunities for detailed land use/cover mapping by costing little [19, 24], and is, therefore, quite suitable for use in this study. The three images generated from GE captured the spatial extent of mangroves from 2009 to 2016.

The data obtained from GE has been incorporated in the analysis and discussion section (Section 3.0) of this chapter to help in the understanding of the extent to which mangrove management is stymied by these issues. The Conceptual Framework in **Figure 2** outlines the requirements of and various issues associated with land use, tenure, and sustainable mangrove management.

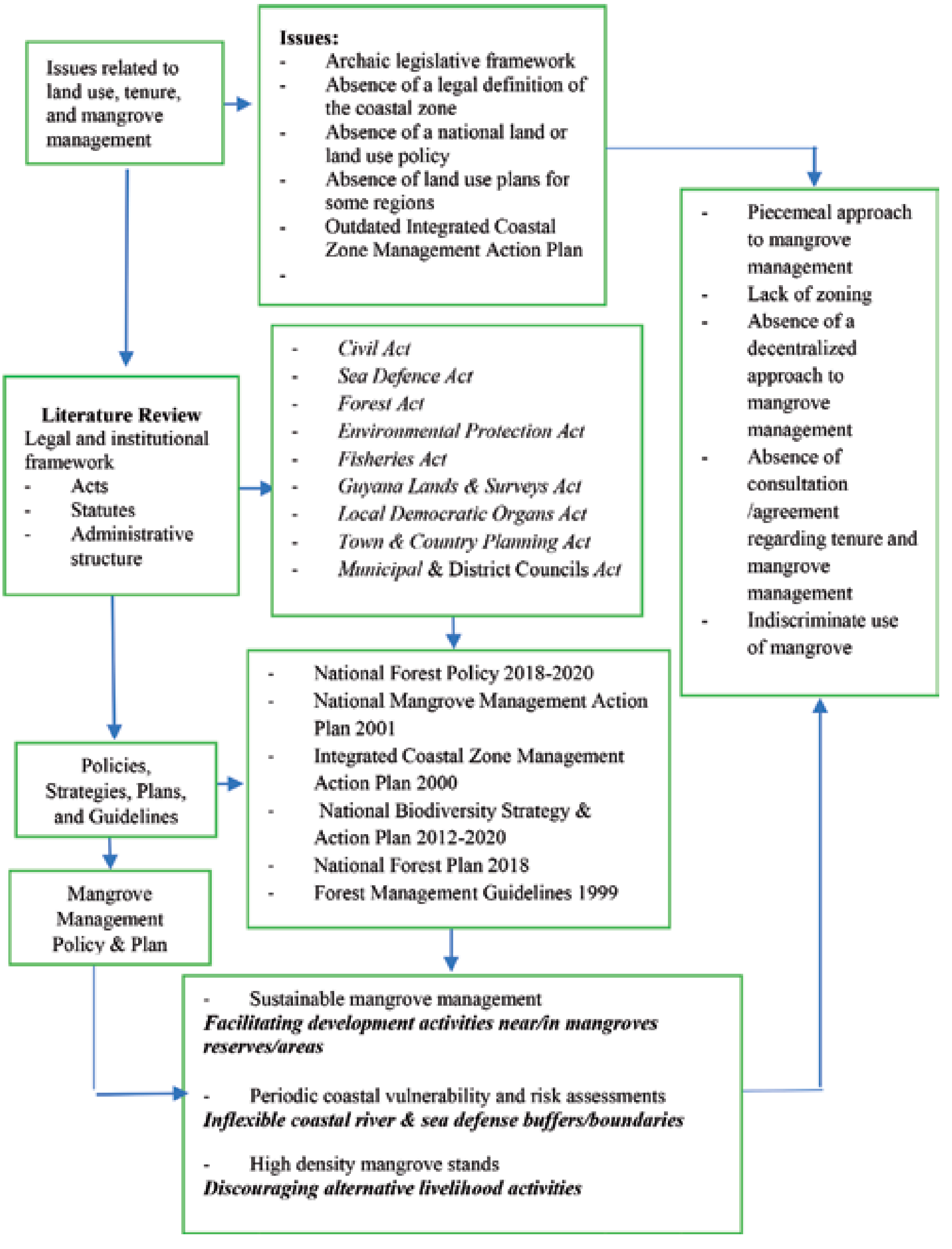

Figure 2.
Conceptual framework of the various issues associated with land use, tenure, and sustainable mangrove management. Data compiled by the author.

3. Effects of land use and tenure issues on management of mangroves

3.1 Land use in the communities over the past 10 years

As observed during the study, land within the study area was used primarily for the purposes of cultivation of mangroves and marshes; for establishment of residential area; for agriculture; and for recreation. Based on the data obtained,

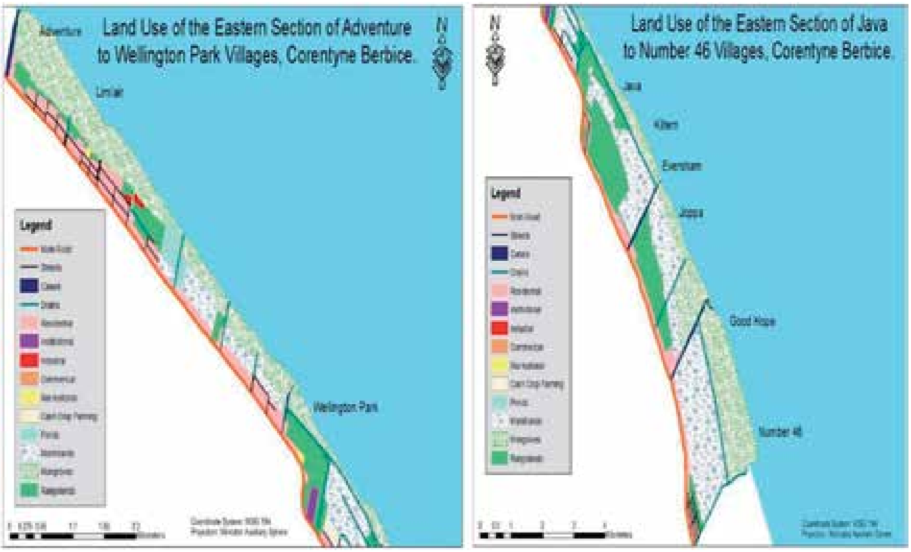

Figure 3.
Land use at the study area in 2016.

land use remained constant from 2009 to 2016. The illustration below (**Figure 3**), which shows land use in 2016—using GE and on-site observation and interviews in 2018—indicates that land use remained unchanged.

3.2 Mangrove coverage in the study area

The intent, initially, was to obtain and use GE images for five-year intervals, from 2009 to 2018, but the GE coverage for 2018 was unclear. For this reason, GE images for the years 2009, 2013, and 2016 were used. The images were obtained on the same date. The quality of the images allowed for the spatial coverage of mangroves at the study area to be determined and evaluated. The amount of land covered by mangrove fluctuated for the period under study. The spatial changes of mangrove coverage in the 8-year period are shown in **Figure 3**. In 2009, mangrove forest coverage was 77.5 hectares, while in 2013 and 2016, it was 91.8 hectares, and 79.08, respectively. A comparison of data for 2009 and 2013 revealed that there was an increase in vegetation coverage of 14.3 hectares—which represents 15 percent increase—with some notable gains along the mudflats around the centre of the study area, and to the southeastern coast closer to Wellington Park for 2013 (**Figure 4(a)** and **(b)**). From 2013 to 2016, figure decreased by 12.72 hectares, which suggest that mangroves were destroyed either naturally or by human activities, or a combination of both (**Figure 4(c)**). The changes in mangrove stock varied in a particularly spatial pattern. They increased constantly toward the extreme west and east of the area, as shown in **Figure 4**, for all of the years, but they fluctuated in the central part. The villages identified in this study are located west and east of the study area as well. Major growth was recorded at Limlair, Eversham, Joppa, Good Hope, and No. 46 Villages. The balance of natural mangrove increase and decrease from 2009 to 2016 could not be determined due to the replanting efforts that were undertaken over the study period. In summary, during the period 2009 to 2016, the cumulative change or net increase in mangrove coverage in the study area was about 1.58 hectares.

Remarkably, the change in residential land use and the sporadic small-scale agricultural activities particularly in the villages of Limlair and Eversham did not cause a corresponding loss of mangrove in the villages, and, therefore, presented no risk to the mangrove ecosystem. However, at Wellington Park, where there has been a systematic attempt to replant and monitor mangroves over the last few years, it was observed in 2017 and 2018 that large sections of the mangrove stand have been severely eroded as a consequence of wave action. This village remained exposed to the natural cycles of erosion and accretion, but the rate of erosion predominates and is accentuated by the presence of a waterway west of the village. The overall decline of and damage to mangrove forest in 2016 could have been attributed to the loss experienced in this village. The decline in mangroves is expected to have resulted in loss of biodiversity and reduction in fishing yield in the village. On the contrary, Java, situated immediately east of Wellington Park and also unprotected from the tides, has witnessed rapid mangrove advancement on private lands, resulting in the clearance of the vegetation by property owners in order to gain access to sections of their plots of land and the seashore.

The proliferation of mangroves in the other villages could only be possible as a consequence of the process of accretion, absence of competition from other vegetation, and protection by community members. The tides transport and deposit sediments and mangrove seeds along the windward side (area closest to the seashore) of the villages. The effect, therefore, has been the expansion of mangrove forests over the last decade. This explains why mangroves increased so rapidly in Adventure, Limlair, Java, Eversham, and No. 46 Villages. The reason for the two contrasting occurrences at Wellington Park and Java—both of which are in the same location only separated by a political demarcation—is still not clearly understood. Overall, the random peasant farming undertaken in some villages did not impact the mangrove ecosystem negatively, and the loss of the vegetation in some villages was appropriately compensated for by the natural regeneration of mangrove in other sites.

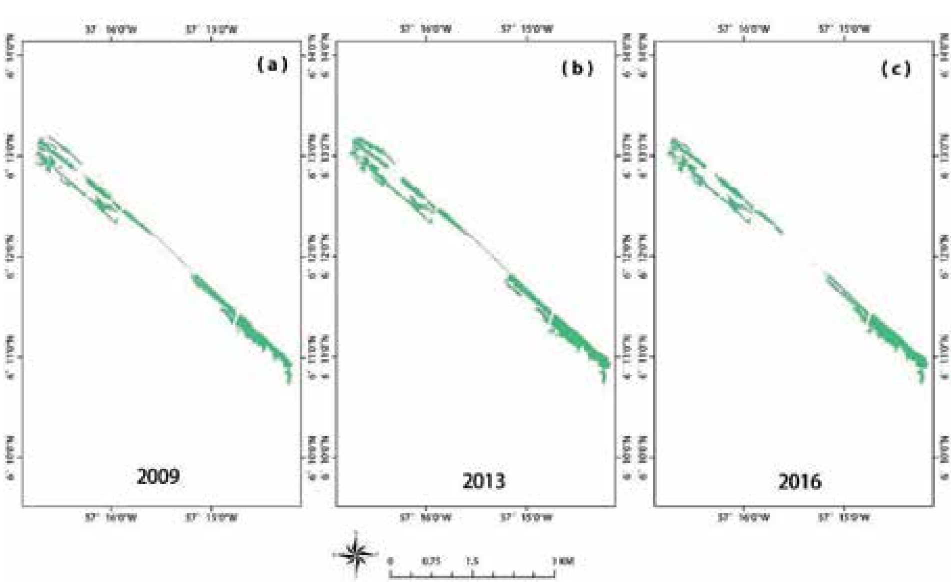

Figure 4.
The distribution of coastal mangroves over the study area in (a) 2009, (b) 2013, and (c) 2016. Courtesy Dina Benn.

3.3 Land tenure issues and mangrove management

In Guyana, land is owned under three distinct legal systems of tenureship: the public (state and government lands), Amerindians (Indigenous peoples), and private freehold/absolute grant arrangement. Interest, or what is commonly known as "ownership," is distributed as approximately 85, 14, and 1%, respectively [24, 25]. While the procedural requirements for leasing of state/public lands and allocation of Amerindian lands are relatively precise, private freehold arrangements and procedures are punctuated by ambiguity in the rules and regulations relative to a number of Acts and Statutes that set out the legislative and administrative frameworks for land management. The policies and regulations regarding private land owners' right to freehold property, which mangroves colonizes are not clear.

The ministerial proclamation was a response to the heightened level of vulnerability of the coast to sea level rise, threats to the protective and ecological functions of the vegetation, and associated issues. This proclamation has led to further hurdles prominently among which are overlapping and conflicting processes that do not represent best practices in tenure arrangements. It also resulted in a conflicting understanding, among policymakers and the local communities as well, of land ownership, and raised legitimate questions about the effectiveness of any mangrove management initiative, especially in those locations contiguous with the seashore. The tradition in some rural communities, including those where mangroves exist, is that individual property right is insecure and deemed by many owners as unnecessary; thus, a relatively large percentage of owners either do not register their property or keep their ownership rights updated. Effective and efficient mangrove management, therefore, requires a comprehensive set of legal and institutional reforms aimed at changing perceptions and understanding of the system at large, and attitudes toward property rights, enforcement, and the natural environment. It also requires a new set of procedures and written legal and institutional structures.

As stated before, in order to manage mangroves, the Government of Guyana, in collaboration with the European Union, established in 2010 the Guyana Mangrove Restoration Project (GMRP) administered by the Ministry of Agriculture and implemented by the National Agricultural Research and Extension Institute (NAREI). Since the commencement of the project, a number of other entities also worked closely with NAREI to undertake mangrove management activities. These include the Guyana Forestry Commission (GFC), the Sea and River Defense Department of the Ministry of Public Infrastructure (MPI), Fisheries Department of the Ministry of Agriculture (MoA), Environmental Protection Agency (EPA), Guyana Lands and Surveys Commission (GLSC), National Drainage and Irrigation Authority (NDIA) of the Ministry of Agriculture, and the Regional Democratic Councils (RDCs). The first four agencies cited have a more direct involvement in mangrove management. These agencies perform various functions, ranging from coordination and facilitation of mangrove activities to sea defense infrastructure development.

3.4 Effects of private land ownership on mangrove conservation and management

It is well established in the literature that the participation of local community members in mangrove conservation projects is imperative for its sustainability. In order to understand how private land ownership affects mangrove conservation and management, a case study was conducted and the results are presented below. The main objective of the case study was to obtain the views of the households in the ways in which private land ownership, as one of the main types of land tenure systems, is likely to impact sustainable mangrove management. The study showed that significant areas of private lands are colonized by mangroves which extend from about 0.5 km

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Figure 5.
Proximity of mangroves to household at No. 46 village. Courtesy of L. Johnson-Bhola.

		Aware that Mangrove is a Protected Species			Total
		Yes	No	Not stated	
Land Owner	Yes	5	26	1	32
	Not stated	1	2	0	3
	No	1	7	0	8
	Disputed land	1	3	0	4
Total		8	38	1	47

Source: Questionnaire Survey.

Table 1.
Awareness of the legal status of mangroves.

east of the main road to the reserve area or buffer zone near the sea shore. **Figure 5** illustrates sections of the vegetation located at the rear of the house lots.

Data collected on awareness of the status of mangroves as a legally protected forest showed that 80% of the households were unaware. Eighty-one percent of those who owned property had no knowledge that mangroves were protected by regulation (**Table 1**). This is a clear indication that there is a need for greater outreach focusing on education and awareness, particularly in areas where primary mangroves emerge.

A recurrent issue raised was statutory jurisdiction over mangroves on private territory without consultation with the local communities. Most of the households were aware of the legitimacy of freehold tenureship and vehemently defended entitlement to their property. **Table 2** illustrates that land tenure arrangements varied in the villages. Sixty-eight percent of the households indicated that the plots were held by transported and title, while 13% did not state the nature of land holdings. Land ownership, in this study, appeared to be one of the key issues linked to households' willingness to support the mangrove restoration project.

Data showed that the households were willing to allow the growth of mangroves on their property. This variable is considered significant as natural regeneration seemed to be less costly, and it showed that the households were ready to contribute to mangrove management. Despite being willing, many households did not understand that the mangrove project is a national initiative intended to benefit vulnerable coastal communities. **Table 3** shows that the majority of the households in the villages for over 10 years were happy that the mangroves were on their property because the vegetation assisted in protecting the property from the sea. While there was less likelihood that conflicts would emerge over the use of unclaimed land for mangrove protection, it appeared that absentee land owners, as well as the communal arrangements that exist in most of the villages, would present difficulty for the mangrove protection.

Many of the households stated that there is a need to address land tenure issues, for they are likely to affect mangrove management. **Table 4** indicates that 80% of the households with married couples required compensation if the lands were to be converted to mangrove forest use. Altogether, approximately 64% of the households needed compensation. This variable is important because it is an indication of long-term land use change, which could limit other potential valuable uses. Fifty percent of the Indo-Guyanese households requested compensation, while 65% of the Afro-Guyanese households and 100% of the households of mixed ethnicity required compensation if they were to allocate parcels of their estate to mangrove protection. This data is significant because it points to the issue of unwillingness of the households to collectively relinquish interest in lands for mangrove protection. A critical factor for successful mangrove restoration and/or management projects is favoring community allocation over household allocation. For titled lands, the interest may be owned similarly, except in special cases such as where separate lots have been awarded to persons.

Type		Frequency	Percent
Valid	Titled	8	17.0
	Transported	24	51.1
	Disputed	2	4.3
	Transport pending	1	2.1
	Informal occupancy	2	4.3
	Not stated	6	12.8
	Leased	4	8.5
	Total	47	100.0

Source: Questionnaire Survey.

Table 2.
Types of land tenure.

Reasons/Period of Residence		Reasons for being happy with mangroves on private land			Total
Period of Residence	Less than 5 years	1	1	0	2
	5–10 years	9	3	3	15
	More than 20 years	17	8	5	30
	Total	27	12	8	47

Source: Questionnaire Survey.

Table 3.
Willingness to allow the growth of mangroves on private property.

	Compensation needed for Relinquishing Land			Total
	Yes	Do not know	No	
Not stated	5	0	1	6
Leased	3	0	1	4
Titled	3	2	3	8
Transported	16	2	6	24
Disputed	0	1	1	2
Transport pending	0	0	1	1
Informal occupancy	1	0	1	2
Total	28	5	14	47

Source: Questionnaire Survey.

Table 4.
Requirement for relinquishing land.

It has been recognized that local buy-in is necessary to support mangrove management. Additionally, awareness of the mangrove intervention project and proper timing of such intervention are important initial elements of a successful and acceptable mangrove management initiative.

3.5 Averting land use and tenure issues as it relates to the sustainable management of mangroves in the study area

A wide range of suggestions was put forward by the households as it relates to how the issue of sustainable management of mangroves at the community level could be addressed. The most important include:

- consulting with the communities with the view of encouraging mangroves on private lands that are not assigned for specific purposes;
- addressing issues, such as land tenure, particularly in Region 6: issues related to private land ownership in mangrove areas. This would strengthen coastal zoning activities for the most critical mangrove areas;
- identifying risks associated with changing policies and laws to protect mangroves;
- designing a framework for controlling change in land use in areas where mangroves exist;
- allocating unclaimed land, where mangroves exist to protective and productive mangrove forest;
- evaluating private land, where mangroves exist with the view to compensate owners;
- defining beneficiaries clearly in order to avoid the exclusion of certain households from mangrove areas; and
- facilitating traditional users of the area and those who need to go through the mangroves to access the intertidal flats and fishing grounds. This is particularly relevant for the poor who own no land.

These suggestions, in effect, form a list of recommendations to be evaluated and adopted by GMRP. It is suggested that the authorities place greater emphasis on improving local communities' knowledge about mangrove management, and their rights and responsibilities, through improved outreach programs. Further, reference was made to the need for consultations with the local communities before decisions that are likely to have great impacts on the land ownership are made. This suggestion is considered crucial because it can instruct the authorities to take precautionary actions and minimize conflicts. Some respondents suggested that—as a strategic approach to preservation of the vegetation—consideration be given to relocate some households that are found within proximity of locations where mangroves exist. However, after consideration of the extent of private lands, which ought to be brought under control for protection of the sea coast against the erosive action of the river current, the need to revisit the laws and regulations governing the 50 ft. extent from the shoreline for sea defense protection will have to be amended. The study has pointed to the fact that some residents are willing to commend portions of their private land toward mangrove protection—despite competition with other potentially lucrative uses of the land, such as farming aquaculture—but they need to be compensated.

4. Conclusions

From the perspective of long-term development, the mangrove areas need to be considered as a multiple-use management area (MUMA) given the different interest groups that exercise jurisdiction over the area. As a MUMA, each stakeholder will be given an opportunity to have its interest addressed, while at the same time, the potential for conflict will be reduced. Sustainable management of mangroves is likely to be impacted by land tenure issues in the communities where the study was conducted. While the households expressed willingness to support mangrove protection, they were unaware of the legal status of the vegetation. Among the concerns raised was their right to deforest their private land whenever the need arose. The general trend was that most households showed willingness to transfer ownership of the land, which has mangrove if compensated accordingly. The effects of human activities and development and land tenure issues on the mangrove sustainability were in part compensated for by the natural growth of mangroves in the study area. So, with the support of local authorities and environmentally friendly use of the community forest, as well as appropriate management of stand structure, the coastal mangrove ecosystem in this area should be able to thrive successfully.

Conflict of Interest

There is no conflict of interest.

Thanks

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References

[1] AizpuruM, AchardF, BlascoF. Global assessment of cover change of the mangrove forests using satellite imagery at medium to high resolution. In: EEC Research project n 15017-1999-05 FIED ISP FR – Joint Research Centre, ISPRA; 2000

[2] Giri C, Ochieng E, Tieszen LL, Zhu Z, Singh A, Loveland T, et al. Status and distribution of mangrove forests of the world using earth observation satellite data. Global Ecology and Biogeography. 2011;**20**(1):154-159

[3] FAO. Mangrove Forest Management Guidelines. FAO Forestry Paper No.1119; 1994. Rome

[4] BrownB. Mangrove Action Project, Indonesia Annual Report 2006; 2006

[5] Goodbody CI, Thomas-Hope EM. Natural Resource Management for Sustainable Development in the Caribbean. Barbados: Canoe Press; 2002

[6] National Mangrove Management Action Plan 2010-2012; 2010

[7] Government of Guyana (GoG). Progress Report, Performance Criterion 1 and 2, Sustainable Coastal Zone Protection through Mangrove Management. Guyana: National Agricultural Research and Extension Institute (NAREI); 2012b

[8] Guyana Lands and Surveys Commission. Guyana National Land Use Plan. Georgetown, Guyana: Guyana Lands and Surveys Commission; 2013. Available from: http://goinvest.gov.gy/wp-content/uploads/GuyanaNLUP.pdf

[9] Ackroyd C. Initial Technical Assistance for a Mangrove Project in Guyana, Technical Assistance for Capacity Building and Institutional Strengthening of the Sea Defenses Sector, Projected to be Implemented by MWH; 2010

[10] Dasgupta S, Laplante B, Meisner C, Wheeler D, Yan J. Impact of Sea Level Rise on Developing Countries: A Comparative Analysis. World Bank Policy Research Paper No. 4136. Washington DC: The World Bank; 2007. Available from: http://documents.worldbank.org/curated/en/156401468136816684/The-impact-of-sea-level-rise-on-developing-countries-a-comparative-analysis

[11] Government of Guyana. Second National Communications to the UNFCCC. Georgetown, Guyana: Communication to the United Nations Framework Convention on Climate Change; 2012. Available from: https://climatechange.gov.gy/en/index.php/resources/documents/18-second-national-communication-to-the-unfccc

[12] EPA. Integrated Coastal Zone Management Action Plan- Guyana; 2002

[13] Government of Guyana. A Low Carbon Development Strategy: Transforming Guyana's Economy while Combating Climate Change. Guyana: Office of the President; 2010

[14] Johnson-Bhola L, Oyedotun TDT. Coastal defence roles of mangroves on the Amazon-influenced coast of Guyana, South America: A review of intervention project of an eroding coastline. Spring 2018 ed. The Zone, Canada Coastal Zone Newsletter; 2018. pp. 12-14

[15] World Bank, ISME, cenTER Aarhus. Principles for a Code of Conduct for the Management and Sustainable use of Mangrove Ecosystems; 2004

[16] Congalton RG, Green K. Assessing the Accuracy of Remotely Sensed Data:

Principles and Practices. New York: CRC Press; 2008

[17] Foley JA, DeFries R, GP Asner C, Barford GB, Carpenter SR, Chapin FS, et al. Global consequences of land use. Science. 2005;**309**:570-574

[18] Joshi N, Baumann M, Ehammer A, Fensholt R, Grogan K, Hostert P, et al. A review of the application of optical and radar remote sensing data fusion to land use mapping and monitoring. Remote Sensing. 2016, 2016;**8**:70

[19] European Commission. EU Land Policy Guidelines. Brussels, Belgium: European Commission; 2004. Available from: https://ec.europa.eu/europeaid/sites/devco/files/methodology-euland-policy-guidelines-200411_en_2.pdf

[20] Lillesand MNF, Kiefer RW. Remote Sensing and Image Interpretation. 6th ed. Toronto: John Wiley and Sons Inc; 2011. pp. 520-537

[21] Son NT, Chen CF, Chang NB, Chen CR, Chang LY, Thanh BX. Mangrove mapping and change detection in Ca Mau peninsula, Vietnam, using landsat data and object-based image analysis. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing. 2015;**8**(2):503-510

[22] Wang Y, Mitchell BR, Nugranad-Marzilli J, Bonynge G, Zhou Y, Shriver G. Remote sensing of land-cover change and landscape context of the National Parks: A case study of the northeast temperate network. Remote Sensing of Environment. 2009;**113**:1453-1461

[23] Kanniah KD, Sheikhi S, Cracknell AP, Goh HC, Tan KP, Ho CS, et al. Satellite images for monitoring mangrove cover changes in a fast growing economic region in southern peninsular Malaysia. Remote Sensing. 2015;**7**:14361-14385

[24] Panaritis E, Kostopoulos A. Guyana Property Rights Study. Washington: Inter-American Development Bank; 2010. Available from: http://www.iadb.org/en/publications/

[25] Kodilinye G. Commonwealth Caribbean Property Law. 2nd ed. Great Britain: Cavendish Publishing Ltd.; 2005

Chapter 4

The Effects of Green Energy Production on Farmland: A Case Study in Yunlin County, Taiwan

Yu-Hsin Tsai, Tzu-Chin Lin, Shih-Yuan Lin, Stephan van Gasselt, Chia-Lin Chen, Chia-Hsin Hsu, Kuan-Ying Lin, Chia-Hsin Liu, Meng-Chin Tsai and Zhu-Shan Xie

Abstract

Taiwan enacted the *Act of Renewable Energy* in the year 2009 which promotes energy safety, green economy, and a sustainable environment, and with that the government envisages a contribution of photovoltaic energy of up to 20% by the year 2025. In this study we look into the motivation and background of this energy policy, plans for implementation and associated challenges, and its actual consequences for farmland use and farmers. In addition, we take a look into the implementation of mixed-use farmland in which agricultural activity and photovoltaic installations are planned to coexist in order to increase land value and productivity. We furthermore report on some of our findings related to a field survey conducted in Taiwan's corn chamber of Yunlin County which has been facing a number of socioeconomic challenges.

Keywords: agriculture, farmland use, rural area transformation, photovoltaic installations, green energy policy, Taiwan

1. Introduction

The shift toward a green(er) renewable energy policy has been on the agenda for most of the industrial countries and is supported by overarching programs such as the *United Nations Development Program* to mitigate effects from climate change [1]. The implementation is not undisputed due to the actual technical as well as financial feasibility and timing in particular. Be it by reducing nuclear power sources or by eliminating energy from conventional sources such as coal, gas, or oil, tools for renewable energy need to be developed, and their implementation needs to be enforced systematically in order to cover increasing national demands. Renewable energy comes, although not exclusively, either from solar energy through the means of photovoltaic and thermal installations, from wind energy through the use of wind turbines, or from hydro energy using hydroelectric generators, often connected to reservoirs (e.g., [2]).

For Taiwan's consumption in 2017, 98% of energy was imported from fossil resources such as oil (48%), coal (30%), natural gas (15%), and nuclear power (4%). Less than 2% of the indigenous 2% of energy was contributed by renewable energy (biomass, hydroelectricity, photovoltaic, and wind). The installed national capacities, however, covered 5276 MW of energy in 2017 with 39% conventional hydroelectric energy, 34% photovoltaic energy, and 13% wind energy [3]. Due to the dependence on energy imports from other countries as well as a change of direction with respect to the implementation of a green energy policy, the government is actively encouraging and supporting developments in this domain.

The county of Yunlin in central Taiwan is one of the areas in which green energy projects are being developed leading to a successive change of the landscape with potential long-term effects on the farmers and farmland. Together with Chiayi County in the south, Yunlin County is located in the Chianan alluvial plain built by sediments connected to the Alishan mountain range in central Taiwan. As such the plains are characterized by farmland agriculture predominantly focused on rice, sugarcane, peanuts, and corn as well as sweet potato. In Yunlin County farmland covers about 68% of the total area. A high density of fish ponds are found along Yunlin's coast with aqua culture focused on, e.g., clams and tilapia. However, Yunlin County has been suffering from structural problems over the last decade which are related to anthropogenically caused subsidence of the land (likely) due to excessive groundwater pumping. Apart from potential destabilization of the high-speed rail construction (**Figure 2**), it causes structural problems on buildings and potentially a significant salinization of farmland (e.g., [4]).

Due to the gently sloping plains of the Yunlin alluvium, rivers contribute a significant amount of hydroelectric energy. Yunlin County hosts the third largest coal power plants in Taiwan, the Mailiao Power Plant (**Figure 2**), with a total capacity of 4200 MW distributed over 7 units [5]. Wind energy has become an important topic with the conceptualization of a number of on- and offshore wind turbines recently. Currently, Yunlin hosts less than 20 coastal onshore wind turbines which constitute no more than 5% of the national wind turbines in operation. With these, a capacity of about 35 MW can be estimated. However, recent investor agreements in late 2018 consolidated plans for setting up an offshore farm with a capacity of 8x80 MW [6] (cf. **Figure 2**).

2. The rise of energy-driven demand for farmland in Taiwan

Taiwan enacted the *Act of Renewable Energy* in the year 2009 which promotes energy safety, green economy, and a sustainable environment. The targeted proportion of electricity generated by renewable energy is set to be 20% by the year 2025 where solar power will account for 20 GW. Researchers rightly pointed out that one critical issue associated with renewable energy is the siting of energy-generating facilities [7]. Renewable energy such as wind turbines and photovoltaic installations cannot generate electricity 24 hours a day due to intermittent wind or total lack of sunlight in the night, respectively. As a result, the acreage of land needed for one unit of electricity generated by renewable energy tends to be larger than for conventional installations of power generation, such as nuclear plants and water reservoirs. The feasibility of renewable energy to become the dominant supply of energy in Taiwan by the year 2025 to a large extent has become an issue of land use. In spite of the land-consuming nature of solar power, the potential vertical multiple uses of land lessen the severity of mass consumption of land. It has been suggested that certain types of crops or vegetation can be grown underneath the solar panels without loss of much productivity. This way of agricultural production presents a way of inclusive instead of exclusive use of land. As far as solar power is concerned, Taiwan government has set a target for the year 2025 of 3 GW generation from solar panels on rooftops and 17 GW from solar panels on the ground (see **Figures 1** and **2**). Given the assumption of 10 m^2 of space needed

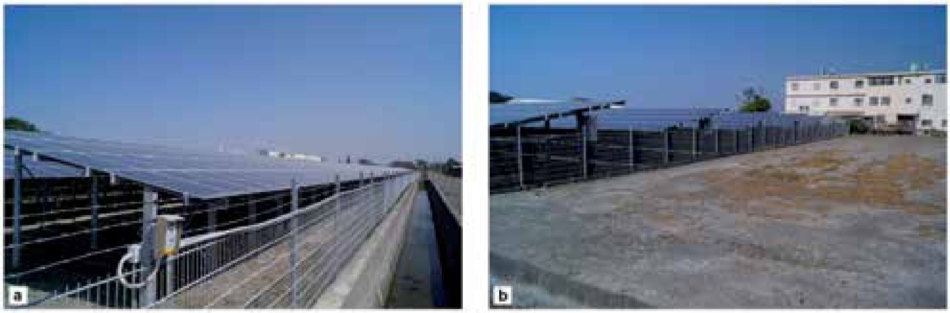

Figure 1.
(a-b): Typical mounted photovoltaic arrays in central Yunlin. (a) Dense spacing of solar modules do not allow for mixed land use. (b) Inactive and probably hypersaline farmland, note irrigation channels at farmland boundaries.

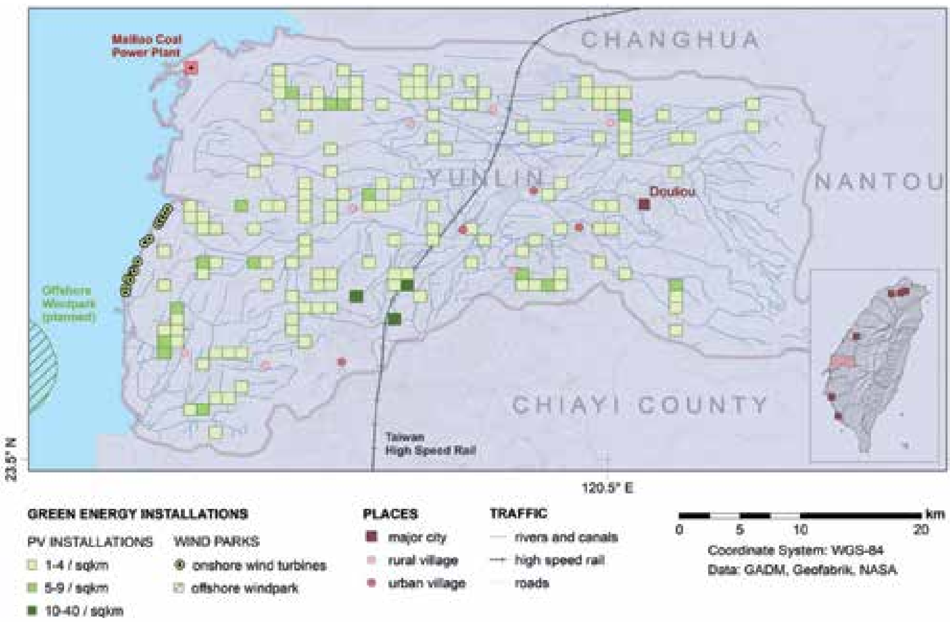

Figure 2.
Sites of energy generation in the Yunlin County, locations and spatial density of rooftop and ground-based solar farms are based on a recent remote-sensing data survey and field observations.

for one rooftop solar panel and 15 m^2 of space for one ground solar panel, a total of 30 km^2 of rooftop and 255 km^2 of ground are, respectively, required island-wide.

In order to attain the targeted figure of energy generation, several priority sites have been identified for installation of solar panels in the 2-year initiative of solar panels proposed by the *Bureau of Energy of the Ministry of Economic Affairs*. The identified preferable location for rooftop panels are on top of state-owned buildings, factories, other buildings, and agricultural production facilities. In addition, the identified preferable sites for ground panels are sites of the salt industry, landfill and contaminated land, severe subsidence areas, and water bodies. Under a rather optimistic scenario assumed in the 2-year initiative of solar panels, 41.34 km^2 of space is thought to be supplied on the rooftop of all public buildings, and that could theoretically generate up to 4.1 GW of electricity. One study arrived at a potential total amount of 26.43 GW power generation contributed by solar panels on the ground surface [8]. This figure is based upon the assumption of full usage of particular types of state-owned land (salt industry land, reservoir, detention basin, landfill, etc.) and 20% of devotion of farmland to the installation of solar panels. The authors, nevertheless, highlighted the possible conflicts between energy production and environmental protection and food security, to mention a few of them. For example, high-quality farmland that enjoys a full exposure to sunlight also tends to be well suited for solar panel installation. In this context, the counties of Changhua (彰化), Tainan (台南), Yunlin (雲林), and Chiayi (嘉義) have been promoted as priority counties for the installation of solar panels to exploit longer hours of sunlight [9] (**Figure 2**).

Besides, the lack of experience and concern over environmental issues caused by the installation of solar panels will certainly lead to impacts on the farmland market, both in terms of sales price and transaction volume. The only study so far that attempted to measure the price effect of solar panels on nearby farmland was conducted by [10]. In this case study of Tainan City, no uniform price effect has been found. The farmland price might either rise or fall with the distance from the solar panels depending on the regions they are located in. However, [10] concluded with a warning saying that the rising farmland value might harm the farming production on a longer term.

The link between energy consumption and location of solar panels on farmland is already recognized: the more the reliance on renewable energy, the more it will lead to a competition among alternative land uses. However, the discussions in Taiwan so far overly simplify the provision of farmland into sites of solar panels. Their conclusions are strongly based on the rosy assumption that a certain percentage, for example, 50%, of private land owners will soon agree to enter a long-term leasehold (of at least 20 years) with an energy company.

In the leasing of farmland for installation of solar panels, the annual rent paid by the solar power company to land owners as advertised, for example, by MOTECH [11], is 40,000 New Taiwan dollars (approximately 1300 USD as of December 2018) for 1000 m^2 that will last for 20 years. Is the rent attractive enough to move the dominant use of land from farming to solar panels? The *Council of Agriculture* reports an average rent for farmland per square meter in the Tuku Township of Yunlin—famous for its garlic farming—to be 9.14 NTD, equivalent to 9140 NTD for 1000 m^2 of farmland [12]. That is to say, the revenue of leasing land to allow for photovoltaic installations earns 4.4 times the market rent for farming. The rent offered from solar panels is apparently alluring.

3. Designating locations for solar panel installations

Governmental criteria for designating land for solar farm use can be classified into three major categories:

1. Land characteristics suggest excluding solar farm designation due to incompatibility reasons.

2. Land characteristics suggest incorporation of solar farms in addition to or as a replacement for original use.

3. The landowner's socioeconomic status suggests incorporating solar farms is a good choice (cf. **Table 1**).

When it comes to the first case of incompatibility, a wide variety of concerns must be considered to avoid intrusion upon or damage to land resources:

environmental, agricultural, landscape, perspectives of cultural heritage, habitat, human settlement, etc. [13–15]. Solar farms are often a more efficient use for land encountering difficulty retaining its original use due to contamination, subsidence, or other deteriorating factors. In the third case, solar farms can be utilized as a tool to aid socioeconomic hardship on the part of landowners by offering a source of extra and potentially higher income, such as for financially disadvantaged or aging landowner communities.

Rooftop solar panels are allowed on agricultural land in Taiwan, but solar farms with panels set directly into the ground are restricted except in cases where the land has already been permanently contaminated and is not fit for further agricultural use. Rooftop panels are encouraged for most buildings, with the exception of greenhouses (who have a 40% maximum limit) and screenhouses, as they have minimal impact on ground-level land use and contribute to the self-sustainability of agricultural production. Ground-level solar farm use is generally not allowed for the protection of agricultural resources except when strict conditions are met, conditions that themselves correspond to the above three criteria (cf. **Table 1**). Under criterion 1, agricultural land of the highest grade (i.e., "special agricultural districts") without actual farming activity is restricted from building solar farms [17]. Under criterion 2, agricultural land with farming activity can build solar farms within designated areas up to a 40% land use maximum. In practice, however, this type of solar farm is not encouraged as local governments fail to designate the appropriate areas. Under criterion 3, contaminated agricultural land is applicable for building solar farms

	Land use type	
	Land in general	**Agricultural land**
Governmental/ theoretical criteria	Three categories of criteria: 1. Land characteristics that suggest excluding solar farm designation due to incompatibility, including (a) landscape and environmental concerns [13], (b) agrological concerns [16], and (c) socioeconomic concerns [15] 2. Land characteristics that suggest incorporating solar farms in addition to or as a replacement for original use 3. Landowner's socioeconomic status suggests incorporating solar farms is a good choice	**Rooftop solar panels:** Solar panels can be installed on the roof of existing buildings in agricultural land except for greenhouses (a 40% maximum) and screenhouses (The Government of Taiwan, 2018b) **Solar farms:** Criterion 1: Agricultural land of the highest grade without farming activity is restricted from building solar farms [16] Criterion 2: Agricultural land with farming activity can build solar farms within designated areas up to 40% land use maximum. In practice, however, land remains undesignated [18] Criterion 3: Agricultural land with a loss of agrological capacity can be considered for solar farm designation up to a 70% maximum, including (a) existing permanently contaminated agricultural land and (b) subsided or salted agricultural land [18]
Issues	Change of land cover and landscape Potential environmental impacts on biodiversity due to land cover change from solar farm implementation [16] Potential economic impact on the original function of the land	Some agricultural land is overzealously replaced or abandoned altogether in lieu of solar farm upkeep by unscrupulous farm owners [19] Some tenants' farming businesses are terminated by landlords seeking better revenues via solar farming [20]

Table 1.
Compilation of designation of solar farm locations and associated issues.

(who have a 70% maximum limit) only when landowners have been devoted to decontamination, but the land has failed to recover. This condition does not apply, however, to potential future contaminated land for a variety of reasons, including to avoid cases of intentional contamination [21]. Furthermore, subsided or salted land that loses agricultural capacity can be considered for the building of solar farms [18].

4. Current challenges with respect to solar farm deployment

The deployment of solar farms may cause a series of issues from changes in land cover and landscape to impacts on environmental and economic functions of the designated land and surrounding areas (cf. **Table 1**). A change in land cover has potential environmental impacts on biodiversity as well as ecological value and function [16]. These environmental impacts are possible not only at the site of the solar farm itself but also in nearby areas whose ecological systems are inseparable. As land is taken up by solar panels, this affects the landscape and original function of the land, and economic impacts on the agricultural industry may occur due to a compromised microclimate under the panels due to a decrease solar radiation, less rain uptake, and so on [22].

In addition to these various generalizable issues, Taiwan has encountered some unique issues of its own in implementing solar farm policy; the original functioning of some agro-farms has degraded or been abandoned altogether due to insufficiently robust design of the relevant laws initiated by the then inexperienced legislature; cheating and illegal behavior of agro-solar farm owners has occurred, and high costs and intensive labor requirements for the monitoring and enforcing of these laws have been incurred (cf. **Table 1**). In 2013 the regulations for building solar panels on agricultural land were first included in the law by the central government's agricultural agency [18]. At this time, however, a considerable amount of farmland had already been replaced by solar farms due to premature laws that did not require the participation of agricultural agencies in the process of reviewing solar farm applications. Later in 2017 newly implemented laws required the agro-solar farm to maintain the agricultural function to the degree required in the review process, and failing to keep up this agricultural performance would cause termination of the solar farms in the worst case. The high financial return possible from solar power caused cheating and illegal farming practices to skirt these requirements to occur, which in turn calls for high-cost and labor-intensive monitoring on behalf of the government to enforce these laws, particularly given the enormous number of cases [19, 23]. In addition to this incentive to mismanage the agricultural side of solar-agro production, some tenants' farming businesses have been terminated altogether by landlords seeking these higher revenues from solar energy [20].

5. Land use codes and their impact on agricultural output and solar power generation on agricultural land

This section illustrates three applications of the land use code in managing solar farms on agricultural land as particularly impactful on the productivity of crop yields and solar energy generation: the mixed use of solar panel installation and original use, the distance between solar arrays, and the elevation of solar panels' aboveground level.

Firstly, incorporating a mixed-use scheme between agriculture and solar panels residing on the agricultural land (crops grown beneath solar panels, cf. **Figure 3**) can be derived from agroforestry experience where the simultaneous implementation of two types of products on the same land area can optimize its overall productivity [24].

Figure 3.
(a-b): Photovoltaic arrays in central Yunlin County with solar trackers to allow for higher efficiency by tracking the direct sunlight beam. Less dense module spacing allow for mixed-land use if feasible.

Although less solar radiation is available under solar panels, potentially affecting crop productivity and types of crops suited for this type of planting, based on simulation analysis, a mixed-use scheme has higher combined productivity (solar power generation plus crop yields) than a single-use solar farm or agro-farm would on its own [25]. Additionally, a full-density solar panel pattern deploys the optimal configuration for electricity generation and can yield higher combined productivity of the land use than a half-density pattern. The higher the proportion of land dedicated to solar panels, the lower the production of crops. However, the correspondence is not one to one. An increase in solar panel land use yields a proportionally lower decrease in crop yield. In Taiwan, to meet food supply targets by keeping some portion of agricultural land for farming, 40% and 70% are set as the respective caps in the land use code for viable and nonviable (or contaminated) agricultural land that may be used for solar farm implementation [18].

The impact of the land use codes regarding the distance between solar arrays has been less studied, although too small of a distance between arrays is likely to negatively affect solar radiation. The third factor at play—solar panel elevation—likely affects the productivity of solar power generation due to dust deposition as well as the productivity of crop yields due to the influenced solar radiation on the ground, ventilation by the wind, and farming activities [24, 25]. A 4-meter elevation is generally regarded as satisfactory [25], and 4.5 meters is adopted as the cap in the codes for Taiwan [18].

These three factors, mixed-use, elevation, and distance between solar panels, can play crucial roles in achieving some of the *Sustainable Development Goals (SDGs)* of the United Nations' 2030 Agenda for Sustainable Development [26], among others, set at the national or regional level. For example, to remain at a certain level of self-sustaining food supply, a maximum level of land designated for solar farms must be adopted to allow ample room for food production. At the same time, a land use code that provides for a full density of mixed use can be adopted to achieve maximum combined productivity of solar power as well as crop yield. This takes full advantage of land and boosts maximum green energy production. Such a mixed-use scheme can be introduced and expanded to diminish poverty, reduce inequalities, and develop sustainable communities. Nonetheless, the knowledge on such potential implementations is still scarce, and further research is required.

6. Outlook

Green energy is not unequivocally met with positive feelings among the population. Reasons for this are complex and hard to pinpoint. Yunlin County is slowly over-aging facing emigration toward structurally better developed areas. In how far this new age structure plays a role is not yet well understood. Conventional agriculture becomes challenging not only because of a changing climate but also because of anthropogenic contributions to county-wide subsidence effects leading to a deterioration of the soil quality and stability. Natural reservations against the placement of wind turbines or photovoltaic installations in the backyard due to fear against, e.g., electromagnetic radiation or ground pollution introduced by cleaning agents (e.g., [27]), respectively, can only be met by targeted information campaigns by the government, the Environmental Protection Administration (EPA), and contributing companies. Based on a local nonrepresentative survey, some of the farmers feel let down by the government regarding information exchange. Furthermore, it remains to be seen in how far the current global dispute among leading industrial countries regarding strategies of mitigating climate risk will negatively influence perception of local farmers in Taiwan as well which only increases the degree of complexity.

During the next period, the group's research will partially focus on establishing a better understanding of this complexity and the interdependence between socioeconomic, socio-technical, and socio-natural effects to be able to contribute to a better understanding and education, in order to find targeted approaches to improve the local situation.

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Conflict of interest

The authors declare no conflict of interest.

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References

[1] United Nations Development Program. Renewable Energy. https://www.undp.org/content/undp/en/home/climate-and-disaster-resilience/sustainable-energy/renewable-energy.html [Accessed: 02-12-2018]

[2] World Energy Council. Renewable Energy Projects Handbook. 2004. vii+87 pp

[3] Bureau of Energy, Statistics Handbook 2017. Taipei: Ministry of Economic Affairs; 2018. p. 184

[4] Tung H, Hu JC. Assessments of serious anthropogenic land subsidence in Yunlin County of central Taiwan from 1996 to 1999 by Persistent Scatterers InSAR. Tectonophysics. 2012;**578**:126-135

[5] Global Energy Observatory. Mai-Liao Coal Power Plant Taiwan. Available from: http://globalenergyobservatory.org/geoid/4138 [Accessed: 20-12-2018]

[6] 4C Offshore. Yunlin. Available from: https://www.4coffshore.com/windfarms/yunlin-yunneng---wpd-taiwan-tw10.html [Accessed: 01-12-2018]

[7] Huang K-L. Massive amount of land is required for renewable energy–Is Taiwan suitable for developing renewable energy? (再生能源需要大量土地面積, 臺灣是否適合發展再生能源) (in Chinese). In: Platform of Energy Information. Taoyuan City: Institute of Nuclear Energy Research; 2018

[8] Hsiao T-H, Huang K-L, Chang Y-J. A model for forecasting of solar power annual electricity and its strategy application. Journal of Taiwan Energy. 2017;**4**(4):401-430

[9] Han J-Y. Potential capacity of production of solar power on ground panels and suggestion for siting of solar panels. (我國地面型太陽光電蘊藏量評估及用地建議) (in Chinese). In: Platform of Energy Information. Taoyuan City: Institute of Nuclear Energy Research; 2016

[10] Lai M-C. The impact of renewable energy policy on agricultural land price in Tainan city—How if planting panels produce good land prices. (master thesis). Department of Agricultural Economics, National Taiwan University; 2018

[11] MOTECH Industries Inc. 2018. Available from: www.motech.com.tw/en [Accessed: 15-01-2018]

[12] Chen F-Y. Methodologies of Farmland Assessment. Taipei: Council of Agriculture; 2014

[13] Garni A, Hassan Z, Awasthi A. Solar PV power plant site selection using a GIS-AHP based approach with application in Saudi Arabia. Applied Energy. 2017:1225-1240. DOI: 10.1016/j.apenergy.2017.10.024

[14] Sánchez-Lozano JM, Teruel-Solano J, Soto-Elvira PL, García-Cascales M. Geographical information systems (GIS) and multi-criteria decision making (MCDM) methods for the evaluation of solar farms locations: Case study in south-eastern Spain. Renewable and Sustainable Energy Reviews. 2013;**24**:544-556

[15] Brewer J, Ames DP, Solan D, Lee R, Carlisle J. Using GIS analytics and social preference data to evaluate utility-scale solar power site suitability. Renewable Energy. 2015:825-836

[16] Hernandez RR, Hoffacker MK, Murphy-Mariscal ML, Wu GC, Allen MF. Solar energy development impacts on land cover change and protected areas. PNAS. 2015;**112**(44):13579-13584. DOI: 10.1073/pnas.1517656112

[17] The Government of Taiwan. Land Use Codes for Non-Urban Areas (非都市土地使用管制規則, in Chinese). 2018. Available from: https://law.moj.gov.tw/LawClass/LawAll.aspx?PCode=D0060013 [Accessed: 12-12-2018]

[18] The Government of Taiwan. Regulations for Reviewing the Application for Annexational Use on Agricultural Land (申請農業用地作農業設施容許使用審查辦法) (in Chinese). 2018. https://law.moj.gov.tw/LawClass/LawAll.aspx?PCode=M0020022 [Accessed: 25-12-2018]

[19] The Control Yuan, The Government of Taiwan. 監察院糾正案。因審查機制規定未臻完善部分農業設施申請屋頂型綠能設施者，未能結合農業經營使用 (in Chinese). 2017. Available from: https://www.cy.gov.tw/sp.asp?xdURL=./di/RSS/detail.asp&ctNode=871&mp=1&no=5759 [Accessed: 25-12-2018]

[20] Our Island. 七股養殖業北上陳情魚塭種電租金漲 (in Chinese). 2018. Available from: http://ourisland.pts.org.tw [Accessed: 25-12-2018]

[21] The Environmental Protection Administration, The Government of Taiwan. 受污染土地改善及太陽光電設施設置併行審查作業原則(in Chinese). 2016. Available from: https://oaout.epa.gov.tw/law/NewsContent.aspx?id=180 [Accessed: 25-12-2018]

[22] Yang SM (楊純明).多贏-農電能共榮發展. 農政與農情月刊:農業試驗所. (in Chinese) 2017. Available from: https://www.coa.gov.tw/ws.php?id=2506246&print=Y [Accessed: 25-12-2018]

[23] The Council of Agriculture (COA), The Government of Taiwan.。光電農棚應落實農業使用不容「假農作、真種電」破壞優良農地 (in Chinese). 2017. Available from: https://age.coa.gov.tw/index.php?theme=news&id=6892. [Accessed: 25-12-2018]

[24] Majumdar D, Pasqualetti MJ. Dual use of agricultural land: Introducing 'agrivoltaics' in Phoenix metropolitan statistical area, USA. Landscape and Urban Planning. 2018;**170**:150-168

[25] Dupraz C, Marrou H, Talbot G, Ferard Y. Combining solar photovoltaic panels and food crops for optimising land use: Towards new agrivoltaic schemes. Renewable Energy. 2011;**36**(10):2725-2732

[26] United Nations. Sustainable Development Goals (SDGs). 2018. Available from: https://sustainabledevelopment.un.org/sdgs [Accessed: 18-12-2018]

[27] Taipei Times. Residents Rally Against Wind Energy. Available from: http://www.taipeitimes.com/News/taiwan/archives/2013/05/30/2003563544 [Accessed: 02-09-2018]

Section 2

Land Use Mapping and Sustainability

Chapter 5

Land Cover/Land Use Mapping Using Soft Computing Techniques with Optimized Features

Selvaraj Rajesh and Gladima Nisia T.

Abstract

The chapter discusses soft computing techniques for solving complex computational tasks. It highlights some of the soft computing techniques like fuzzy logic, genetic algorithm, artificial neural network, and machine learning. The classification of the remotely sensed images is always a tedious task. So, here we explain how these soft computing techniques could be used for image classification. Image classification mainly concentrates on the feature's extraction process. The features extracted in an efficient manner improve classification accuracy. Hence, the different kinds of features and different methods for these extractions are explained. The best extracted features are selected using genetic algorithm. Various algorithms are shown and comparisons are made. Finally, the results are verified using a hypothetical case study.

Keywords: land cover/land use mapping, soft computing techniques, feature extraction, artificial neural network, wavelet transforms, feature classification

1. Introduction

The remote sensing (RS) image has millions and millions of details hidden into it. The interpretation of RS images thus leads to a variety of new improvements in our daily life. Since RS image coils a lot of areas in a single image, intensive care has to be taken while handling each and every pixel [25, 41, 42, 61]. Also, extraction of features plays an important role. Using those features, a particular pixel can be classified easily [32, 33, 46, 55, 56]. Deciding which features we are going to extract is important, and it has to be done based on the application and type of image.

The classified output has several uses in civil engineering. It is also useful in planning for large airports, industrial estates, and harbors and the construction of dams, bridges, and pipelines. It also provides valuable data for the process and design of roads and highways. The application areas also extend to extracting building footprints, detecting roads, and outlining urban changes from a pair of images taken at different dates. It also extends to the field of forest investigation, water management, and disaster management.

Similarly, the interpretation of RS images has many applications [34]. They include the study of forest where investigating the landscape of forest area can avoid deforestation and degradation processes. Forest land cover describes the physiographical characteristics of the environment from bare rock to tropical forest.

So, classifying these will result in the understanding of the variety and type of land cover. Another important advantage with forest land cover is identification of very specific habitats and distribution of both individual species and species assemblies. In the case of urban planning, the year-wise RS images are analyzed to find whether the occupation is growing in the right place. While planning the urban area utilization, the government may plan with the RS image, so that the road construction plan, water pipeline construction plan, and power supply connection plan can be made easy. If in case our urban occupation is happening in the vegetation area, then it should be taken care of and constructions are to be made in other areas.

RS images are also used in water management system to clearly display sediment pollution and oil spills over water bodies and help to monitor the quality of water resources. They are also used in disaster management. In case of natural disaster, risk-prone areas are detected, and risk management is undertaken. When sudden natural disaster happens, it is difficult for humans to collect data at that moment, and so using RS technology, we can handle the situation.

The application area also covers the hazard management. As water-related natural hazards occur due to a number of factors, such as structure, drainage, slope, land use, road network, etc., they must be taken into account when assessing the region's instability and potential hazard risks. It is essential because proper hazard management can help us take timely measures to prevent flooding and following landslides.

The chapter is organized in the following way. Section 2 explains the feature extraction process, Section 3 explains the feature subset selection, Section 4 explains about feature classification, and Section 5 concludes the chapter.

2. Feature extraction

To classify/segment the different objects in a digital image, features are of much important. Texture feature is one such important feature. Texture is more useful as it is expressed in terms of smoothness, coarseness, fineness, linearization, granularity, and randomness. Analysis of texture requires the identification of features that will differentiate the textures for classification, segmentation, and recognition [17–19, 22, 23, 26, 35–37, 43]. Scale is another important property of texture. The appearance of texture changes when it is viewed at different resolutions. Remotely sensed images are analyzed using gray-level co-occurrence features, features extracted from Gabor filter. There are many methods for extracting features.

2.1 Extraction of features using wavelet packet transform

The main reason for the usage of such wavelet-based multi-resolution analysis [7–10, 12, 27, 29, 30, 39] in remote sensing is that the resolution of the remotely sensed imagery may be different in many cases and it is important to understand how information changes over different scales of imagery.

The work in [1] proposed a system in which statistical and co-occurrence features of the input patterns are first extracted, and those features are used for classification [11–13, 20, 38, 48]. The continuous wavelet transform of a 1-D signal f(x) is defined using Eq. (1):

$$W(a,b) = \int f(x)\Psi_{a,b}(x)dx \tag{1}$$

where $\Psi_{a,b}(x) = \frac{1}{\sqrt{a}}\Psi\left(\frac{x-a}{b}\right)$.

The mother wavelet y has to satisfy the admissibility criterion to ensure that it is a localized zero mean function [39]. Typically, some more constraints are imposed on y to ensure that the transform is non-redundant and complete and constitutes a multi-resolution representation of the original signal. This results in a good real-space transform implementation using quadrature mirror filters. The convolution is performed, and the results with the low-pass filter are called approximation image, and the results with the high-pass filter in specific directions are called detail images. In earlier processes, the image is split into an approximation and detail images. The approximation is then split itself into a second level of approximation and details. For a n-level, the signal decomposition can be represented using Eq. (3):

$$
\begin{aligned}
A_n &= \left[H_x * \left[H_y * A_{n-1}\right] \downarrow 2,1\right] \downarrow 1,2 \\
D_{n1} &= \left[H_x * \left[G_y * A_{n-1}\right] \downarrow 2,1\right] \downarrow 1,2 \\
D_{n2} &= \left[G_x * \left[H_y * A_{n-1}\right] \downarrow 2,1\right] \downarrow 1,2 \\
D_{n3} &= \left[G_x * \left[G_y * A_{n-1}\right] \downarrow 2,1\right] \downarrow 1,2
\end{aligned}
\tag{2}
$$

where "*" denotes the convolution operator, "↓2,1" denotes the downsampling along the rows (columns), A0 = I is the original image, and H and G are low-pass and high-pass filters, respectively. I(x, y) is the original image. A_n is obtained by low-pass filtering and is the approximation image at scale n. The detail images D_{ni} are obtained by band-pass filtering in a specific direction (i = 1, 2, 3 for vertical, horizontal, and diagonal directions, respectively) and thus contain directional detail information at scale n. The original image, I, is thus represented by a set of sub-images at several scales: $\{A_n, D_{ni}\}$.

The wavelet packet decomposition offers a richer signal analysis. Here, the split happens for both detail image and approximation image. This results in a wavelet decomposition tree. The details present in detail images are helpful in analyzing texture and discrimination. To characterize a texture, the features derived from detail images are used. The following section discusses the way in which the features from wavelet transformed image to be used for classification.

The filter choice and its order may vary for each application. Here, two levels of wavelet packet decomposition with different wavelet families are done and shown in **Figure 1**. There is no need to perform a deeper decomposition because, after the second level, the size of images become too small and no more valuable information is obtained. Sixteen wavelet coefficient matrices containing texture information are produced from the second level of decomposition.

In texture training, the known texture images are decomposed using DWPD. To create feature database, a set of WPSF, such as mean and standard deviation, is

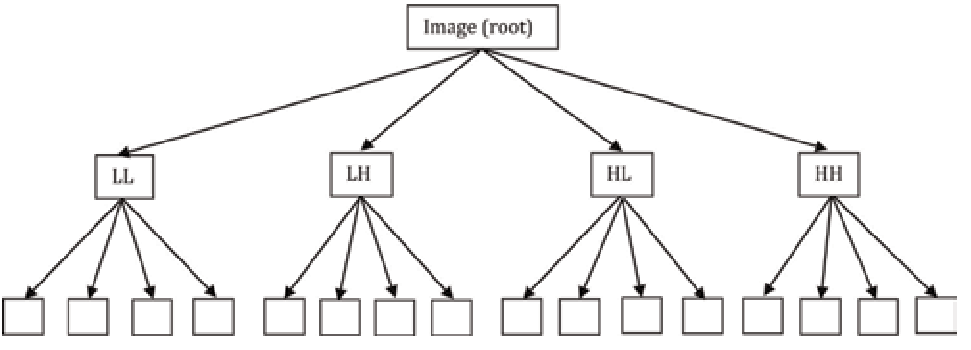

Figure 1.
A wavelet packet tree.

calculated to form the original image, and a set of wavelet packet co-occurrence features and spectral feature NDVI is calculated using Eqs. 4–11 and Eq. (12), respectively. These features are saved for further use in texture classification.

$$Mean \quad \overline{x} = \frac{1}{N^2}\sum_{i=1}^{N}\sum_{j=1}^{N} x_{i,j} \tag{3}$$

$$Variance \quad V = \frac{1}{N^2}\sum_{i=0}^{N}\sum_{j=1}^{N} \left(x_{i,j} - \overline{x}\right)^2 \tag{4}$$

$$Entropy = -\sum_{i=1}^{N}\sum_{j=1}^{N} (C(i,j)) \log (C(i,j)). \tag{5}$$

$$Contrast = \sum_{i,j=0}^{N} (i-j)^2 C(i,j) \tag{6}$$

$$Energy = \sum_{i=1}^{N}\sum_{i=1}^{N} C(i,j)^2 \tag{7}$$

$$Local\ homogeneity = \sum_{i,j=0}^{n} 1/\left(1+(i-j)^2\right)C(i,j) \tag{8}$$

$$Cluster\ shade = \sum_{i,j=0}^{n} \left(i - M_x + j - M_y\right)^3 C(i,j) \tag{9}$$

$$Cluster\ prominence = \sum_{i,j=0}^{n} \left(i - M_x + j - M_y\right)^4 C(i,j) \tag{10}$$

where $M_x = \sum_{i,j=0}^{n} iC(i,j)$ and $M_y = \sum_{i,j=0}^{n} jC(i,j)$.

$$Correlation = \frac{\sum_{i=1}^{N}\sum_{j=1}^{N} [ijC(i,j)] - \mu_x\mu_y}{\sigma_x\sigma_y}. \tag{11}$$

where $\mu_x = \sum_{i}^{N} i \sum_{j}^{N} C(i,j)$, $\mu_y = \sum_{j}^{N} j \sum_{i}^{N} C(i,j)$, $\sigma_x{}^2 = \sum_{i}^{N} (a-\mu_x)^2 \sum_{j}^{N} C(i,j)$, $\sigma_y{}^2 = \sum_{j}^{N} \left(b-\mu_y\right)^2 \sum_{i}^{N} C(i,j)$.

$$\text{NDVI} = (\text{near IR band} - \text{red band})/(\text{near IR band} + \text{red band}) \tag{12}$$

The input Madurai LISS IV image is shown in **Figure 2**. The procedure for classification is explained in the later content, but the results are presented here for better understanding. The classification of LISS IV Madurai image is done with wavelet filters such as Daubechies (DB2), symlet (Sym2), Coiflet (Coif2), and bi-orthogonal (Bi-or2.2) and is shown in **Figure 3(a)–(e)**.

2.2 Extraction of deep features

Deep feature learning plays an important role in image classification. In order to extract different features automatically, the convolution neural network (CNN) is

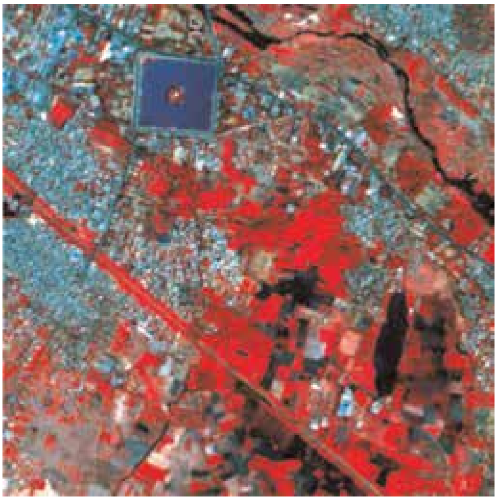

Figure 2.
Madurai city (size 400 × 400).

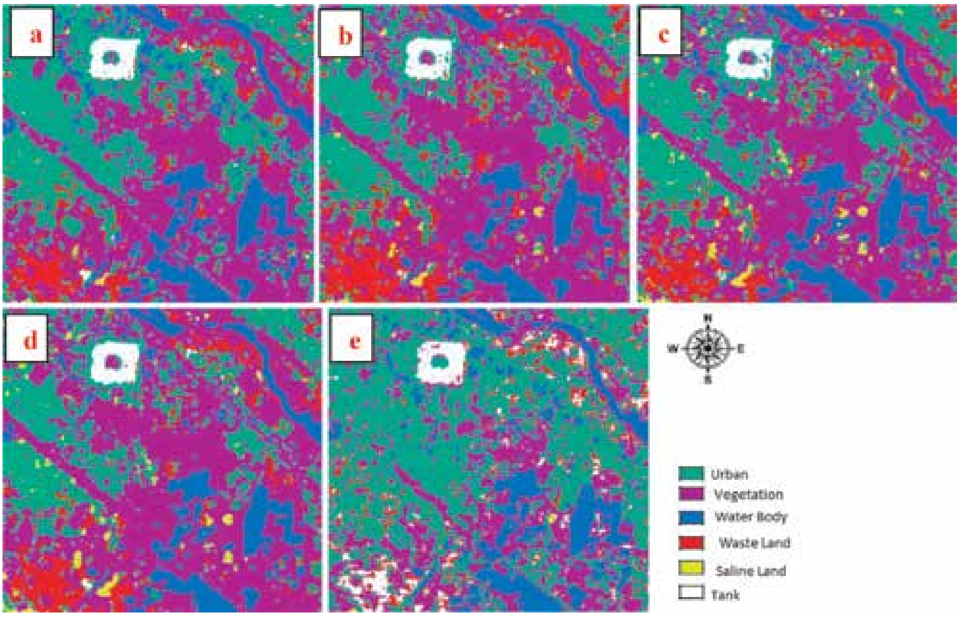

Figure 3.
Classified output images using (a) DB2, (b) symlet 2, (c) Coiflet 2, (d) Bi-or 2.2, and (e) DB2 without NDVI.

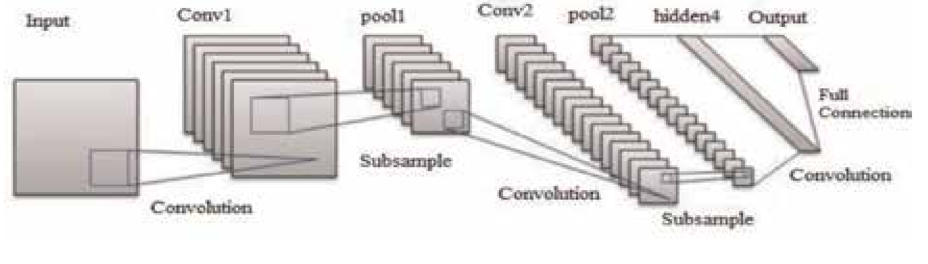

Figure 4.
Architecture of convolutional neural network. [source: https://images.app.goo.gl/YcBQH2Y4ZXPyMhVr8].

utilized [2]. The architecture of CNN is shown in **Figure 4**. In convolution layer, the features are extracted using different filters to input image. The ReLU layer handles the output from convolutional layer by figuring out the negative pixel value into zero, retaining the dimensionality of the matrix unchanged. Pooling helps in retaining the most important information while reducing the size of feature map. Each training sample is applied with the same processes and thus resulting in different feature sets.

3. Feature subset selection

Feature subset selection is the process of selecting those features that are most useful to a particular classification problem from all those available. The most popular methods for feature reduction in remote sensing are the use of the principal components transform [6]. The principal components (PC) transformation transforms the original data into a new smaller set, which are less correlated to the first data set. Therefore, a reduced number of new variables represent the information content of the original set. However, although frequently used, the PC transform is not appropriate for feature extraction in classification, because it does not consider the classes of interest, but only the data set. Therefore, it may not produce the optimum subspace for the classification. So, we are utilizing genetic algorithm (GA) for feature subset selection [3, 49–54, 57–60, 63–66].

3.1 Genetic algorithms

Computational studies of Darwinian evolution and natural selection have led to numerous models for computer optimization. GAs comprise a subset of these evolution-based optimization techniques focusing on the application of selection, mutation, and recombination to a population of competing problem solutions. Being a directed search rather than an exhaustive search, population members cluster near good solutions; however, the GA's stochastic component does not rule out wildly different solutions, which may turn out to be better. This has the benefit that, given enough time and a well-bounded problem, the algorithm can find a global optimum. This makes them well suited to feature selection problems, and they can find near optimum solutions using little or no prior knowledge.

There are three major design decisions to consider when implementing GA to solve a particular problem. A representation for candidate solutions must be chosen and encoded on the GA chromosome, an objective (fitness) function must be specified to evaluate the quality of each candidate solution, and finally the GA run parameters must be specified, including which genetic operators to use, such as crossover, mutation, selection, and their possibilities of occurrence. Until a satisfactory solution is found, the fitness-dependent selection and application of genetic operators to generate successive generations of individuals are repeated many times.

In the problem of feature selection, feature subsets are represented as binary strings where a value of 1 will represent the inclusion of a particular feature in the training process and a value of 1 will represent its absence. Since a chromosome is represented through a binary string, genetic algorithm will operate on a pool of binary strings. The mutation and crossover operators operate in the following way: mutation operates on a single string and generally changes a bit at random. Thus, a string 10,010 may, as a consequence of random mutation, get changed to 10,110. Crossover on two parent strings produces two offsprings. With a randomly chosen crossover position 2, the two strings 01101 and 11,000 yield the offspring 01000

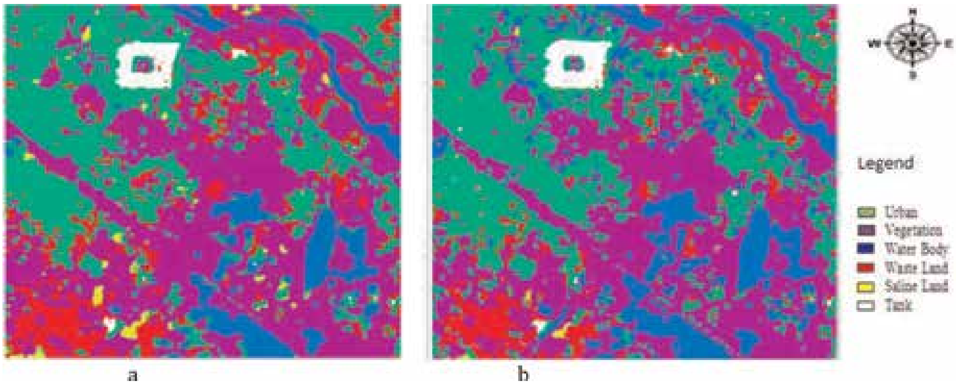

Figure 5.
Classified output using DB2 with (a) full feature set and (b) optimal feature set.

Number of features	Accuracy indices			
	Overall	Kappa	Producer	User
10	84.2437	0.7717	81.8685	78.8469
13	84.534	0.7802	82.2341	79.8645
15	85.5042	0.7898	83.1250	80.5573
16	85.2941	0.7875	82.8616	80.1797
17	**86.528**	**0.8125**	**84.5967**	**81.8991**
18	85.2941	0.7855	81.7592	79.8890
19	84.6639	0.7772	79.9678	79.6327
21	85.5042	0.7900	81.0822	80.2417
23	85.0840	0.7855	82.3767	80.3079
25	85.9244	0.7958	82.0482	80.2008

Bold: 17 Features is giving Max Overall Kappa Producer and User's Accuracy.

Table 1.
Accuracy indices for various feature sets.

and 11,100 as a result of crossover. If the obtained feature set X using wavelet-based technique contains 45 features for each pixel of the image of size 400 × 400 pixels, then the feature set X of the data is of dimension 160,000 × 45, where each column represents the features of the respective pixel in the data. Using GA, the feature set X of size 45 × 400 × 400 is mapped into new feature set denoted by Y of size 17 × 400 × 400. This reduction in feature set improves the overall execution speed and the classification accuracy [52]. The classification results (for both full feature set and optimal feature set) are shown in **Figure 5**.

The accuracy assessments are made using accuracy indices, namely, overall accuracy, producer accuracy, user accuracy, and kappa coefficient and are listed in **Table 1**.

4. Classification

Using the features obtained, so far the classification is done using the obtained features. We use different classifiers for the classification. The classifier is an algorithm that maps the input data to a specified category.

4.1 Classification based on Mahalanobis distance

In this method, the decomposition for test texture image is done using DWPD. In the same manner, another set of features are obtained and compared with the obtained feature values. The class of textures is represented as C, the mean signature of class C is represented with m_c, and the Mahalanobis distance is given by

$$D^2(x_{i,} C) = (x_i - m_c) \sum (x_i - m_c) \tag{13}$$

If the distance D(i) is smallest, then the test texture image is classified as ith texture [15, 21, 47]. Features are obtained using many wavelet filters, and it is followed using classification process [14, 28, 44]. The overall, user, producer, and kappa accuracy indices obtained for the different wavelet filters presented in **Table 2** show that the DB2 wavelet filter gives superior results than the other wavelet filters. Thus, the DB2 wavelet filter will be more useful for land cover/land use mapping.

4.2 Classification based on adaptive neuro-fuzzy inference system (ANFIS)

The adaptive network-based fuzzy inference system (ANFIS) is a useful neural network approach for the solution of function approximation problems [4, 31, 40, 45, 62]. To determine the optimal distribution of membership functions, the ANFIS gives the mapping relation between the input and output data. ANFIS architecture consists of both artificial neural network (ANN) and fuzzy logic (FL). The system includes five layers. The node function describes several nodes, which are to be included in the ANFIS layer. The inputs of present layers are obtained from the previous layers. For example, consider two inputs (x, y) and one output (fi) are used in this system. The rule base contains fuzzy if-then rules. Thus, the two rules are:

- Rule 1: If x is A1 and y is B1, then z is f1(x, y).
- Rule 2: If x is A2 and y is B2, then z is f2(x, y).

where x and y are the inputs and A and B are the fuzzy sets fi (x, y). The feature extraction is done using DB2 wavelet filter, and the optimum features are obtained using GA [16]. Then the classification is done using GA with neural network and GA with ANFIS, and the results are shown in **Figure 6**. Based on the classified output, it is clearly understood that the GA and ANFIS shows the better classification.

4.3 Classification using CNN

The classification using CNN is done using the deep features obtained from the training phase of CNN [2, 5, 24]. In training, it carries out the predefined process with one or multiple layers. In a fully connected layer, every neuron is connected to

	Overall	User	Producer	Kappa
DB2	87.60	82.02	89.57	0.82
Symlet 2	78.78	76.45	76.43	0.69
Coiflet 2	77.3	73.3	70.6	0.67
Bi-or 2.2	79.2	79.76	76.69	0.69

Table 2.
Classification results of Madurai city for different wavelet packet transforms.

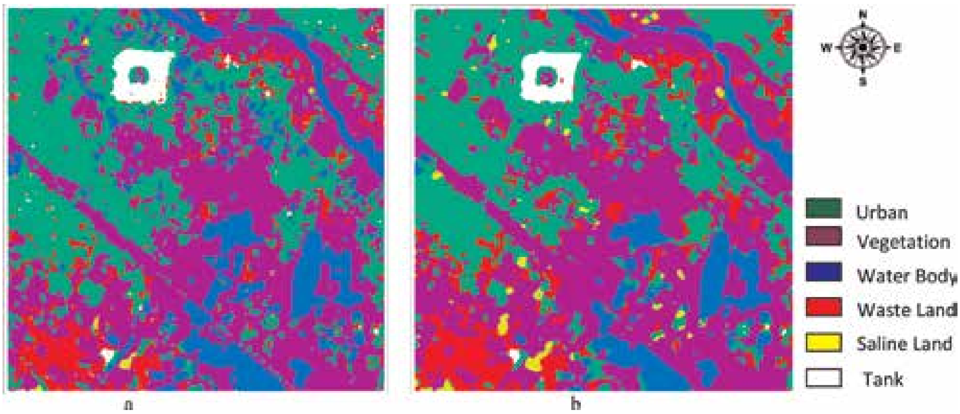

Figure 6.
Classified output using DB2 with (a) GA and neural network and (b) GA and ANFIS.

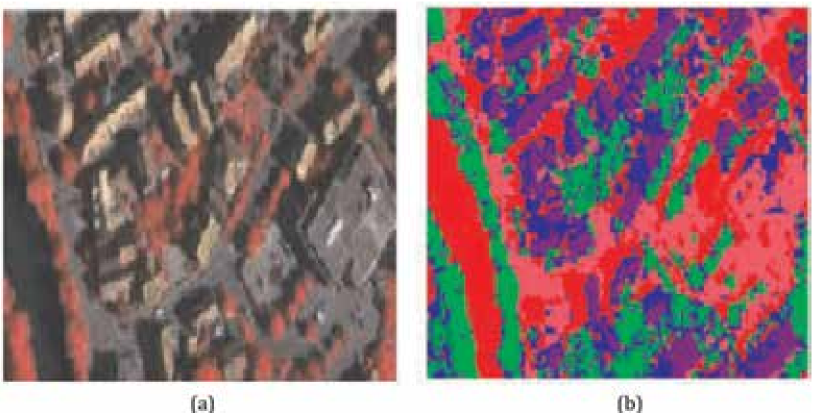

Figure 7.
(a) Vaihingen city and (b) classified output of Vaihingen city.

every other neurons of previous layer. Softmax is the final layer and it calculates the probability value. The higher probability becomes the output. After training, the system will be able to classify the image automatically without human intervention. The classification is done for Vaihingen city and the results are displayed in **Figure 7**.

4.4 Classification using multilayer perceptron layer

The multilayer perceptron (MLP) layer realizes intelligent classification using features from the wavelet layer. The training parameters of the MLP are shown in **Table 3**. These parameters were selected to give best performance, after several experiments, such as the number of hidden layers, size of the hidden layers, value of the moment constant and learning rate, and type of the activation functions.

4.5 Limitations of different methodologies

4.5.1 Genetic algorithm

In GA, the selection of wrong fitness value may affect the solution of the problem. Other parameters like population size, mutation and crossover also plays

Architecture	
The number of layers	4
The number of neuron on the layers	
Input	17
Hidden1	25
Hidden2	25
Output	6
The initial weights and biases	Random
Activation functions	Tangent sigmoid
Training parameters	
Learning rule	Back propagation + Levenberg-Marquardt
Learning rate	0.01
Momentum constant	0.8
Mean-squared error	1e_07

Table 3.
MLP architecture and training parameters.

an important role in providing solution. GA belongs to a non-deterministic class of algorithms. The optimal solution we get from GA may vary each time we run our algorithm for the very same input data.

4.5.2 Convolutional neural network

CNN requires a lot of training. Also, it requires a lot of data sets for training. A convolution is always a slower operation. Deeper the network, the longer is it's processing time.

4.5.3 ANFIS

Defining the membership function remains a difficult task.

5. Field survey

The results of the entire work are verified with the help of the ground truth. Ground truth is the process done onsite, in which a "pixel" on a satellite image is compared to what is there in reality. It is done in order to verify the contents of the "pixel" on the image. For an image of 400 $\times$ 400 size, we have taken 500 points as ground truth data. By performing field visit, these data are collected. The outcome of each method is verified with those points.

6. A hypothetical case study

A hypothetical case study is presented to show the application of land cover/land use mapping in real-life scenario. Assume the XXX company wants to plan their production center construction in Madurai city. For the production centre to be established, large area is needed and thus unoccupied areas in the city have to be investigated. Also, it sends out waste material that is toxic and should not be present in the urban areas. The products, which the company produces, are sent to other parts of the country and some are exported. So, road routes also have to be checked.

So, initially a place has to be selected and a plan to be made accordingly. In order to plan the construction, it acquires the satellite image of Madurai city. Then the features are obtained using wavelet feature extraction method, and the classified output is obtained using adaptive neuro-fuzzy inference system classification. The classified image can be clearly understood and can be given to the construction planning team for their further processing. Here, also in addition if the PAN image of the Madurai city and MS image of the Madurai city are fused and then if classification is performed, it would yield still better classification results.

7. Conclusion

The chapter focused on the methods used to obtain the perfect classification of the RS images. It discusses various methods used for feature extraction. Different feature extraction methods are discussed. After feature extraction, the number of obtained features is reduced using the feature subset selection methods. The best features are considered and the features which contribute less are neglected. The optimal features are thus taken into account for the classification process. The classification also discusses different techniques through which efficient results are obtained. The methods are implemented using LISS IV image of Madurai city. The classified outputs are shown wherever necessary, and accuracy assessments are also calculated. Thus, the chapter gives overall idea for handling RS image using optimal features.

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References

[1] Rajesh S, Arivazhagan S, Pratheep Moses K, Abisekaraj R. Land cover/land use mapping using different wavelet packet transforms for LISS IV Madurai imagery. Journal of the Indian Society of Remote Sensing. Jun. 2012;**40**(2): 313-324

[2] LeCun Y, Bengio Y, Hinton G. Deep learning. International Journal of Science. May 2015;**521**:436-444

[3] Rajesh S, Arivazhagan S, Pratheep Moses K, Abisekaraj R. Genetic algorithm based feature subset selection for land cover/land use mapping using wavelet packet transforms. Journal of the Indian Society of Remote Sensing. Jul. 2013;**41**(2):237-248

[4] Rajesh S, Arivazhagan S, Pratheep Moses K, Abisekaraj R. ANFIS based land cover/land use mapping of LISS IV imagery using optimized wavelet packet features. Journal of the Indian Society of Remote Sensing. Jul. 2014;**42**(2): 267-277

[5] Priya KP, Rajesh S, Nisia TG. Object-based convolutional neural network for remote sensed imagery classification. International Journal of Pure and Applied Mathematics. 2018;**119**(12): 13837-13844

[6] Du H, Qi H. An FPGA implementation of parallel ICA for dimensionality reduction in hyper spectral images. In: Proceedings IEEE International Geosciences and Remote Sensing Symposium (IGARSS). Vol. 5. Sep. 2004. pp. 3257-3260

[7] Rajesh S, Arivazhagan S. Land cover/ land use mapping using different wavelet packet transforms for LISS IV imagery. In: Proceedings of the IEEE International Conference on Computer, Communication & Electrical Technology (ICCCET). Vol. **2011**. 2011. pp. 103-108

[8] Acharyya M, Kundu MK. Adaptive basis selection for multi texture segmentation by m-band wavelet packet frame. In: Proceedings of the 2001 International Conference on Image Processing. 2001. pp. 622-625

[9] Acharyya M, Kundu MK. Wavelet-based texture segmentation of remotely sensed images. In: Proceedings of the 2001 International Conference on Image Analysis and Processing. 2001. pp. 69-74

[10] Acharyya M, Kundu MK. Image segmentation using wavelet packet frames and Neuro-fuzzy tools. International Journal of Computational Cognition. 2007;**5**(4):27-43

[11] Acharyya M, De RK, Kundu MK. Extraction of features using m-band wavelet packet frame and their neuro-fuzzy feature evaluation for multi texture segmentation. IEEE Transactions on Pattern Analysis and Machine Intelligence. 2003;**25**(12): 1639-1644

[12] Acharyya M, De RK, Kundu MK. Segmentation of remotely sensed images using wavelet features and their evaluation in soft computing framework. IEEE Transactions on Geoscience and Remote Sensing. 2003; **41**(12):2900-2905

[13] Alagu Raja S, Anand V, Maithani S, Senthil Kumar A. Wavelet frame based feature extraction technique for improving classification accuracy. Journal of the Indian Society of Remote Sensing. 2009;**37**:423-431

[14] Arivazhagan S, Ganesan L. Texture classification using wavelet transform. Pattern Recognition Letters. 2003;**24**: 1513-1521

[15] Arivazhagan S, Ganesan L. Performance analysis of texture classification techniques using MRMRF

and WSFS & WCFS. In: Proceedings of the Sixth International Conference on Computational Intelligence and Multimedia Applications (ICCIMA'05). 2005

[16] Bandyopadhyay S, Pal SK. Pixel classification using variable string genetic algorithms with chromosome differentiation. IEEE Transactions on Geo science and Remote Sensing. 2001; **39**(2):303-308

[17] Baraldi A, Parmiggiani F. An investigation of the textural characteristics associated with gray level cooccurrence matrix statistical parameters. IEEE Transaction on Geoscience and Remote Sensing. 1995; **33**(2):293-304

[18] Chen C, Chen DC. Multiresolution Gabor filters in texture analysis. Pattern Recognition Letters. 1996;**17**(10): 1069-1076

[19] Du LJ. Texture segmentation of SAR images using localized spatial filtering. Proceedings of the International Geoscience and Remote Sensing Symposium. 1990:1983-1986

[20] Fukuda S, Hirosawa H. A wavelet-based texture feature set applied to classification of multi frequency polarimetric SAR images. IEEE Transactions on Geoscience and Remote Sensing. 1999;**7**(5):2282-2286

[21] Fung T. An assessment of TM imagery for land-cover change detection. IEEE Transactions on Geoscience and Remote Sensing. 1990; **28**(4):681-684

[22] Haralick RM. Statistical and structural approaches to texture. Proceedings of the IEEE. 1979;**67**(5): 786-804

[23] Haralick RM, Shanmugam K, Dinstein I. Textural features for image classification. IEEE Transactions on Systems, Man, and Cybemetics. 1973; **SMC-3**(6):610-621

[24] Shah H, Mitra SK, Banerjee A. Information slicing: An application to object classification in satellite images. CVGIP: Image Understanding. 2008; **57**(3):458-465

[25] Knipling EB. Physical and physiological basis for the reflectance of visible and near-infrared radiation from vegetation. Remote Sensing Environment. 1970;**1**:155-159

[26] Lillesand MT, Ralph Kiefer W, Jonathan Chipman W. Remote Sensing and Image Interpretation. 5th ed. Wiley International Edition; 2004. pp. 586-592

[27] Lindsay RW, Percival DB, Rothrock DA. The discrete wavelet transform and the scale analysis of the surface properties of sea ice. IEEE Transactions on Geoscience and Remote Sensing. 1996;**34**(3):771-787

[28] Mahalanobis PC. On the generalised distance in statistics. 1936. Available from: http://www.insa.ac.in/insa_pdf/20005b8c_49.pdf

[29] Mallat S. A theory for multi resolution signal decomposition: The wavelet representation. IEEE Transactions on Pattern Analysis and Machine Intelligence. 1989;**11**(7): 674-693

[30] Niedermeier A, Romaneesen E, Lehner S. Detection of coastline SAR images using wavelet methods. IEEE Transactions on Geoscience and Remote Sensing. 2000;**38**(5):2270-2281

[31] Pal SK, Ghosh A, Uma Shankar B. Segmentation with remotely sensed images with fuzzy thresholding, and quantitative evaluation. International Journal of Remote Sensing. 2000;**21**(11): 2269-2300

[32] Perumal K, Bhaskaran R. SVM-based effective land use classification system for multispectral remote sensing images. International Journal of Computer Science and Information Security. 2009;**6**:2

[33] Perumal K, Bhaskaran R. Supervised classification performance of multispectral images. Journal of Computing. 2010;**2**:124-129

[34] Quackenbush LJ, Hopkins PF, Kinn GJ. Developing forestry products from high resolution digital aerial imagery. Photogrammetric Engineering and Remote Sensing. 2000;**66**(11): 1337-1346

[35] Reed TR, Du Buf JMH. A review of recent texture segmentation and feature extraction techniques. CVGIP: Image Understanding. 1993;**57**(3):359-372

[36] Reed TR, Wechsler H. Segmentation of textured images and gestalt organization using spatial/spatial frequency representation. IEEE Transactions on Pattern Analysis and Machine Intelligence. 1990;**12**:1-12

[37] Rignot E, Kwok R. Extraction of textural features in SAR images: Statistical model and sensitivity. In: Proceedings of IEEE Geoscience and Remote Sensing Symposium. 1990

[38] Sklansky J. Image segmentation and feature extraction. IEEE Transactions on System Man and Cybernetics. 1978;**8**: 237-247

[39] Soman KP, Ramachandran KI. Insight into Wavelets from Theory to Practice. 2nd ed. Prentice-Hall of India Pvt. Ltd.; 2005. p. 44

[40] Thitimajshima P. Multi resolution fuzzy clustering for SAR image segmentation. In: Proceedings of the International Geoscience and Remote Sensing Symposium IGARSS'99; vol. 5. 1999. pp. 2507-2509

[41] Tucker CJ. Red and photographic infrared linear combinations for monitoring vegetation. Remote Sensing of Environment. 1979;**8**:127-150

[42] Tucker CJ, Sellers C. Satellite remote sensing of primary production. International Journal of Remote Sensing. 1986;**7**:1395-1416

[43] Unser M, Eden M. Multi resolution feature extraction and selection for texture segmentation. IEEE Transactions on Pattern Analysis and Machine Intelligence. 1989;**11**:717-728

[44] Unser M. Texture classification and segmentation using wavelet frames. IEEE Transactions on Image Processing. 1995;**4**(11):1549-1560

[45] Blum AL, Langley P. Selection of relevant features and examples in machine learning. Artificial Intelligence. 1997;**97**:245-271

[46] Bittencourt HR, Clarke RT. Feature selection by using classification and regression trees (CART). International Archives of Photogrammetry Remote Sensing and Spatial Information Sciences: Natural Resources Canada. 2004;**35**:66-70

[47] Bruske J, Merényi E. Estimating the intrinsic dimensionality of hyper spectral images. In: ESANN. 1999. pp. 105-110

[48] Bon FJ. Selection y Extraction de Characteristics. 2005. Available at: h ttp://www.etsi2.ugr.es/depar/ccia/rf/ www/tema5_00-01_www/node/node 16.html

[49] Huang C-L, Wang C-J. A GA-based feature selection and parameters optimization for support vector machines. Expert Systems with Applications. 2006;**31**:231-240

[50] Du H, Qi H. An FPGA implementation of parallel ICA for

dimensionality reduction in hyper spectral images. In: Proceedings of the IEEE International Geosciences and Remote Sensing Symposium (IGARSS), vol. 5. 2004. pp. 3257-3260

[51] Van Coillie FMB, Verbeke LPC, De Wulf RR. Feature selection by genetic algorithms in object-based classification of IKONOS imagery for forest mapping in Flanders, Belgium. Remote Sensing of Environment. 2007; **110**(4):76-487

[52] Foody GM, Arora MK. An evaluation of some factors affecting the accuracy of classification by an artificial network. International Journal of Remote Sensing. 1997;**18**(4): 799-810

[53] Goldberg DE. Genetic Algorithms in Search Optimization and Machine Learning. Addison Wesley; 1989. p. 41

[54] Uğuz H. A two-stage feature selection method for text categorization by using information gain, principal component analysis and genetic algorithm. Knowledge-Based Systems. 2011;**24**(7):1024-1032

[55] Kavzoglu T, Mather PM. The use of back propagating artificial neural networks in land cover classification. International Journal of Remote Sensing. 2003;**24**(23):4907-4938

[56] Kumar S, Ghosh J, Crawford MM. Best-bases feature extraction algorithms for classification of hyper spectral data. IEEE Transactions on Geo science and Remote Sensing. 2001;**39**(7)

[57] Lennon G, Mercier M, Mouchot C, Hubert-Moy L. Independent component analysis as a tool for the dimensionality reduction and the representation of hyper spectral images. In: Presented at IGARSS 2001. Australia: Sydney; 2001

[58] Lin H, Bruce LM. Parametric projection pursuit for dimensionality reduction of hyper spectral data. Proceedings of the IEEE International Geoscience and Remote Sensing Symposium (IGARSS). 2003;**6**: 3483-3485

[59] Mather PM. Computer Processing of Remotely-Sensed Images: An Introduction. 3rd ed. Chichester: John Wiley and Sons; 2004

[60] Tseng M-H, Chen S-J, Hwang G-H, Shen M-Y. A genetic algorithm rule-based approach for land-cover classification. ISPRS Journal of Photogrammetry and Remote Sensing. 2008;**63**(2):202-212

[61] Pal M. Support vector machine-based feature selection for land cover classification: A case study with DAIS hyper spectral data. International Journal of Remote Sensing. 2006;**27**: 2877-2894

[62] Roger Jang JS, Sun CT. Functional equivalence between radial basis function networks and fuzzy inference systems. IEEE Transactions on Neural Network. 1993;**4**:156-159

[63] Serpico SB, D'inca M, Melgani F, Moser G. A comparison of feature reduction techniques for classification of hyper spectral remote-sensing data. Transactions of Image and Signal Processing of Remote Sensing. 2002;**8**: 4885

[64] Wang J, Chang C. Independent component analysis-based dimensionality reduction with applications in hyper spectral image analysis. IEEE Transactions on Geo science and Remote Sensing. 2006; **44**(6)

[65] Zhang Y, Desai MD, Zhang J, Jin M. Adaptive subspace decomposition for hyper spectral data dimensionality reduction. In: IEEE International Conference on Image Processing, vol. 2. 1999. pp. 326-329

[66] Liu Z, Liu A, Wang C, Niu Z. Evolving neural network using real coded genetic algorithm (GA) for multispectral image classification. International Journal of Future Generation Computer Systems. 2004; **20**:1119-1129

Chapter 6

Applying Systems Analysis to Evaluate Options for Sustainable Use of Peatlands in Central Kalimantan in Indonesia

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Abstract

Peat fire and the consequent degradation of peatland have had significant negative environmental and economic consequences at national and global levels. A green economy transition path is seen as a socioeconomic solution to address peat degradation. Swamp agriculture, better known as paludiculture, is a green economy action holding promise. However, little knowledge exists on the socioeconomic outcomes of this option, vis à vis conventional development. This research is the first attempt to quantify the implications of a green economy strategy to the management of peatland, in a province where 30% of the land is peat. The research uses the system dynamics methodology to create a customized green economy assessment model, named the Central Kalimantan Green Economy model (KT-GEM). The model is used to assess how three different development scenarios perform against social, economic, and environmental indicators. The analysis shows that the business as usual (BAU) scenario leads to the highest profitability. On the other hand, positive economic performance is countered by unsustainable social and environmental outcomes. The paludiculture scenario instead curbs peat fires and externalities (e.g., cost of health) and results in the most sustainable societal outcome.

Keywords: system dynamics, sustainable land use, peat, climate adaptation

1. Introduction

Poor peatland management practices in Indonesia have led to large areas of degraded peatlands, which are causing increasing environmental and socioeconomic problems. Deforestation and canalization for agricultural development have drained the naturally water-logged peat swamps and have left behind dry, carbon-rich land that is extremely prone to fire [21, 52]. Recurrent fires on peatlands cause environmental destruction, greenhouse gas (GHG) emissions, and health impacts from toxic haze pollution, which translates into high socioeconomic costs [28, 53]. The 2015 fire episode has pushed Indonesia to the third place for global GHG emitters and led to an estimated damage of IDR 221 trillion [17, 53]. Besides fires, the decomposition

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of stored organic matter in the drained peatlands also contributes substantially to Indonesia's total GHG emissions [21, 54] and leads to irreversible land subsidence [9, 20, 21, 33, 35]. As the majority of the underlying mineral soils are below sea level, this land subsidence will result in the future flooding of land [21]. Additionally, mineral soil contains acid sulfate soil, which turns acid when exposed and tends to be extremely infertile [34]. Thus, continuous peat degradation and subsequent flooding will prevent the productive use of land for agriculture or for other purposes.

As a result of the failed "Mega Rice Project" (MRP) that deforested and drained peat swamp forests to develop rice paddies, a large part of Central Kalimantan's peatlands is degraded.[1] This results in regular fires that are linked to the El Niño Southern Oscillation climate phenomenon (ENSO). In so far, a lack of anticipatory fire responses has made the province of Central Kalimantan one of the most affected by fire and haze [13, 24, 45]. The 2015 fire episode burnt an estimated 429,000 hectares and caused a financial loss of 233 million Indonesian rupiah [53]. Deforestation and canalization under the MRP have paved the way for further exploitation of the region and pressure on the peatlands is increasing as a result of migration to the area, the opening up of new land for smallholder and industrial plantations, and slash and burn farming practices [15, 42, 52]. Rapid agricultural development, in particular palm oil expansion, is one of the main drivers of deforestation and peatland degradation in Central Kalimantan and deforestation and palm oil expansion rates are now among the highest in Indonesia [1, 45, 48, 49]. As palm oil and other conventional cash crops require drainage for cultivation, the peatlands are continuously degrading, which leads to an increase in fire vulnerability and land subsidence in Central Kalimantan [13].

In light of the serious environmental, social, and economic impacts of degraded peatlands, restoration and sustainable peatland management is critical in order to reduce emissions, maintain biodiversity, and ensure a long-term solution to the recurring fire and haze problems in Indonesia [1, 9]. This requires a revision of land management policies and land use planning of these areas. The Indonesian government has taken up several regulations on peatland management and has committed to restore 2 million ha of peatlands [53].[2] Besides reducing social hazards and economic costs from peat fires, peatland restoration can lead to a large reduction of GHG emissions from fire and peat decomposition and in this way assist Indonesia in reaching its GHG emission reduction target of 29% compared to business as usual levels by 2030 [1, 9]. However, in addition to these policies, the government is also looking to expand its agricultural production and has pledged to double its palm oil production by 2020 [1]. Despite sustainability concerns, there is a large economic interest in the conversion of the degraded peatlands into plantations and large areas have already been licensed to pulp or palm oil companies [29]. Hence, the conflict between the social and environmental benefits of peatland restoration and

[1] The Mega Rice Project was a government project initiated in 1996 that aimed to convert 1.7Mha of unproductive and sparsely populated peat swamp forest into rice paddies by deforesting and canalizing the area. However, the project was unsuccessful and was eventually abandoned after severe environmental damage had already occurred. The deep drainage of the peatlands. Has resulted in annual fire hotspots during the dry season (see.e.g. [18, 19, 47]).

[2] For regulations on peatland see for example Government Regulation (Perpes) No. 71/2014 on the Protection and Management of Peatland Ecosystems and Presidential Instruction (Inpres) No.8/2015 on the postponement of the exisiting moratorium on the conversion of peatlands and primary forest. President Joko Widodo has also called for a moratorium on new peatland concessions and a cancelation of existing concessions that have not been developed, thereby halting the legal conversion of peatland and peat swamp forests into agricultural land ([53], 23 October Statement).

the economic benefits of industrial crops needs to be addressed in order to achieve effective peatland restoration.

An option that can offer a solution to this problem is paludiculture, which is the cultivation of native wetland crops on peatlands [13] and is currently being promoted by the Government of Indonesia [11]. Peatland restoration is not an easy process and requires careful consideration of the relationship between the native vegetation, hydrology, and peat soil [10]. Since paludiculture species can be commercially planted on rewetted peatlands, while maintaining the natural conditions of the peat, they can be effectively used in rehabilitation efforts and offer an alternative to the production of conventional commercial crops [13]. Restoring the peatlands this way is in line with Indonesia's ambitions to transit toward a "Green Economy," an economic framework that improves both human welfare and the environment by fully incorporating the value of natural capital [55]. In Indonesia, an estimated 60–80 species have been identified as having potential for paludiculture development, one of which is Jelutung (*Dyera* sp.), a native tree species that naturally grows in peatlands and can be used for latex and timber production [13, 56]. Over the last 20 years, planting Jelutung to rehabilitate peatlands has been tested by the Kalimantan Forests and Climate Partnership (KFCP) initiative, the Central Kalimantan Peatland Project (CKPP) of Wetlands International, and in ICRAF's Reducing Emissions from Land Use (REALU) in Sumatra [13].

While many small-scale efforts of paludiculture development have been implemented, no large scale attempts have been tried so far. This study aims to provide an initial investigation on the impacts of the large scale use of paludiculture development, as an effort to restore degraded peatlands. It will do so by modeling the impacts of jelutung development and other peatland management strategies in Central Kalimantan using an extended version of the Kalimantan Green Economy Model (KT-GEM) [3, 43, 44]. This model is a regional application of the Indonesia Green Economy Model (I-GEM) that was developed to inform, strengthen, and facilitate long-term policy planning and financing within the transition toward a Green Economy by evaluating the trade-offs between conservation and development scenarios [43, 44]. Central Kalimantan was chosen for this study because of its large areas of degraded peatlands, the existing fire and haze problems and the availability of the KT-GEM.

With the use of the KT-GEM, we review the outcomes of different policy scenarios for peatland use in order to assess whether the Jelutung approach of peatland restoration holds social, environmental, and economic benefits. This study further aims to provide a better understanding of the impacts of different policy decisions for peatland restoration, focusing on the most crucial issues of degraded peatlands: hotspots, GHG emissions, and economic development. Building on previous efforts of peatland restoration and paludiculture, the study provides a basis for further research into paludiculture development for peatland restoration in Indonesia.

2. Method

2.1 Study area

Central Kalimantan is the third largest province in Indonesia and covers approximately 15.4 million hectares (Mha), of which around 3.47 Mha is peatland [27] and Government of Central Kalimantan [14]. The province has a tropical climate and its forests and peatlands are part of the biodiversity hotspot of Borneo that provides vital ecosystem services [48, 49]. Around 2.7 million ha is degraded in one form or the other. In 2015 alone over 429,000 ha burnt. In 2014, the province had a total population of 2.4 million inhabitants, with a population density of 16 inhabitants/

km^2 [7]. Agriculture is the main economic sector contributing to local GDP, with the most important crops being, rice, oil palm, and rubber [8, 45]. Other important sectors include mining and tourism and to a limited extend other sectors such as industries and transportations [7, 45].

2.2 KT-GEM and system dynamics modeling of peatland scenarios

Moving toward a greener economy involves the design and implementation of key interventions such as public expenditure, policy reforms, and regulation changes that aim to foster sustainable economic growth, employment generation, inclusive income opportunities, and environmental conservation. As a result, methodologies and models are needed in order to support policymakers in the assessment of cross-sectoral economic, social, and environmental impacts of green economy policies. In particular, methodological approaches and models should allow to quantitatively project and evaluate trends (for issue identification), identify entry points for interventions and set targets (for policy formulation), assess ex-ante the potential impact across sectors and the effectiveness in solving stated problems (or exploiting opportunities) of selected interventions (for policy assessment), as well as monitor and evaluate the impact of the interventions chosen against a baseline scenario (for policy monitoring and evaluation ex-post assessment/analysis).

Finding that most currently available national planning models are either too detailed or narrowly focused, this study proposes an approach that:
(a) extends and advances the policy analysis carried out with other tools by accounting for the dynamic complexity embedded in the systems studied and
(b) facilitates the investigation and understanding of the relations existing between natural capital, society, and the economy. The inclusion of cross-sectoral relations supports a wider analysis of the implication of alternative green economy policies, and the long-term perspective proposed allow for the identification of potential side effects and sustainability of different strategies.

The approach proposed uses the system dynamics (SD) methodology as its foundation, serving primarily as a knowledge integrator. System dynamics modeling is a form of computer simulation modeling designed to facilitate a comprehensive approach to development planning in the medium to long term [12, 30, 37]. A key characteristic of SD is that it allows to integrate the three spheres of sustainable development in its analytical process. SD operates by simulating historical data for a period of at least 1 decade and comparing simulation results with the available data. The purpose of such models is not to make precise predictions of the future; rather, they are a tool for exploring alternative policy scenarios in order to identify those policies which could improve conditions in the future and contribute
to the achievement of desired goals and objectives [36, 39]. System dynamics allows to represent explicitly stocks and flows of human, built and natural capital, and to create linkages among them through the use of feedbacks, delays, and non-linearity.

The green economy model (GEM) is well suited to: (1) generate projections of future developments, though acknowledging that long-term accurate projection cannot easily be produced, even when simulating a large number of endogenous key variables; (2) provide an integrated analysis and evaluation of policy choices; and (3) increase the understanding of the relations underlying the system analyzed. The following paragraphs briefly describe the principal aspects of the GEM application customized to Mauritius.

- *Boundaries*: Variables that are considered an essential part of relevant development mechanisms are endogenously calculated. For example, GDP and its main determinants, population and its main determinants, and the demand

and supply of natural resources are endogenously determined. Variables that have an important influence on the issues analyzed, but which are only weakly influenced by the issues analyzed, are exogenously represented.

- *Time horizon*: GEM applications are built to analyze medium to long-term green economy scenarios. Also, simulations start in the past in order to allow validation against historical data. In the customization to Mauritius (M-GEM), the time horizon for simulation starts back in 1980 and extends up to 2030.

- *Structure*: despite the variety of green economy opportunities considered, GEM is a relatively small model. Its complexity lies in the high number of cross-sectoral linkages (dynamic complexity), but its vertical detail (within a sector, or detailed complexity) is far from overwhelming. This makes so that the model is fully tailored to a green economy analysis, being based on stakeholder inputs, and does not compete with the models already being used by the government and its partners. In fact, GEM is developed to fill a gap in the current modeling work in relation to the green economy, and to identify research needs to be addressed with more detailed sectoral models.

The main outputs of GEM, and of the green economy analysis carried out with it, include the investment required to implement the intervention desired, added benefits, and avoided costs. Among the benefits, indicators include sectoral value added (as driven by natural resources stocks and flows, e.g., sustainable agriculture yield and production), direct employment creation, and relative income generated, for example, additional employment in public transport or energy efficiency sectors. Avoided costs include savings from avoided consumption (e.g., water, through resource efficiency interventions), and potential avoided ecosystem restoration costs. These are compared with costs, and potential damages created by the business as usual case and by the policy implemented, to estimate the economy-wide annual cash flow, as well as the break-even point, and the return on investment (and, for instance, the return on employment, and emissions).

By generating systemic, broad, and cross-sectoral scenarios over time that address environmental, economic, and social issues in a single coherent framework, the GEM simulates the main short, medium, and long-term impacts of investing in a greener economy. The most important contribution of this model is its systemic structure that includes endogenous links within and across the economic, social, and environmental sectors through a variety of feedback loops. Most existing models focus on one or two sectors and make exogenous assumptions about other sectors that affect and are affected by the sector under consideration. Using endogenous formulations instead improves consistency over time and across sectors, because changes in the main drivers of the system analyzed are reflected throughout the model and analysis through feedback loops. While detailed sectoral analysis is very important, it is not adequate to demonstrate the whole set of relations and feedback loops that properly represent the functioning of the real world and that must be taken into account in making the necessary transitions to greener economic and social structures.

The study uses different indicators that capture the value of natural capital in order to represent a green economy, which are green GDP and GDP of the poor. These indicators were developed in the I-GEM as an alternative to conventional GDP, which only captures a small portion of nature's contribution to people's livelihoods [43, 44]. The model mainly used Green GDP as an indicator of the Green Economy, which is an alternative measurement of GDP growth that accounts for

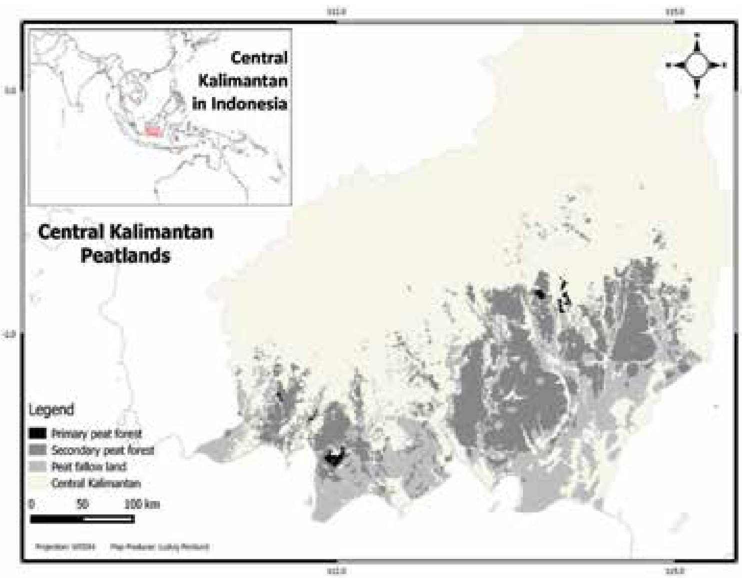

Figure 1.
Extent of peatland and the land use on peatland in Central Kalimantan.Data source: The Ministry of Forestry Republic of Indonesia. [57].

natural capital depreciation and changes in the value of human capital. The GDP of the Poor indicator measures the contribution of nature and environmental services to the household incomes of poor communities **Figure 1** [43, 44].

2.3 Peatland management scenarios

Four peatland management scenarios in Central Kalimantan were chosen: a business as usual (BAU) scenario, a BAU and palm oil expansion (BAU + Palm) scenario, a green economy (GE) scenario, and a Jelutung scenario. The **BAU scenario** assumes the continuation of historical and present trends of peatland management, which includes land use changes, policies, and interventions currently implemented and enforced. The **BAU + Palm scenario** represents a likely future scenario of the rapid conversion of fallow lands into palm oil. It follows the assumptions of the BAU scenario with the additional assumption of gradually converting all fallow lands into palm oil starting from 2015 until the end of the study period in 2030. Under the **GE scenario**, the implementation of several management and conservation efforts are assumed, including the implementation of government regulation No. 71/2014 on the Protection and Management of Peatland Ecosystems; rehabilitating and rewetting the peatlands in order to keep the water table depth (WTD) below the peatland surface less than 20 cm; halting the conversion of peatlands; and gradually rewetting fallow lands and converting them to secondary peatland forests over the years. Other green economy transitions included are the implementation of sustainable agriculture, vessel removal, fish conservation, waste reuse, and energy and solar efficiency. The scenario assumes the implementation of Government Regulation 71/2014 from 2015 onward and the other policy changes from 2020 onward. Finally, the **Jelutung scenario** models the outcome of a policy that converts all palm oil plantations to Jelutung forest or agroforestry systems in order to provide an extreme case of using paludiculture to rehabilitate degraded peatlands from 2015 onward. The scenario further assumes the same policy changes as the GE scenario.

2.4 KT-GEM key equations for peatland analysis

To assess the impact of paludiculture development and other policies in a green economy scenario, the study looked at various indicators in the KT-GEM peatland module, namely total peatland emissions, subsidence and flooding impacts, and costs and profits, in order to calculate impacts on natural capital change, Green GDP and GDP of the Poor. The implications of the different policy scenarios were analyzed for the period 2015–2030.

2.4.1 Total peatland emissions

Total peatland emissions were obtained by summing up the total biological emissions and emissions from fire. To estimate the biological emissions, a biological emission factor on different land types in Central Kalimantan was estimated. Land use and land use change in the KT-GEM Peatland Module was adapted from the classification of peatlands from Krisnawati et al. [25] and categorized into four land uses on peat: agricultural peatland, secondary peatland forest, production forest on peatland, and fallow peatland. The emission factor on the four different land uses was calculated by adapting the linear regression equations from Husnain et al. [23] and Hooijer et al. [22] and the water table depths for the land uses in each scenario came from data obtained from several publications [16, 21, 23].

Fire emissions were calculated based on the amount of burnt areas, which were estimated by calculating fire hotspots. Because of the significant influence of the El Niño Southern Oscillation (ENSO) on fire activity in Indonesia [41], the KT-GEM integrated an ENSO indicator, namely Nino3.4 Sea Surface Temperature (SST) Index to forecast fire hotspots.[3] Historical dry season data from the Nino3.4 SST Index from 2000 to 2014 and MODIS-derived hotspot data from 1998 to 2006 from Reynolds et al. [38] were used for the assessment. Data from the Nino3.4 Index was extrapolated to create a trend in the relationship between SST and hotspots until 2030. The historical and extrapolated data were then used to predict the amount of hotspots per dry season in Central Kalimantan by measuring the relationship between Nino3.4 index data and fire hotspots using an exponential regression analysis as can be seen in **Figure 2**.

The exponential regression model was then adapted to each management scenario and set into formulas to forecast the amount of hotspots in each scenario.[4] The formula developed by Tansey et al. [50], in their study in Central Kalimantan, was then used to calculate the total burnt area:

$$\text{Burnt area (hectare)} = 2925 \times \text{Hotspots} \times 155.49.$$

Finally, to calculate fire emissions, the KT-GEM Peatland Module adapted a method used by the Indonesia National Forest Reference Emissions Level or FREL [6]:

$$L_{fire} = A \times MB \times CF \times G_{ef}$$

where **A** denotes the extent of burnt area (in hectares), **CF** is the combustion factor with a default factor that equals to 1.0, and **MB** denotes the mass of fuel

[3] A hotspot is a fire pixel in a satellite imagery that indicates fire in an area. Yet it does not specify the number, size or intensity of fires and burned areas. See further [40].

[4] The study by Thoha et al. (2014) found that 63 percent of all hotspots in Central Kalimantan occur on peatlands and total hotspots calculated were therefore multiplied by 0.63 to adjust the results.

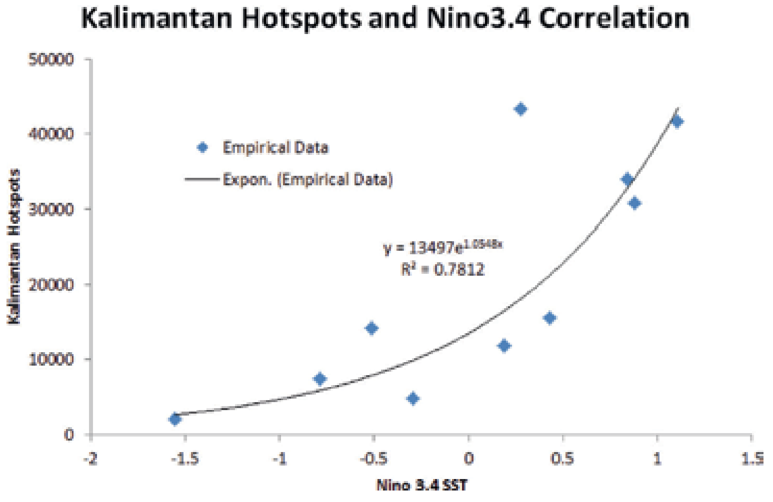

Figure 2.
Central Kalimantan hotspots and Nino3.4 SST correlation (for the period July–August–September–October) [57].

available for combustion. The latter is estimated for the BAU scenario by multiplying the mean depth of burned peat with the bulk density (BD) as assumed in the studies by Mulyani et al. [32] and Ballhorn et al. [2]. From here, the average depth of burned peat in other scenarios was calculated by building a linear relationship between the assumed water table depth (WTD) and the burned depth. Furthermore, $\mathbf{G}^{ef}$ denotes the CO_2 emission factor calculated by multiplying the organic carbon content (Corg, % of weight) of 0.4986 [32] with the conversion factor from tC to tCO_2e which is 3.67. This conversion factor was derived through dividing the atomic weight of carbon dioxide (i.e., 44) by the atomic weight of carbon (i.e., 12).

2.4.2 Land subsidence and flooding

Land subsidence was estimated to forecast the amount of flooded agricultural land to be subtracted from agricultural land, production, and profits in the Green GDP calculations. The KT-GEM Peatland Module calculates the subsidence rate using the equation from Hooijer et al. [21] which measured a relationship between water table depth and subsidence level, as follows:

$$Subsidence\ rate\ (cm\ per\ year) = 0.69 - 5.98 \times WTD$$

This formula was simulated for each land use category in all selected peatland management scenarios and adjusted the WTD accordingly. Based on the subsidence rate, the module then measured the risk of flooding in agricultural peatlands with an equation from that demonstrates the relationship between the accumulated agricultural subsidence and the proportion of flooded agricultural peatlands. The result was then multiplied with the existing agricultural land (in hectare) and the inverted Nino3.4 SST Index (where wet years are positive instead of the other way around) in order to obtain the extent of flooded agricultural land.

2.4.3 Calculating costs and profits

In estimating the total costs and profits, the KT-GEM included costs of rewetting and reforestation, costs from fires, and profits from palm oil plantations and jelutung.

Rewetting and reforestation costs in the green economy and jelutung scenarios applied mainly to production forests, secondary forests, and fallow lands and were gradually implemented between 2015 and 2025, after which only small rewetting costs for maintenance were calculated. In order to estimate rewetting and reforestation costs, data on peat forests rehabilitation costs by were used. The cost of fire damage was calculated by multiplying the extent of burnt areas with fire damage cost per unit, which were estimated at 172 USD per hectare of burned area by Tacconi [51].

Palm oil is the main crop on agricultural land, especially in the BAU + Palm scenario, and the profits of palm oil plantations were estimated based on calculations in the study by Suharno et al. [46]. This number was multiplied by the agricultural peatland (Ha) to obtain the total profits from oil palm production (IDR/Year). Jelutung profitability was calculated based on a cultivation period of 30 years [52] and the value reported in the ICRAF report, which was multiplied with the total area of jelutung (ha). The value used is the net profit per hectare per year, which contains all the annual costs. Hence, the capital (CAPEX) and operational (OPEX) costs associated with intervention are lumped together to minimize the complexity of the model.

2.4.4 Calculating natural capital change and Green GDP

The estimation of Green GDP was performed by adding the change in natural capital to real GDP. Real GDP of Central Kalimantan is calculated by adding the production value from several sectors, namely agriculture, fisheries, forestry, industry, services, labor, mining, and tourism [43, 44]. Natural capital change is calculated by adding the carbon loss value and the value of emissions and fires in peatlands. To do so, the study uses a fixed-rate carbon price (i.e., 5 USD per tCO_2) through the entire study period and assumes a functioning carbon credit markets in order to incorporate the benefits from GHG emissions reduction.

3. Results and discussion

1. Policy interventions in the GE and Jelutung scenarios lead to lower cumulative peatland emissions

Figure 3 shows the total cumulative peatland emissions in the four selected peatland management scenarios. Up to 2015, the year in which the interventions are expected to begin, total peatland emissions are the same in all the scenarios considered. The GE and Jelutung scenarios result in significantly lower cumulative peatland emissions in Central Kalimantan compared to the BAU and BAU + Palm scenarios in the simulation up to 2045, with the scenario BAU + Palm having the highest level of cumulative emissions. Given the large contribution of peat-related emissions in Central Kalimantan to Indonesia's total GHG emissions, the adoption of policies aimed at reducing peatland emissions will significantly help the country achieve its climate change mitigation goals [31].

High peatland emissions are correlated with higher costs associated with fires on peatlands, as reflected in **Figure 4**. Results of the BAU and BAU + Palm coincide and are highly fluctuating over time, signifying that there is a high variability in the probability that peat fires will take place on any given year. Ultimately, this trend illustrates that both the BAU and the BAU + Palm scenarios generate the highest costs related to annual fire damage as compared to the other two scenarios. The model forecasts that future fire damage costs in the BAU and the BAU + Palm scenarios could reach up to 700 billion IDR; whereas, in the GE and Jelutung scenarios,

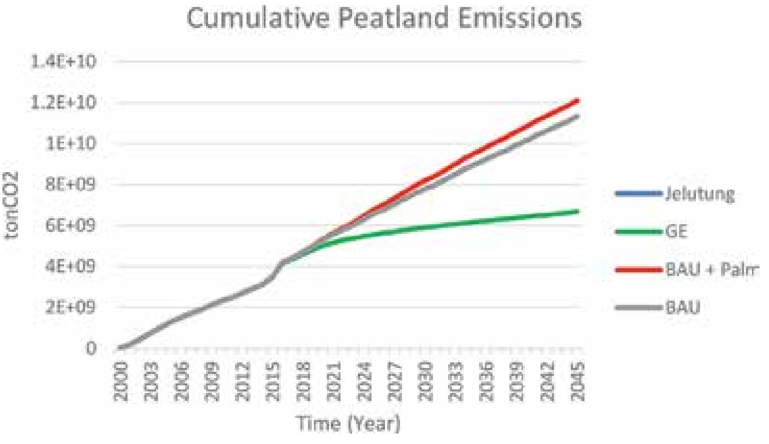

Figure 3.
Cumulative peatland emissions of different policy scenarios in Central Kalimantan.

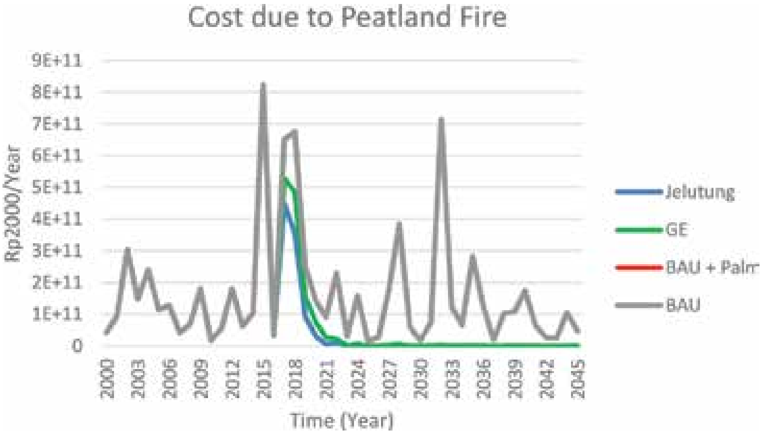

Figure 4.
Cost due to peatland fire in Central Kalimantan.

these costs would be equal to zero after the initial years of intervention. In the KT-GEM peatland module, these results are further integrated in the calculation of Green GDP as part of natural capital losses and the BAU and BAU + Palm scenarios are therefore significantly contributing to lower Green GDP than the other two scenarios.

The 2015 fires, which were caused by El Niño, are proof that historical data alone are inadequate to be used as a benchmark for forecast the actual costs of fire damage. In addition to the direct impacts and costs of fire and haze, studies indicate long-term negative health impacts from endured exposure to haze, including a significant increase in mortality [26]. The World Bank [53] calculated that post-fire and haze rehabilitation costs of 2015 amount to USD 16.1 billion, more than double the costs of the Aceh-Nias tsunami in 2004.

The BAU and BAU + Palm Oil scenarios are so-called high risk, high reward scenarios with short-term economic benefits. Keeping in mind Indonesia's sustainability and economic ambitions, the more effective scenarios (Jelutung and GE)—as illustrated on the graphs—should be prioritized; as they signify the lower levels of deviation from predicted future emission levels, and this "predictability" is a stable environment for government officials to formulate policies as well as for other key stakeholders that have initiatives in this area.

Implicitly, the lower cost due to reduced peatland fires will inherently improve results of Green GDP.

2. Jelutung and GE scenarios are less profitable than palm oil development, but the latter is unsustainable

The GE and Jelutung scenarios are less profitable than palm oil development when relying on traditional GDP indicators, as is made apparent in **Figure 5**. The calculation of the natural capital component in the Green GDP valuation is dependent on both the release of emissions, as well as on the revenues from agricultural activities. As a result, the direct income derived from palm oil production increases short-term profitability, but the negative impacts of depleting natural resources and generating more emissions are not captured by traditional GDP.

At the end of the study period, the GDP of BAU + Palm Oil scenario would reach more than 100 trillion IDR, while the real GDP in the other three scenarios approximates IDR 75 trillion. The major increase in GDP for the BAU + Palm Oil scenario is due to the high profits obtained from palm oil plantations. This remains as one of the direct challenges faced by key stakeholders that want to shift practices to more sustainable alternatives.

However, the conventional GDP indicator has many shortcomings, which makes it unreliable as a measure of social welfare. The GDP indicator ignores the future consequences of current consumption [5] and is criticized for not internalizing environmental externalities and natural resources depletion (e.g., [4]). Consequently, the value of nature is often underestimated in policy making since its contribution is deemed low, and this leads to struggling efforts in conserving nature. In Indonesia, conventional GDP only captures a small portion of nature's contribution to the economy, estimated around 21% of the total GDP. Yet, Indonesia has approximately 99 million poor inhabitants who depend on ecosystem services, and their dependence on nature is not considered in the conventional GDP indicator.

The KT-GEM clearly points out these shortcomings, and estimates an alternative indicator: Green GDP. This indicator shows that the GE and Jelutung scenarios would reduce economic volatility and the vulnerability to external shocks as well as to climate change (and peat fires). Furthermore, the economic performance now differs only slightly across all the scenarios, indicating that the value of nature is relevant and should be explicitly considered. Overall, the GE scenario achieves the best performance with regard to the Green GDP indicator, as its value is higher than BAU

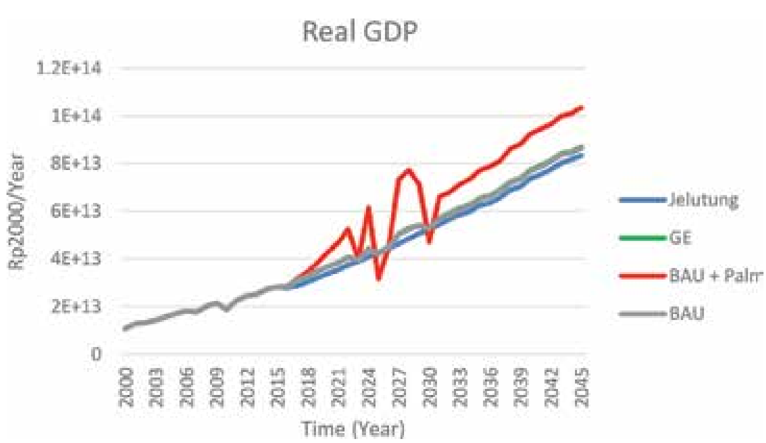

Figure 5.
The projection of GDP of the simulated policy scenarios in the Central Kalimantan.

Figure 6.
The projection of green GDP of the simulated policy scenarios in Central Kalimantan.

and Jelutung annually and cumulatively, and it is also highly competitive with the BAU + Palm oil scenario. Most importantly, the growth of the GE scenario is more consistent and resilient than what is observed for the other scenarios (**Figure 6**).

3. The Jelutung and GE scenarios result in lower total natural capital change costs

The analysis shows that both the BAU and the BAU + Palm Oil scenario result in heavily fluctuating costs due to peat fires and natural capital depletion, a sign that palm oil and continued deforestation continue to undermine the value of natural capital throughout the study period (**Figure 7**). This is also one of the strong inputs that explain the reduced fluctuation of Green GDP, in which a smaller number of peat fires is forecasted. The years 2018 and 2032, in particular, show high losses of natural capital due to forest fires, but only in the BAU and BAU + Palm Oil scenarios.

The total Natural Capital Net Change becomes a key piece of information when development practitioners attempt to negotiate with private sector institutions that a win-win solution can be obtained by adopting GE or Jelutung policy scenarios and moving away from traditional BAU practices and palm oil development. Many initiatives—most famously, efforts by Pavan Sukhdev and the TEEB initiative—have attempted to formulate tools and processes to give ecosystem services a numerical

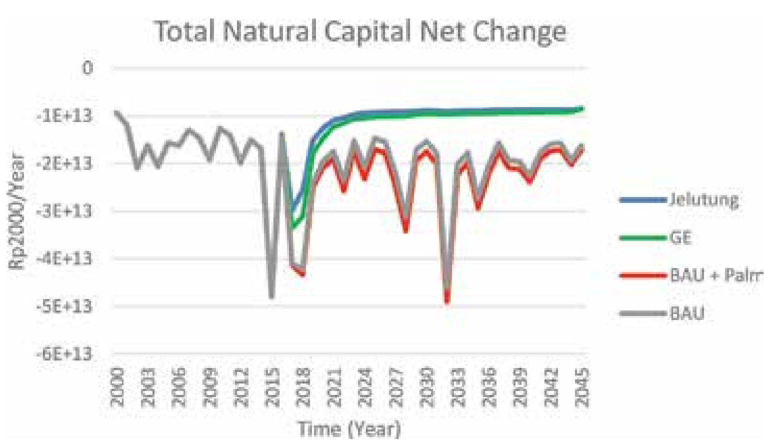

Figure 7.
Total Natural Capital Net Change.

value; intended to drive new conservative business practices that go along with the assumed primary interest of businesses—maximizing profit. This can be looked at as a marketing attempt to increase the tangibility of ecosystem services. By giving natural resources and ecosystem services a numerical value, private sector institutions—especially those in industries that are highly dependent on these shared assets—become inclined to input these numbers onto their financial scorecards and balance sheets.

Doing so could lead to a more sustainable business environment, with a long-term accumulation of profit for businesses at a consistent rate. The question and challenge is whether businesses, government officials, and other key stakeholders are able to envision this outcome and make the trade-off between BAU/BAU + Palm oil and GE/Jelutung scenario, which leads to short-term profit loss, but sustainable long-term business activity—inherently meaning, increased accumulative profit. In fact, the GE scenario has the highest cumulative Green GDP, and that even though BAU + Palm oil is a little more profitable than Jelutung, the Jelutung scenario is just as competitive considering it possesses far more intangible benefits (e.g., in the provision of ecosystem services and resilience) for policy makers, businesses, and communities. On the other hand, being intangible and not being accrued by any specific economic actors, these benefits are difficult to quantify and can hardly influence decision making.

4. Under a higher carbon price the Jelutung scenario outperforms the BAU + Palm Oil scenario

The valuation of natural capital in the Green Economy Model is dependent on the carbon price that is used, which in this case is the baseline carbon price that is set in the Letter of Intent between Indonesia and Norway. However, carbon prices may fluctuate leading to different impacts on Green GDP depending on land use management scenarios. As the effect of the Jelutung scenario on Green GDP is highly dependent on carbon price and profitability of Jelutung, a sensitivity analysis of the carbon price on the cumulative Green GDP was carried out. Results demonstrate that under a higher carbon price, the Jelutung scenario generates a higher cumulative Green GDP than the BAU and the BAU + Palm Oil scenarios (see **Figure 8**). This is caused by the gain in revenues from the decrease in peatland emissions

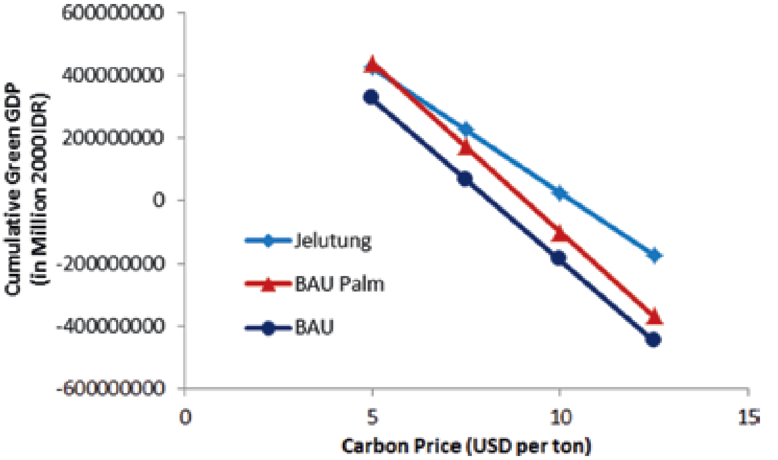

Figure 8.
The effect of the carbon price on the cumulative Green GDP in Central Kalimantan.

under the Jelutung scenario as compared to the high peatland emissions under BAU and BAU + Palm Oil scenarios.

For policy makers, this means that an increase in carbon prices will result in more favorable conditions—higher profit—for GE/Jelutung scenarios and an increase in the costs of BAU/BAU and oil Palm ones. As carbon prices increase, these results become more distinct and would encourage a change in policies. Yet, if national policy makers remain reluctant in adopting sustainable policy options with carbon pricing incentives, local government, the private sector, and local communities will not be incentivized to transition to the GE and/or the Jelutung scenario, because the profit margins remain low.

4. Conclusions

The assessment carried out with KT-GEM has pointed out that the BAU scenario and the continuation of palm oil expansion are not only best performers concerning economic profitability, but also lead to the highest variability in revenues, leading unsustainable social as well as environmental outcomes. When these outcomes are valued economically, taking a societal perspective, the BAU, and oil palm expansion are not economically viable. In fact, with increased emissions, fire and land subsidence, the BAU, and palm oil expansion scenarios will continue to cause significant economic damage to the communities of Central Kalimantan and beyond, negatively affecting the health of both Indonesian population as well as those in adjacent countries. Further, when taking land subsidence into account, expanding plantations across the peatlands is unlikely to be feasible beyond 50 years, which calls for a different approach to the utilization of the degraded peatlands.

The Jelutung and GE scenarios are less profitable than palm oil development when relying on traditional economic indicators, such as GDP. On the other hand, if the transformation of current practices into paludiculture development on peatland are coupled with strengthening market access for these products, and if the lower profitability of jelutung cultivation—and many other paludiculture species—compared to palm oil could be improved by implementing investments in jelutung across the value chain, the efficiency and profitability of jelutung production is expected to improve and it may be turned into a more viable alternative than palm oil production.

The KT-GEM Peatland model has shown that sustainable peatland management as included under the GE and Jelutung scenarios have a positive impact on Green GDP in Central Kalimantan and will be essential for achieving sustainable economic growth. Further, since the sustainable management of peatland also reduces fire risks and emissions, this scenario would contribute to the ambitions of a haze-free ASEAN by 2020 and Indonesia's emission reduction target. Indonesia has a lot to gain from restoration with paludiculture species in relation to reduced fires, health impacts, emissions, and potential for other forms of community-based development.

Despite its limitations, the KT-GEM Peatland Module and Green GDP calculations provide interesting insights for policy makers, especially in finding solutions to the fire problem and exploring policy options for peatland rehabilitation. It further demonstrates the impact of natural capital change on economic growth and supports a better understanding among policy makers that current GDP calculations are not adequate. It shows that building environmental resilience can not only maintain natural resource assets, but also lead to lower social and environmental costs.

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References

[1] Austin KG, Kasibhatla PS, Urban DL, Stolle F, Vincent J. Reconciling oil palm expansion and climate change mitigation in Kalimantan, Indonesia. PLoS One. 2015;**10**(5):e0127963. DOI: 10.1371/journal.pone.0127963

[2] Ballhorn U et al. Derivation of burn scar depths and estimation of carbon emissions with LIDAR in Indonesian peatlands. Proceedings of the National Academy of Sciences of the United States of America. 2009;**106**(50):21213-21218

[3] Bassi AM. Moving towards integrated policy formulation and evaluation: The green economy model (GEM). Environmental and Climate Technologies. 2015;**16**(1):5-19

[4] Bergh, van den JCJM. The GDP paradox. Journal of Economic Psychology. 2009;**30**(2):117-135. Available from: http://www.sciencedirect.com/science/article/pii/S0167487008001141

[5] Boyd J. Nonmarket benefits of nature: What should be counted in green GDP? Ecological Economics. 2007;**61**(4):716-723. Available from: http://www.sciencedirect.com/science/article/pii/S0921800906004642

[6] BP REDD+. National Forest Reference Emission Level for Deforestation and Forest Degradation in the Context of the Activities Referred to in Decision 1/CP.16, Paragraph 70 (REDD+) Under the UNFCCC: A Reference for Decision Makers, Jakarta: BP REDD+;2015

[7] BPS Provinsi Kalimantan Tengah. Kalimantan Tengah Dalam Angka 2014 (Kalimantan Tengah in Figures 2014), Palangka Raya; 2014

[8] BPS Provinsi Kalimantan Tengah. Potensi Desa Kalimantan Tengah 2014. Palangka Raya, BPS Provinsi Kalimantan Tengah; 2015

[9] Couwenberg J, Dommain R, Joosten H. Greenhouse gas fluxes from tropical peatlands in Southeast Asia. Global Change Biology. 2010;**16**:1715-1732

[10] Dommain R et al. Hydrological self-regulation of domed peat swamps in South-East Asia and consequences for conservation and restoration. Mires and Peat. 2010;**6**(Art 05):1-17

[11] FAO and MOEF. Workshop on Paludiculture. 2016

[12] Forrester JW et al. Road Maps: A Guide to Learning System Dynamics, System Dynamics Group, Sloan School of Management, MIT.Wakker, E. 2006. The Kalimantan Border Oil Palm Mega-Project. Amsterdam: AID Environment; 2002

[13] Giesen W. Paludiculture: Sustainable alternatives on degraded peat land in Indonesia. Report on activity 3.3 of project. In: Quick Assessment and Nationwide Screening (QANS) of Peat and Lowland Resources and Action Planning for the Implementation of a National Lowland Strategy. For Partners for Water, the Netherlands (PVW3A10002), Indonesian Ministry of Public Works & Bappenas; 2013. 71 p

[14] Government of central kalimantan (2017) gambut: Available from: https://kalteng.go.id/INDO/Gambut.htm [Assessed: January 10, 2017]

[15] Joosten H, et al. Peatlands - Guidance for Climate Change Mitigation through Conservation, Rehabilitation and Sustainable Use, published by the FAO. 2012. Available from: http://www.fao.org/3/a-an762e.pdf

[16] Government of Indonesia. Government regulation of the Republic

of Indonesia No. 71/2014 on the protection and Management of Peatland Ecosystems, Indonesia; 2014

[17] Harris N, et al. With latest fires crisis, Indonesia Suprasses Russia as World's Fourth-Largest Emitter. World Resources Institute. 2015. Available from: http://www.wri.org/blog/2015/10/latest-fires-crisis-indonesia-surpasses-russia-world's-fourth-largest-emitter [Accessed: November 7, 2016]

[18] Hayasaka H et al. Peat- fire-related air pollution in Central Kalimantan, Indonesia. Environmental Pollution. 2014;**195**:257-266. Available from: ttp://dx.doi.org/10.1016/j.envpol.2014.06.031

[19] Hooijer A, Van der Vat M, Prinsen G, Vernimmen R, Brinkman JJ, Zijl F. Hydrology of the EMRP Area –Water Management Implications for Peatlands. Technical Report No. 2, Master Plan for the Rehabilitation and Revitalisation of the Ex-mega Rice Project Area in Central Kalimantan. Euroconsult Mott MacDonald and Deltares and Delft Hydraulics; 2008

[20] Hooijer A, Page S, Canadell JG, Silvius M, Kwadijk J, Ẅosten H, et al. Current and future CO_2 emissions from drained peatlands in Southeast Asia. Biogeosciences. 2010;**7**:1505-1514

[21] Hooijer A, Page S, Jauhiainen J, Lee WA, Lu XX, Idris A, et al. Subsidence and carbon loss in drained tropic peatlands. Biogeosciences. 2012;**9**:1053-1071

[22] Hooijer A, et al. Carbon Emissions from Drained and Degraded Peatland in Indonesia and Emission Factors for Measurement, Reporting and Verification (MRV) of Peatland Greenhouse Gas Emissions; 2014

[23] Husnain H et al. CO_2 emissions from tropical drained peat in Sumatra, Indonesia. Mitigation and Adaptation Strategies for Global Change. 2014;**19**(6):845-862

[24] Kieft J, Smith T, Someshwar S, Boer R. Towards anticipatory management of peat fires to enhance local resilience and reduce natural capital depletion. Ecosystem-based disaster risk reduction and adaptation in practice. Advances in Natural and Technological Hazards Research. 2016;**42**:361-377

[25] Krisnawati H, et al. Interim Estimates of CO_2 Emissions for Central Kalimantan: A Simple CO_2 Emissions Account from Deforestation and Peat Decomposition Components for Central Kalimantan, Bogor; 2013

[26] Koplitz SN et al. Public health impacts of the severe haze in equatorial Asia in September–October 2015: Demonstration of a new framework for informing fire management strategies to reduce downwind smoke exposure. Environmental Research Letters. 2016;**11**:094023. Available from: http://iopscience.iop.org/article/10.1088/1748-9326/11/9/094023

[27] Limin SH, Ermiasi Y. History of the development of tropical peatland in Central Kalimantan , Indonesia. Tropics. 2007;**16**(3):291-301

[28] Marlier ME et al. El Niño and health risks from landscape fire emissions in Southeast Asia. Nature Climate Change. 2013;**3**(2):131-136. Available from: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=4219417&tool=pmcentrez&rendertype=abstract

[29] Mawdsley N, Hooijer A, Vernimmen R, Tollenaar D, Giesen W. Status and vulnerability of lowland peat land in Sumatra and Kalimantan. Ambio. 2010;**39**:2010

[30] Meadows D. The unavoidable a priori, excerpt from Randers. In: Elements of the System Dynamics Method; 1980

[31] Ministry of Environment and Forestry. Ministry of Environment and Forestry. National forest reference emission level for deforestation and forest degradation: In the context of decision 1/CP.16 para 70 UNFCCC; 2015. 24p

[32] Mulyani H, Sasongko SB, Soetrisnanto D. Pengaruh preklorinasi terhadap proses start up pengolahan limbah cair tapioka sistem anaerobic baffled reactor. Momentum. 2012;**8**(1):21-27

[33] Murdiyarso D, Hergoualch K, Verchot LV. Opportunities for reducing greenhouse gas emissions in tropical peatlands. Proceedings of the National Academy of Sciences of the United States of America. 2010;**107**:19655-19660

[34] Osaki M. Tropical Peatland Ecosystems. Japan: Springer; 2016

[35] Parish F, Sirin A, Charman D, Joosten H, Minayeva T, Silvius M, et al., editors. Assessment on Peatlands, Biodiversity and Climate Change. Global Environment Centre. Wageningen: Kuala Lumpur and Wetlands International; 2008

[36] Probst G, Bassi A. Tackling Complexity: A Systemic Approach for Decision Makers. Greenleaf Publishing; 2014

[37] Randers J. Elements of the System Dynamics Method. Portland, OR: Productivity Press; 1980

[38] Reynolds RW et al. An improved in situ and satellite SST analysis for climate. Journal of Climate. 2002;**15**(13):1609-1625

[39] Roberts N et al. Introduction to Computer Simulation. Reading, MA: Addison-Wesley; 1983. p. 16

[40] Siegert F, Hoffmann AA. The 1998 Forest fires in East Kalimantan (Indonesia). Remote Sensing of Environment. 2000;**72**(1):64-77. Available from: http://www.sciencedirect.com/science/article/pii/S0034425799000929

[41] Someshwar S, Rizaldi B, Esther C. World Resources Report Case Study. Managing Peatland Fire Risk in Central Kalimantan, Indonesia. World Resources Report, Washington DC. 2010. Available from: http://www.worldresourcesreport.org

[42] Spessa AC, Field RD, Pappenberger F, Langner A, Englhart S, Weber U, et al. Seasonal forecasting of fire over Kalimantan, Indonesia. Natural Hazards and Earth System Science. 2015;**15**(3):429-442

[43] Sukhdev P, Varma K, Bassi AM, Mumbunan S. Kalimantan Tengah Green Economy Model (KT-GEM). Indonesia: Low Emission Capacity Building Programme; 2015

[44] Sukhdev P, Bassi A, Varma K, Allen E, Mumbunan S. Indonesia Green Economy Model (I-GEM), Final Report; 2015

[45] Sumarga E, Hein L. Benefits and costs of oil palm expansion in Central Kalimantan, Indonesia, under different policy scenarios. Regional Environmental Change. 2016;**16**(4):1011-1021

[46] Suharno DY et al. Opportunities for Increasing Productivity and Profitability of Oil Palm Smallholder Farmers in Central Kalimantan. Palangkaraya: Palangkaraya Institute for Land use and Agricultural Research (PILAR); 2015

[47] Suriadikarta DA. Pembelajaran dari kegagalan penanganan kawasan plg sejuta hektar menuju pengelolaan lahan gambut berkelanjutan 1. Pengembangan Inovasi Pertanian. 2009;**2**(4):229-242

[48] Suwarno A, Hein L, Sumarga E. Who benefits from ecosystem services? A case study for Central Kalimantan, Indonesia. Environmental Management. 2016;57(3):1-14. Available from: https://doi.org/10.1007/s00267-015-0623-9

[49] Suwarno A, Hein L, Sumarga E. Governance, decentralization and deforestation: The case of Central Kalimantan Province, Indonesia. Quarterly Journal of International Agriculture. 2015;**54**(1):77-101

[50] Tansey K et al. Relationship between MODIS fire hot spot count and burned area in a degraded tropical peat swamp forest in Central Kalimantan, Indonesia. Journal of Geophysical Research. 2008;**113**(D23112):1-8

[51] Tacconi L. Fires in Indonesia: Causes, Costs and Policy Implications. Bogor: Center for International Forestry Research; 2003

[52] Tata HL, van Noordwijk M, Sakuntaladewi N, Wibowo LR, Bastoni TA, Susmianto A, et al. Stopping Haze When It Rains: Lessons Learnt in 20 Years of Alternatives-to-Slash-and-Burn Research in Indonesia. ABS Policy Brief 45. 2015. Available from: http://www.asb.cgiar.org/

[53] The World Bank. Indonesia Economic Quarterly: Reforming Amid Uncertainty. 2015. Available from: www.worldbank.org/id

[54] Thoha AS, Saharjo BH, Boer R, Ardiansyah M. Spatiotemporal distribution of peatland fires in Kapuas District, Central Kalimantan Province, Indonesia. Agriculture, Forestry and Fisheries. 2014;**3**(3):163-170

[55] UNEP 2011. UNEP, Towards a Green Economy: Patways to Sustainable Development and Poverty Eradication, United Nations Environment Programme. 2011. Available from: www.unep.org/Greeneconomy

[56] Williams L. Lactiferous plant of economic importance IV jelutong (*Dyera* sp). Economic Botany 1963;17(2). New York Botanical Garden Press

[57] Yulianti, N., Hayasaka, H. 2013. Recent active fires under El Niño conditions in Kalimantan, Indonesia. American Journal of Plant Sciences, vol. 4, pp. 685-696

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This book discusses aspects of land use change and sustainability in ways that may generate further research ideas. It brings together discussions from leading researchers and scholars in the field of land use change and sustainability from five different countries including the USA, Ethiopia, Guyana, Taiwan, and Indonesia. Based on empirical research and case studies, the book is divided into two sections. The first section is subdivided into four chapters and discusses land use sustainability in the Northern Great Plains of the USA; effects of rural land use and tenure on sustainable management of mangroves in Corentyne, Guyana; the property formation process in peri-urban areas of Ethiopia; and the effects of green energy production on farmlands in the Yulin County of Taiwan. The second section of the book is subdivided into two chapters and discusses cases pertaining to land use mapping and sustainability including land cover/land use mapping using soft computing techniques with optimized features; and applying systems analysis to evaluate Jelutung as option for sustainable use of peat lands in Central Kalimantan, Indonesia. The book is insightful, thought provoking, concise, and easy to understand. It could serve as an important reference material on land use change and sustainability.

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