Application of Unmanned Aerial Vehicle and Satellite Imagery for Management Zoning in Aketajawe Lolobata National Park, Indonesia

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As Ari Wahyu Utomo

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Indonesian national park management utilises a zoning classification process, which is crucial to maintaining forest integrity, and ultimately providing the widest possible benefits to diverse human and non-human communities. Appropriate zoning management is essential in the regulation of spatial land use purposes, definition of natural resource use, and the imposition of land use limitations. As part of zoning development, current land cover information is fundamental for reliable environmental databases. These data represent the actual conditions of forest structure. Satellite imagery is a powerful resource for identifying land cover though it is not easy to provide updated information with this imagery. To fill this gap, a new approach with aerial surveys by Unmanned Aerial Vehicle (UAVs) has been adopted in this study to monitor national park forest coupled with GIS analysis techniques (Arc Map 10.6) to provide valuable and up to date information to evaluate zoning management in Aketajawe Lolobata National Park, Indonesia.

A remotely piloted UAV captured high-resolution images from 687 hectares in a relatively more efficient time allocation (4 hours 19 minutes and 10 seconds) than conventional GPS surveys. This aerial survey clearly identified indigenous people's house distributions, their home range activities in Tayawi and some coconut plantations in Tabanalau and Akejawi. Following land cover analysis using Landsat 8, it was shown that Aketajawe primarily consists of primary forest at 65,590.3 ha (84.3%), followed by secondary forest at 9748.9 ha (12.5%), open area 2045.5 ha (2.6%), and waterbodies 396.1 ha (0.5%). These data combined with several spatial data in order to generate spatial planning models for Aketajawe National Park.

Two spatial models (zonal and eco-social) were developed to identify areas of priority in terms of ecological and social value in zoning classification for Aketajawe. In both models, the distribution and location of core, wilderness and rehabilitation zone were relatively similar, even though the total area is slightly different, possibly due to the digitising process. However, in the spatial planning related to indigenous protection and livelihood, there is a different distribution of the traditional and utilisation zone in eastern and southern parts of the Aketajawe region. This study provides evidence that the combination of a zonal model and an eco-social model can be used for improved national park spatial planning, as more accurate and current information better represents actual field conditions. This study also demonstrated that the application of UAV technology for periodic forest surveys to update land use patterns has the potential to contribute valuable information for national park programmes or policy evaluation.

Keywords: zoning classification, unmanned aerial vehicle (UAV), satellite imagery, geographical information system (GIS), weighted overlay, ecological, socioeconomic.

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Chapter 1

Introduction

1.1 Study Background

Since 1990, the number of Indonesian tropical forests has decreased gradually due to Indonesia being a developing country with a high dependency on natural resources. The exact rates of forest loss have varied with different figures quoted by researchers and the government. However, in a new study, which claims to be the most comprehensive yet, (Margono, Potapov, Turubanova, Stolle, & Hansen, 2014) primary forest losses totalled 6.02 M hectares between 2000 and 2012, increasing to around 47,600 hectares each year over this time. As one of the mega-biodiversity countries (Whitmore, 1990), Indonesian forests play a significant role in conserving over a thousand species of wildlife and a unique cultural heritage. As a response to concerns about forest loss, the government of Indonesia has designated some biodiversity hotspots as nature reserves, often as national parks. The Ministry of Environment and Forestry described 54 national parks in Indonesia currently in an Indonesia Forest Statistics report in 2017, with Mt. Maras National Park, Zamrud National Park and Mt. Gandang Dewata National Park being the newest, in 2016. These national parks are some of the last places available to preserve Indonesian rainforests and biodiversity, making it essential to secure national parks from any potential detrimental factors. There are six main objectives of National Park management: (1). To protect indigenous people's lifestyle, including their subsistence resource use, so it will not have detrimental effects on other national park management objectives; (2) to preserve natural resources for educational, scientific, spiritual and tourism purposes; (3) to provide ecological stability and diversity; (4) to eliminate exploitation or any destructive activities; (5) to provide educational, cultural and tourism value for visitors; and, (6) to raise awareness of the geomorphologic, ecological and aesthetic attributes (IUCN, 2018).

To meet these goals, the Ministry of Environment and Forestry manages Indonesia's national parks by dividing their area into nine different zones to accommodate various management categories: namely: core, wilderness, utilisation, traditional, rehabilitation, cultural/religion/historical, specific purpose and marine protection for marine national parks (2015/76 act). These zones were created to promote and protect the natural resources, ecosystem types, social and economic activities, levels of interaction by local people and landscape formations of protected areas. The primary objective for the management of zones is to indicate the areas where the various strategies or policies of conservation development can be carried out and to determine the future of a protected area (Zafar, Baig, & Irfan, 2011), such as the utilisation zone, which is mainly for supporting tourism activities and infrastructure development, core and wilderness zones, which is for biodiversity protection and supporting people's livelihoods and their local knowledge is accommodated in the traditional zone. Overall, zone planning plays a significant role in the development of national parks in Indonesia.

1.1.1 Zoning Classification in Aketajawe Lolobata National Park

Aketajawe Lolobata National Park (ALNP) is located in North Maluku with a total area of 167,319 hectares (Ministry, Environment, & Forestry, 2016). As the only national park in the North Maluku region, this park has a significant role in conserving biodiversity in the Wallacea region. It was formally declared as a reserve area on 19 October 2004 by Ministry of Forestry decree number 397/Kpts-II/2004. The park area is divided into two management blocks, namely Aketajawe and Lolobata. ALNP spatial planning was first officially released in 2014, and then reviewed in 2017 due to land cover changes, public infrastructure development, tourism policies and the establishment of park borders. The following table and figure show the current ALNP zone classification proportions.

Table 1.1 The official total area and proportion zoning classification in Aketajawe Lolobata National Park

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Source: ALNP, Spatial Planning Document in 2017

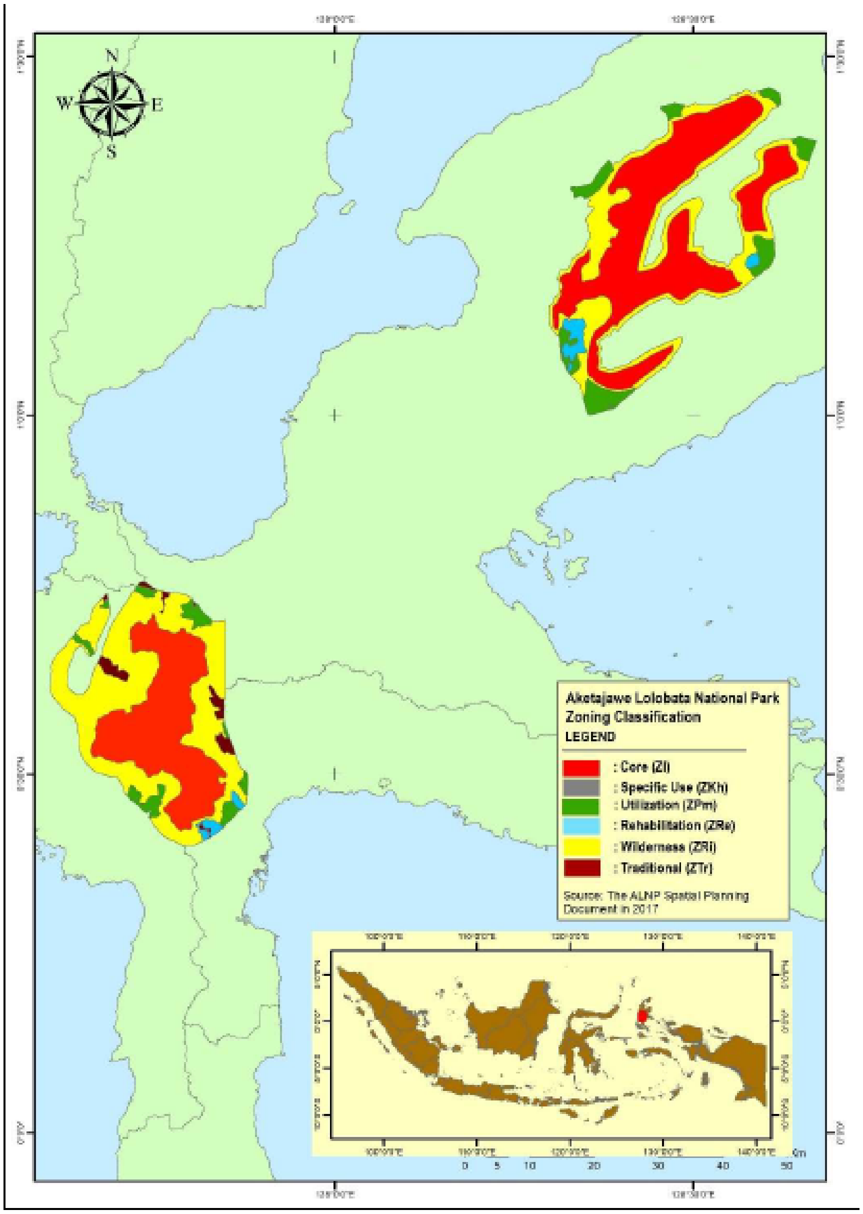

Figure 1.1 Present zoning classification map in the Aketajawe Lolobata National Park

Looking specifically at the Aketajawe block (Figure 1.2), this area experiences more pressure from human activity due to several existing settlements near the ALNP border with its inhabitants having a high dependency on the natural resources found within the park. Consequently, human conflicts and land fragmentation occurs more often in this management block, so this requires more effort by the park managers to keep the forest intact. Some examples of the challenges in managing the Aketajawe Block include a community coconut plantation (Pintatu, Tomares, Kobe villages), legal land ownership inside the park area, open areas resulting from logging activities 20 years ago, illegal mining activity at Mt. Durian, and 20 hectares of an overlapping agricultural area inside the national park at Binagara Resort;this resort is the smallest management unit for national park administration in the field.

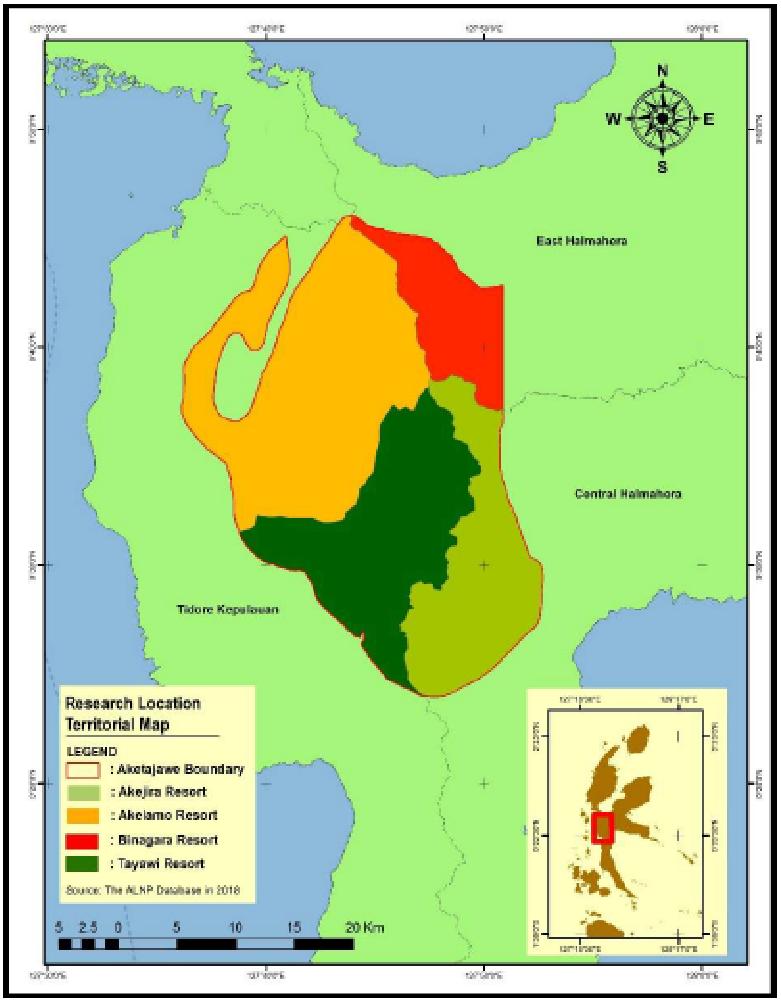

Figure 1.2 Aketajawe Block, Aketajawe Lolobata National Park (study area)

As a consequence, these problems contribute to the fragmentation of the ALNP area . In general, habitat loss and fragmentation are major pressures on biodiversity (Fahrig, 2003), (Wilcove, Rothstein, Dubow, Philips, & Losos, 1998) and many planning decisions about infrastructure, human settlements, public transportation and other developments contribute significantly to such problems (Forman & Deblinger, 2000). Habitat fragmentation reduces the connectivity of a habitat; as a consequence, the home range of many species may decline due to the barrier effect (Van der Ree et al., 2007). Habitat and species relation calculations have estimated that the number of species will decrease by 50 per cent if there is a 90 per cent habitat loss (Heywood & Stuart, 1992). Moreover, habitat fragmentation eventually leads to impacts on biodiversity at the genetic, species and ecosystem levels and, thus, each level should be considered in environmental assessments (Slootweg & Kolhoff, 2003).

Since habitat fragmentation has raised deep concerns in national park management, methods for evaluating, modelling and quantifying the impacts are necessary to develop for national park planning. Spatial analysis using Geographical Information Systems (GIS) provides practical methods for determining impact evaluation from habitat loss (Şahin & Kurum, 2002) and are widely used by environmental consultancies for all impact assessment stages (E. M. João, 1998). These techniques have been applied to a wide range of different impact assessments and government planning projects. The most common GIS applications for impact evaluation and resource development are biodiversity distribution and disturbances, roads management, housing developments, flood protection works and tourism planning. Such systems are also useful for communicating the impacts with maps and are used to detect primary and spatial impacts, identify land use patterns and predict future scenarios (E. M. João & Fonseca, 1996).

As a land survey technique, the development of Unmanned Aerial Vehicle (UAV) technology offers a valuable approach to earth surface classifications. The application of this technology in scientific studies has become more frequent as it addresses the limitations of conventional remote sensing-based surveys of land cover change. The ability to provide current spatial information over the area of interest and to produce high resolution images for visual identification and land cover mapping is undoubtedly useful (Ishihama, Watabe, & Oguma, 2012). The combination of this technology and GIS for forest management allows managers to combine spatial data with more recent imagery. As well, this equipment can reach remote or sensitive areas that cannot be easily accessed and has the ability to collect data on demand with a high spatial and temporal resolution (Laliberte, Herrick, Rango, & Winters, 2010). Despite the advantages of UAVs, this technology also has limitations relating to flight duration and coverage. As a result, relatively small areas are covered compared to satellite imagery. Additionally, problems with lower visibility and shorter signal ranges due to topography must be taken into account in aerial surveys. (Nex & Remondino, 2014). Since national park management face serious challenges related to habitat loss or fragmentation, UAV technology can be used to provide more accurate calculations of the total loss area and identify the impacts from aerial images.

The primary research focus of this study was an evaluation of the Aketajawe National Park zones; as the ALNP managers need comprehensive and up-to-date field information in order to create better strategies for park management. A new approach in environmental assessment is developed in this study by integrating UAV technology and GIS analysis to evaluate zone classifications for national park spatial planning. This will be accomplished by evaluating the existing spatial planning, interpreting the land cover and land use data from satellite imagery, mapping human activities inside the park areas by UAV surveys and identifying areas of great ecological importance and social value. By incorporating all relevant data into government regulations, a more applicable framework for spatial planning in Aketajawe Block will be established.

1.2 Research Objectives

1.2.1 The Conceptual Framework

It is essential to evaluate current spatial planning in Aketajawe due to land cover, and land use changes over the last five years. The conceptual study framework aims to provide the best formulation for effective spatial planning in Aketajawe by incorporating a new approach to land survey classification which integrates UAV technology and satellite imagery to derive updated land cover features, including land cover changes from the impact of any human interventions or activities inside the forest. These primary data are fundamental for further national park management, particularly for decision-makers as they need reliable data for better national park strategies, policies, actions and spatial planning. To achieve this objective, GIS analysis and techniques has been applied to formulate multiple spatial data and any relevant Indonesian regulations in national park zoning classification.

1.2.2 Problem formulation and research objectives

The research had the following two objectives:

1. Develop an effective strategy to monitor national park forest using Unmanned Aerial Vehicles (UAV) technology coupled with GIS analysis techniques to provide valuable and up to date information to the national park management.
2. Provide the best advice for evaluating zones management spatial planning at Aketajawe Block in the ALNP.

The following activities were identified to achieve those objectives:

1. Develop a new methodology for forest monitoring and interpreting the images based on the UAV aerial survey.
2. Collate national park spatial data of the areas needed for further analysis. These kinds of maps encompass indigenous people's distribution, biodiversity, land cover, tourism spots, infrastructure, the ALNP master plan spatial planning and other related maps that are required for the analysis.
3. Carry out land cover analysis using satellite imagery to enable better national park zone classifications by capturing data related to extents and areas of:
    - Primary forests
    - Secondary forests
    - Critical areas (open area)
    - Human plantations or agricultural farms inside the national park
    - Illegal mining areas
    - Tourism spots
    - Biodiversity spots.

    These data will provide detailed maps showing the impacts of human activities inside the national park and some potential factors that contribute to forest degradation, such as natural disasters.

4. Capture updated land use data for focussed areas based on UAV observations particularly in areas with high human activities inside the park, such as 'indigenous people's territories and settlements inside the national park area.
5. Evaluate the existing ALNP management policy for each zone classification based on field investigations and a literature review.

Overall, this research will generate a spatial assessment of the national park forest at a landscape level to, exposes how different land cover types are impacted due to human activities in the proposed study area; it includes the effect of forest loss on national park policies and provides some recommendations to deal with that problem.

1.3 Thesis Structure

This thesis is broken into several chapters as follows:

Chapter 2 provides general information on the Aketajawe Lolobata National Park, such as the existing conditions, landscape characteristics, national park history, accessibility, demography, biodiversity resources, and national park management.

Chapter 3 focusses on theoretical approaches and a literature review related to UAV technology, aerial surveys, national park zoning classifications, remote sensing and geographic information system.

Chapter 4 covers the research methodologies including the quantitative and qualitative methods used in the analysis. This chapter also describes the primary and secondary data are used in the analysis, including how these data were gathered and analysed in order to formulate a more effective national park zoning formulation.

Chapter 5 presents the results from the UAV survey, image classification, and national park zoning classification.

Chapter 6 explains the aerial survey contribution to national park zoning management and further development in forest survey, including some information related to the strengths and weakness of the zoning model used in this study.

Chapter 7 concludes with some highlighted points related to aerial survey using UAV and national park zoning modelling classifications and some recommendations for further study.

Chapter 2

Study Area

2.1 Early Development of Aketajawe Lolobata National Park

ALNP establishment was initiated by National Conservation Indonesia, a cooperative group between several non-government organisations (NGOs) and the Ministry of Agriculture and Forestry, through proposing four new protected areas in Halmahera Island, namely Aketajawe, Lolobata, Saketa, and Mt. Gamkonora in 1981 (ALNP planning documents, 2016). This action offered approximately 120,000 hectares of Aketajawe forest as a reserve area in the initial planning, included a coastal region in the west, and inland of Halmahera Island between the elevations of 0 to 1,513 m.a.s.l. and 189,000 hectares of Lolobata forest as a nature reserve area. This initial planning encompased a coastal area in Dodaga in the eastern part of Halmahera Island between the elevations of 0 to1,417 m.a.s.l. (see Figure 2.1).

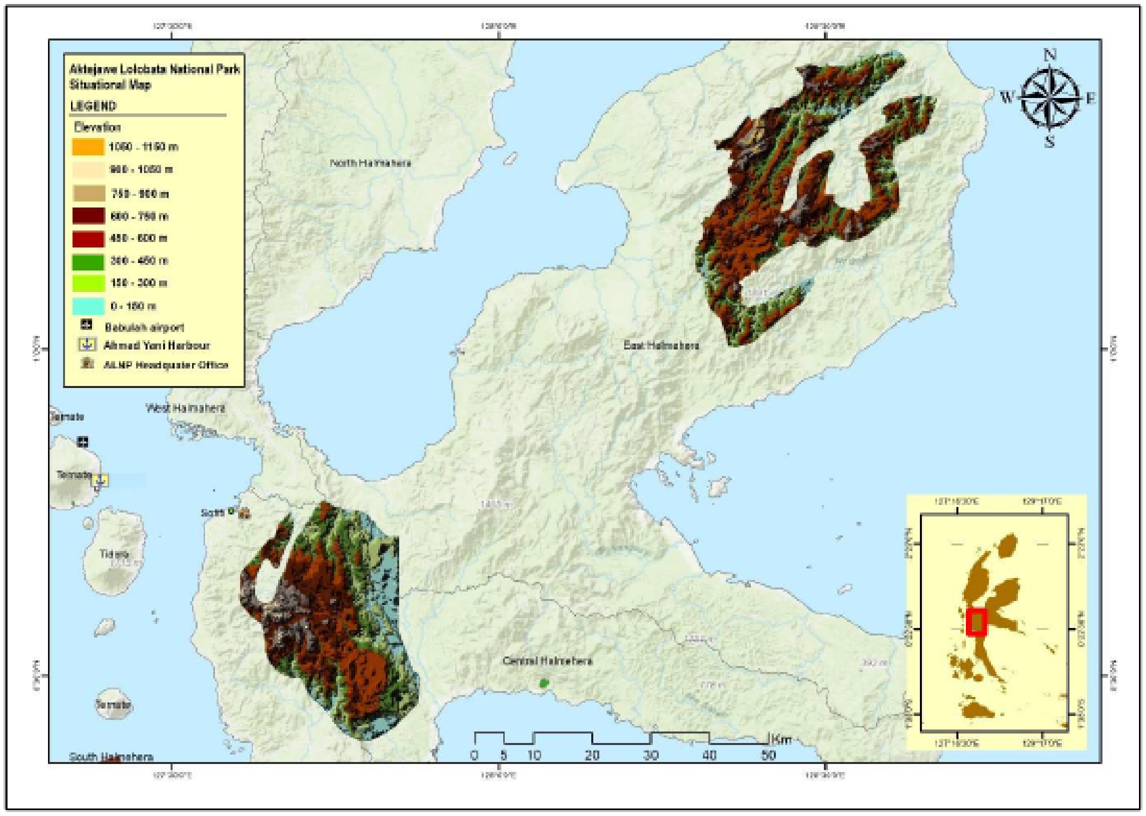

Figure 2.1 Situation of Aketajawe Lolobata National Park

An action plan in 1993 suggested the importance of one primary mainland protected area that included all habitat types in Halmahera Island. Therefore, in 1995, with cooperation between Birdlife Indonesia and the Nature Forest Conservation Agency (Section VIII-Maluku) a report entitled: "The urgent development of conservation area Aketajawe Lolobata in Halmahera" was delivered to the Ministry of Agriculture and Forestry (Birdlife Indonesia, 1993). This report highlights that as Halmahera people are mainly involved in the agricultural sectors, attention is needed to anticipate the possibility of social conflicts and to accommodate an equal area for development in the future. As a consequence of this report, the coastal region was eliminated and the total protected area of 73,000 hectares and 140,000 hectares, respectively for Aketajawe and Lolobata was proposed.

Local authority involvement is needed for national park development in Indonesia, particularly in national parks with more than two local administration areas. This was part of a government reform policy after the Reformation Era in 1998, which required power-sharing between state and local governments. In Indonesian policy, a national park is a conservation area that is part of a state forests, and local "authorities" participation's is required to anticipate policy overlap and allow programme collaboration to empower local communities near national parks. Therefore, in 2000, the Central Halmahera government agreed to convert some of their forest into a national park. Then in 2004, The East Halmahera, Tidore Kepulauan, and North Maluku governments followed this agreement. Finally, on 19 October 2004, the Indonesia Government, through the Minister of Forestry decree number 397/Menhut-II/2004, officially declared the creation of Aketajawe Lolobata National Park (ALNP) with a total area of around 167,300 hectares. This total area is divided into two management blocks. Aketajawe block (±77.100 ha), which is located administratively in Central Halmahera and Tidore Kepulauan Regencys (Figure 2.1). The large size of ALNP makes it the most extensive tropical rain-forest reserve area in Halmahera island.

2.2 North Maluku Visitors

The North Maluku province is an archipelago (Figure 2.1), for which Ternate is the economic centre, and Sofifi is the capital city. Babulah airport and Ahmad Yani harbour are the main gateways for visitors who arrive at this island. North Maluku is a popular tourism destination in East Indonesia. Some popular tourism activities in include diving, birdwatching and cultural tours. To support regional tourism, a visitor centre is available in the park office; this facility offers detailed information about park management, including publications, management reports, and other documents. ALNP provides part of this tourism information, including the requirements for international or domestic visitors entering the park area, and can facilitate local guides as requested by visitors. Tayawi and Akejawi are favourite tourist places because of the monitored bird sites to view and its beautiful landscape. Both locations can be reached in two or three hours by motorbike or car.

In total number domestic and international visitors, in 2017, were 193,829 and 734 respectively (see Table 2.1) (The BPS-*Statistics of Maluku Utara Province,* 2018). However, it is difficult to calculate exact visitors number in ALNP, because not all visitors report to the park office, and not many ALNP guides or officers are avalaible at the park entrance. The large number of visitors to North Maluku (presented in Table 2.1) reveals the challenges to ALNP management and encourages them to be more creative in attracting more visitors to the park. The more visitors come to ALNP, the more contribution to the national income from the tourism tickets, tourism tax and also give additional benefit to local people economic condition by involving villagers as local guide or providing a good accommodation. As ALNP tourism is still underdeveloped, not many visitors come to this area. Lack of information, accessibility and infrastructure are some big challenges in tourism development, so as part of solution, the management has agreed to include tourism as a one national park priorites that, includes with a focus on two tourism sites, Akejawi and Tayawi as tourism destination priorities that, include tourism infrastructure, empowering local people, and promotion of the sites. This immediate actions aim is to attract more visitors to come to the these priority sites.

Table 2.1 The number of international and domestic visitors in North Maluku province in 2017

Source. BPS-Statistics of Maluku Utara Province, 2018 https://www.bps.go.id/publication/download.html

2.3 Ecosystem Types

Land cover interpretation from Landsat 7 imagery-ETM (path/row 109/059, 109/060, 110/059, and 110/060), captured in 2007 with a spatial resolution (pixel size) of 30 m x 30 m, showed that approximately 88.66 per cent of the national park area was forested with primary forest at 85.94 per cent of the total area and secondary forest at 2.66 per cent of the total area. ALNP forests represents 7.5 per cent of the total mainland in Halmahera Island (Susanto, 2009). There are several habitat types on this island, including: low land evergreen tropical rain-forest, forest above alluvial sedimentation, freshwater swamp forest and seasonal swamp forest, tropical semi-evergreen rain forest, tropical montane forest, beach vegetation, mangrove forest, tropical subalpine forest (Poulsen, 1999). Geographically, ALNP's position is in the centre of Halmahera Island (refer to Figure 2.1). As a consequence, there are no significant effects from a sea climate on the park ecosystem. Refering to the ecosystem classification by Poulsen (1999), the ALNP ecosystem is divided into: low-land evergreen tropical rain-forest, freshwater swamp forest, seasonal swamp forest, and tropical montane forest. Typically, the Dilleniaceae and Dipterocarpaceae families are the plants mainly seen in the lowland forest (Park, 2016).

2.4 Biodiversity

2.4.1 Flora

Halmahera, as the biggest island in North Maluku, has a vital role in biodiversity protection. This island is the part of a biodiversity hotspot (Myers, 2000)). The Halmahera rainforest is a distinctive ecoregion (Wikramanayake, 2001)) and its biota also has conservation priority (Jepson & Whittaker 2002). As ALNP is the only national park in Halmahera, national park biodiversity might represent the total variety of Halmahera wildlife. In 2016, an ALNP database reported that 152 tree species have been identified, including 46 species of the Pteridophyta family, 19 species of the Arecaceae family, and 22 species of orchids, such as *Anoectochilus Bl.; Dendrobium Swartz.; Agrostophyllum Bl.; Bulbophyllum and.; Grammatophyllum Bl*. The Grammatophyllum family is renowned as being giant orchids. The updated reports mention that some national park plants have potential for further applications as herbal medicines. Recently, 78 species were listed as medicinal plants in ALNP, most of them are from the Fabaceae family (Lis Nurrani, 2015). Interestingly, the exact plant diversity in this area is still unknown, as limited research or study has been undertaken in this reserve. This situation could be challenging for researchers or scientists to discover new species that are valuable for scientific study. For instance, a joint study in 2011 by Bogor Botanical Garden, Indonesia, and Botanical Garden Fairchild, USA, found two new begonia species; *Begonia aketajawensis* [Ardi & D.C. Thomas] and *Begonia holosericeoides* [Ardi & D.C. Thomas] (Ardi et al., 2014) from the park area.

2.4.2 Fauna

Halmahera has a unique environmental profile. This island has a large land area in the northeast Wallacea region and is the biggest island in North Maluku. The Oxford dictionaries defines Wallacea as a zoogeographical area that encompasses a transition between the Australian regions and the Asian continents, and included the Moluccas, Sulawesi and the Lesser Sundas. This region has a great range of wildlife diversity and serves as a habitat for Wallaceae wildlife. Zoogeographically, this island is separated from the Asian and Australian continents. Therefore, Halmahera fauna have specific distinctive features. Typically, ALNP fauna have close relationships with Papua Island, e.g., hornbills, and birds of paradise (Ririmasse, 2014), rather than the western parts of Indonesia. In fact, some national park birds are identical to Papuan species, such as the Papuan hornbill *Aceros plicatus*. This bird is the only hornbill in Halmahera island, and is originally from Papua; there are also two endemic birds of paradise, *Semioptera wallacii* and *Lycocorax pyrrhopterus*. Limited terrestrial wildlife is found in this park, with 33 mammals in total which include 26 species of Chiroptera ordo (bats) and one endemic Halmahera primate, 43 reptiles, 21 amphibian, and 141 birds (ALNP, 2015). A group from Bogor Agriculural University (SURILI) also undertook an exploration in 2014 and discovered 77 species of butterfly.

Semioptea Wallacii (Wallace's Standardwing) is a well-known bird from the Wallacea region that is easy to find in this reserve area. As part of the Paradisaeidae family, this bird has a specific song and features. The male bird is more colourful with two unique feathers like the two flags or antennae and a slimmer body (23 cm) than the male (26 cm) (Figure 2.2) (Frith, C., Frith, D. & Sharpe, C.J., 2018). Interestingly, parrots are an endangered species in the Halmahera region. Nine species of the Psittacidae family have been identified in ALNP and three of them, *Loriculus amabilis, Cacatua alba, and Lorius garrulus* are endemic in North Maluku. *Cacatua alba, Lorius garrulus* and *Eclectus roratus* are the most endangered parrots in North Maluku. These are hard challenges for North Maluku bird conservation, due to the fact that many people keep parrots as their pets and a lack of law enforcement (Bashari, 2013). As part of an initiative by ALNP management, a parrot sanctuary programme began in 2015. This programme includes the construction of a sanctuary facility, raising public awareness and supporting local people to initiate parrot breeding as an addition to their income.

Image removed for Copyright compliance

Figure 2.2 Male Wallace's standardwing (Credit: Ansar, ALNP)

A recent comprehensive Birdlife Indonesia study, which was conducted, by Hanom Bashari and (Bas) van Balen in 2012 found a new bird species in Lolobata. It has been identified as *Coracina caeruleogrisea* (Stout-billed Cuckooshrike). Originally, this bird's habitat is in Papua Nugini, Mt. Yapen Papua or Aru Island Aru (Beehler et al. 1986, Coates 2001, Birdlife International 2012). In this report, they highlighted that the ALNP biodiversity is still a mystery. Further research, study or exploration is needed to discover the hidden treasures of Aketajawe and Lolobata.

2.5 Topography and Climate

2.5.1 Topography

The Aketajawe topographic conditions are primarily mountainous and hilly with a relatively small proportion of flat area. The elevation range on Aketajawe is between 70 – 1,100 m.a.s.l. (ALNP, 2016). Theoretically, there are three tectonic plates crossing Halmahera Island, namely the Philippine, Eurasian and Pacific plates (Hall, 1998). As an result, Halmahera is part of the 'ring of fire' in Indonesia. Even though there are no active volcanoes in ALNP, four active volcanoes are relatively close and surround this park, namely, Dukono, Gamkonora, Ibu, and Gamalama on nearby Ternate island. The slope classification is divided into several classes; Aketajawe has the largest proportion in the area with slopes between 8° – 15° for 33.59 per cent of the total area, followed by slopes between 3° – 8° for 29.29 per cent of the total area. Table 2.2 below shows detailed information about slope classifications in Aketajawe.

Table 2.2 Slope classifications in Aketajawe Block

No.	Slope Classification	Total Area (ha)	Proportion (%)
1	0 – 3	7.021	8.83
2	3 – 8	23.289	29.29
3	8 - 15	26.707	33.59
4	15 - 25	17.447	21.94
5	25 - 45	5.016	6.31
6	>45	25	0.03
Total		79.505	100.00

Source. Primary data, 2018

2.5.2 Climate

North Maluku has a tropical sea climate. As an archipelago province, the sea has a significant effect on the regional climate. The highest rainfall happens in December, with sunlight intensity around 86 per cent in February. The highest temperature is approximately 33°C in March, and the lowest is at 23°C in June. The highest average air humidity is 85 per cent in December (BPS North Maluku, 2018). A summary of climate information over a four-year period (2014 to 2017) is presented in Table 2.3 below.

Table 2.3 Average of temperature, relative humidity, atmospheric pressure, wind velocity, rainfall and sunrays from 2014 to 2017

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Source: Meteorology Climatology and Geophysics Agency of Babulah Meteorology Station, 2017

2.6 Sampling Area for the UAV Aerial Survey

The estimated total area of the Aketajawe block is around 77,794 hectares, which is too large for an aerial survey by UAVs. The biggest constraint on UAV flight is related to battery life (Hartley, 2017). The DJI Phantom 4 used in this study can fly for 25 to 28 minutes on a single battery, but this may be lower depending on aircraft elevation, wind speed, and the additional equipment attached. In a tropical forest survey, the problems are more complex, due to the potential loss of signal during the flight due to high interference from different topographic conditions and forest density. In the operation of Phantom 4, the data connection between aircraft and pilot may be interrupted if it is lost for more than 1 second (DJI, 2018). In anticipation of this issue; DJI has developed a Return to Base (RTB) or home point operation when the connection is lost and has added obstacle sensors to anticipate aircraft crashes. Considering with these drone performance limitations, aerial surveys focussed on areas with high human activity inside the park boundary in order to identify the current condition of people's activities in fragmented geographically such as Tayawi, Akejawi, and Tabanalou. In this study aerial surveys were carried out at three sites with detailed explanations following below:

2.6.1 Tayawi

Administratively, Tayawi is located in Koli village, Oba District, Tidore Kepulauan with the total area around 16,182 ha (ALNP, 2016). An interpretation of Landsat 8 imagery from 2016 showed that the most extensive land cover in this region was primary forest followed by secondary forest. Historically, the existing secondary forest happened as a result of forest harvesting in the period from 1980 to 1990. The impacts of these forestry activities are easy to find, and include logging roads and logging camps. After the concessions ended in 2004 and national park management began, the logging areas slowly recovered naturally with the domination plant being *Anthocepalus cadamba*. In an effort to accelerate this succession process, ALNP implemented restoration programmes in 2010 and 2013.

Tayawi is a renowned tourism destination. Havo waterfall and Wallace's Standardwing bird sites are favourite tourism spots. Uniquely, visitors here can easily meet indigenous tribes. A famous local tribe is the Tobelo Dalam "Togutil". They are a nomadic tribe; sometimes they will migrate from their settlement for hunting or to find a new plantation area. The Tobelo Dalam people in Tayawi are amiable and have relatively good relations with villagers or visitors. As a result, some of them are familiar with modern products, such as television, clothes, smartphones, and motorbikes. Most of them are living in a traditional/semi-permanent house (Figure 2.3).

Credit: Utomo, 2018

Figure 2.3 Temporary shelter Tobelo Dalam alongside the Tayawi River

However, in other park areas, untouched Tobelo Dalam still existed. This group always lives inside the forest, using primitive clothes, and they cannot speak Bahasa, the Indonesian language. Some Halmahera people believe that this group is an aggressive community and will avoid interactions with modern communities. The complexity of park management in Tayawi is mainly driven by economic interests since infrastructure development has becomes a national priority in Indonesia. The demand for construction material, such as stone, that are plentiful alongside the river, has increased significantly. Eventually, this massive exploitation could damage the Tayawi landscape and disrupt the Tobelo Dalam community.

2.6.2 Akejawi

Administratively, Akejawi is located in East Halmahera and it is a priority area for tourism development, as stated in the ALNP planning document 2016-2024. Following this policy, higher budget allocations for infrastructure and community services were made available. Support policies to strengthen community engagement in park management have emerged as a well-used strategy, with many developing countries implementing these policies (Resosudarmo et al., 2014; Rasolofoson et al., 2015). With adequate financial support, the villagers and the management have more flexibility in designing a programme. One such programme is related to ecotourism based on the idea that appropriate tourism development in national parks has the potential to contribute to conservation (Newsome, Moore and Dowling, 2013). Akejawi ecotourism aims to encourage local people to use local resources as part of tourism management as well as to protect local biodiversity, such as by providing a guesthouse for accommodation, local handicrafts for souvenirs, providing local transportation and developing experienced local guides.

Akejawi has a scenic landscape, and this area is habitat for more than a hundred tropical rainforest species so is suitable for wide-ranging tourism activities. The Wallace drummer rail is a favourite birdwatching target as well as Wallace's Standardwing. These endemic birds are listed as vulnerable species on the IUCN endangered species list. “No limit exploring” is the tagline for outdoor activity in ALNP because of the many unforgettable outdoor activities here, particularly for speleology and hiking. So far, around ten caves have been explored with many karst formations to see.

Historically, before ALNP establishment in 2004 some areas in Akejawi were protected forests; those that were adjacent to non-forest estate areas. In the 1980s, the non-forest estate was converted to a transmigration area by the Ministry of Agriculture, with the majority of migrants coming from Banyuwangi, East Java (ALNP, 2016). Twenty years later, the forest conversion to a national park in 2004 stimulated land tenure problems because of overlapping areas between the reserve and agricultural lands. This is not an easy problem to solve because some villagers have legal land certificates from the local authorities. In fact, the forest does not exist anymore and has been replaced by agricultural land. In order to address this problem, ALNP encourages more community participation, simultaneously opening discussions with related stakeholders for finding the best solutions for this land tenure issue.

2.6.3 Tabanalou

Tabanalou is situated in South Wasile District, East Halmahera, and is under the authority of the Binagara ALNP site office. In total, there are 93 villages surrounding ALNP, and Tabanalou is directly adjacent to the national park border (ALNP, 2016). Since the establishment of the national park establishment in 2004, the relationship between park management and villagers has been poorly maintained as some believe that the national park occupied their land illegally. People lack knowledge and have high resistance to the park’s management, which makes the conditions worse. As a result, information about Tabanalou is relatively limited. Human activities are relatively high in this area, and they mainly use the existing ex-logging roads to access the national park area to collect resin and carry out some agricultural activities. Recent forest monitiong by using the interpretation of Landsat 8 satellite imagery, identified some degraded areas occurring inside the park forest in Tabanalou, and some villagers' coconut plantations have been monitored near the park border. The three sites from the photogrammetric survey are shown in Figure 2.4, below.

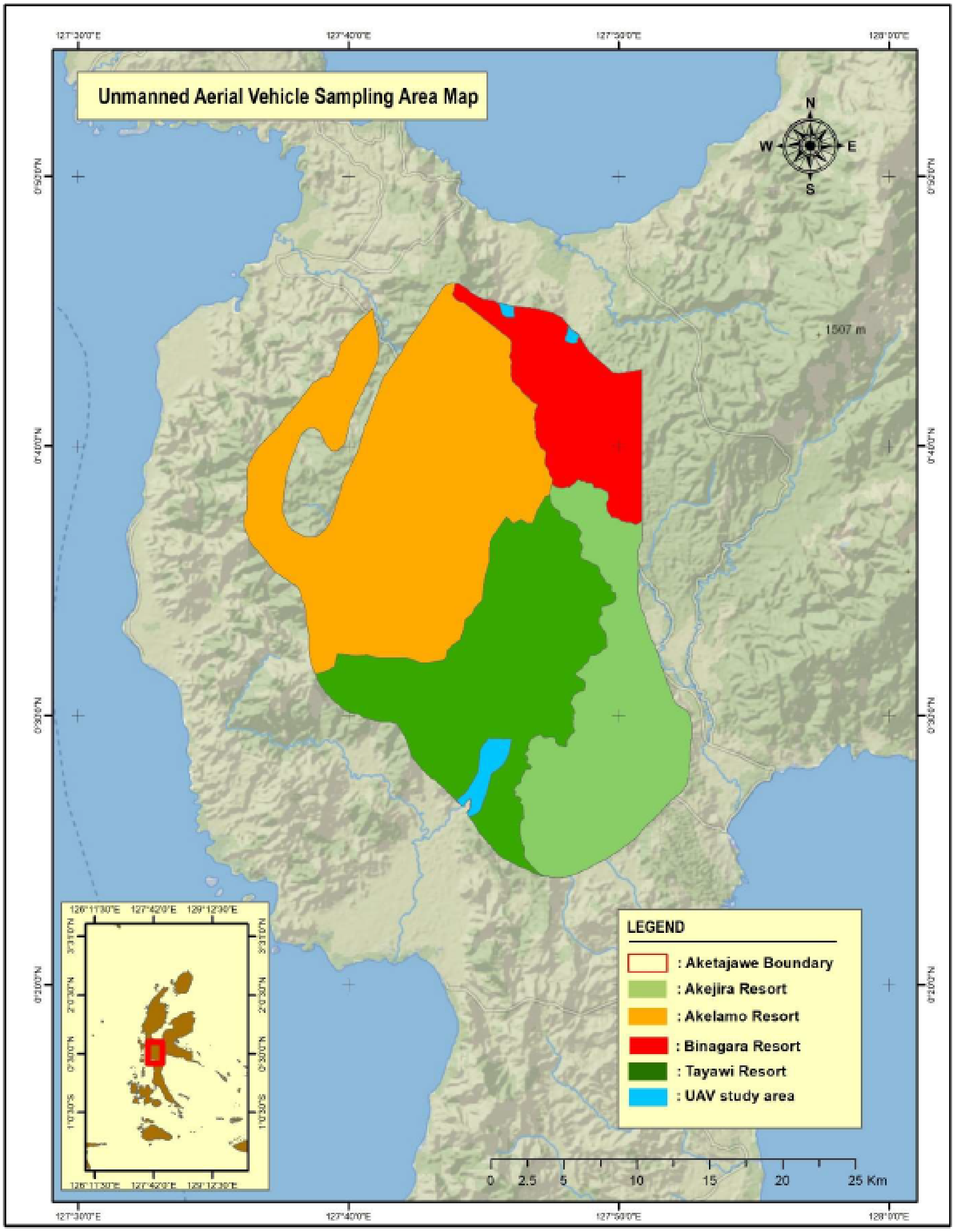

Figure 2.4 The unmanned aerial vehicle survey sampling area in Aketajawe, ALNP

2.7 Chapter Summary

The discussion, above, has provided information about ALNP, in general, the Aketajawe Block as study area location and three sites for photogrammetric survey. This chapter illustrated that human pressure is relatively high in Aketajawe because these human activities are happening more frequently; for example, indigenous people activities, agricultural land and some illegal activities. Beside the negative impacts from human pressure, Aketajawe has a scenic landscape and a unique biodiversity with the potential for tourism development, such as in Akejawi. Therefore, accurate spatial planning is essential to accommodate the people's needs as well as conserve Aketajawe biodiversity. This planning represents the potential of local resources, accessibility, and a clear border for regulating several national park objectives, including access for the local people. The following chapter gives detailed information and examples about the importance the spatial zoning classification, some Indonesia regulations related to zone management, and the application of UAV and GIS for the establishment of national park zoning.

Chapter 3

Literature Review

This chapter discusses some theoretical approaches to national park management, spatial planning, the application of satellite imagery and photogrammetric surveys for surveying forests, and the benefits of the GIS technique in formulating spatial data to create more effective zoning classifications. The fundamental theoretical framework used will be explained in detail in this chapter, while the research design/research framework is described in chapter 4. In order to understand the concept of national park spatial planning in Indonesia, this chapter briefly describes a definition of each zoning classification, zone objectives and some mandatory parameters that are used in zoning classifications, as stated in government regulations under the Ministry of Environment and Forestry. To elaborate on the spatial planning models, the application of GIS is discussed in detail in this chapter, including some fundamental techniques related to zoning classifications used when developing a new spatial model based on photogrammetric surveys and satellite data as well as software operation.

3.1 National Park in Indonesia

Globally, Indonesia is recognised as a mega-biodiversity hotspot (White & Martin, 2002), particularly for its variety of rare and endemic species and diverse ecosystem communities that contribute to conservation planning and management (Reid, 1998). In fact, while Indonesia's territory is less than 2 per cent of the total global mainland, its tropical forests provide habitats for 10 per cent of global plant species, 17 per cent of bird species, 12 per cent of mammals, 25 per cent of fish, 15 per cent of insects, and 16 per cent of reptiles (BAPPENAS, 1993). These valuable resources are considered a national asset, particularly with regard to sustainable resource management (Linkie, Smith, Zhu, & Martyr, 2008). The annual forest statistical report released by the Ministry Environment and Forestry in 2018, showed the total forest area in Indonesia as 120,601,155 ha, of which the total conservation area accounted for 18.3 per cent with 24.6 per cent of this being in protected forest (Pusdatin, 2018). The Indonesian government has full authority to manage this forest, which is equal to two-thirds of the total Indonesian mainland (Nurrochmat, Darusman, & Ruchjadi, 2014). The national reformation in 1998 gave significant power to state and local governments to share responsibility for forest management, as stated in 'Autonomy Government' Act number 32 in 2004. As a consequence, local governments have the authority to invite more investment in the forestry sector as long it gives benefits to their regional development and they retain biodiversity hotspot protection in their policies (Bank, 2006).

The Government of Indonesia implemented national park management in early 1980 by developing five areas as national parks to represent the different regions in Indonesia, namely: Komodo, Baluran, Gunung Gede Pangrango, Gunung Leuser and Ujung Kulon (Wiratno, 2001). The national park concept was adopted from Yellowstone National Park in the United States of America (MacKinnon, 1986). In the early development, the government focus on national parks was only for biodiversity or forest protection. During this period, the national parks made fewer contributions to regional development, and forest resource conflicts happened more frequently because local communities now had limited access to the natural resources and lacked public participation as forests were treated as of political interest (Dunggio & Gunawan, 2009). Eventually, public participation was integrated into park management by a Ministry of Forestry initiative that promoted collaborative management between reserve areas and conservation areas[1]. This policy influenced public perceptions of national park management as people now had more power to become involved and contribute their ideas as national park stakeholders. At the national scale, park management shifted from a security approach to be more *business friendly* with the intention of encouraging more public participation. The public voice now provides essential information to national park development, and business activities have been implemented in an effort to contribute to the regional or, even, national economic growth (Dunggio & Gunawan, 2009).

Importantly, Indonesia Act number 5, in 1990, and number 41, in 1999, legalised national parks as the official forest management model in Indonesia. This policy defines national parks as nature conservation areas, which have an original ecosystem, are managed by zoning management, and function for education and research, biodiversity protection and support ecotourism. The number of national parks in Indonesia has increased significantly from five, in 1980, to 54, in 2018 (Pusdatin, 2018). This shows the Indonesian government's concern

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[1] Indonesia Act No. 41 in 1999 define reserve area is mainly for biodiversity protection without or less human intervention. Conservation areas is a protected area for preserving biodiversity, and human intervention is allowed for sustainable forest utilisation and restoration.

with conservation and biodiversity protection as a national policy. Interestingly, after the presidential election, in 2014, the Indonesian system on forest and environment management changed, when the Ministry of Environment and the Ministry of Forestry merged into the Ministry of Environment and Forestry. This breakthrough set forestry as an integral part of the national environmental policy, which created a more effective, efficient and systematic organisation. One implication was simplifying the bureaucractic structure. Some national parks merged, such as Laiwangi Wanggameti National Park and Manapeu Tanah Daru National Park, into the Manapeu Tanah Daru Laiwangi Wanggameti National Park.

National park management in Indonesia involves the integration between reserve areas and conservation areas (Forestry, 2015). The relevant regulation described the requirements for developing some areas as national parks, for example: (1) one or more types of ecosystem to support ecological processes (Zahawi et al.), intact native natural resources and ecosystems (M. A. Wulder, Skakun, R.S., Kurz, W.A., and White, J.C), sufficient area for sustainable ecological systems, and; sufficient areas for several management zones, namely: core, wilderness, utilization, and others zones depending management planning.

3.2 Zoning Classifications in National Park Management

Zoning is the primary form of national park management that defines spatial land use purposes, imposes land use limitations and regulates natural resource use (Portman, 2007). The stakeholders may refer to spatial planning documents to contribute to national park management (Rotich, 2012). This spatial planning is the fundamental tool used in order to develop a territorial structure by allocating specific areas for specific management purposes (Goldberg & Horwood, 1980; Walther, 1986). Land use zoning has now become a standard practice in natural resource management around the world and is a standard tool in the administration and management of parks and protected areas (Eagles, 2002; Resources, 2009); (Wright & Rollins, 2009). Typically, zoning is used explicitly to delineate the various conservation values of the ecosystem and to regulate visitor use activities and capacities (Wright & Rollins, 2009). Zoning is also a fundamental method used in various sustainable tourism strategies (Lane, 1994) and is common in outdoor recreation planning in national parks around the world (Newsome, Moore, & Dowling, 2013).

In general, zoning consists of identifying specific zones for specific purposes, such as for biodiversity protection or areas where human activities are allowed to occur or increase (Sabatini, Verdiell, Rodriguez, & Vidal, 2007)). Another zoning classification could be implemented based on socioeconomic characteristics, regional representation, local wisdom, and government policy. The specific official classifications in Indonesia include: rehabilitation, traditional, historical or cultural, and religious zones, (Forestry, 2015). Zone development in national parks depends on the ecological value, the level of landscape uniqueness or geographical features, and includes some factors that are listed below (Nikijuluw, 2002):

1. The majority of public acceptance in terms of cultural, social and politic aspects;
2. Gradual implementation to evaluate public response and accommodate public opinions. It is a national park management strategy to evaluate the negative impacts from zoning development;
3. Economic and ecological management approach;
4. Efficiency and innovative application. Public participation is needed to encourage public involvement in park management;
5. Secure financial support or available funding or resources for programme implementation;
6. Provision of indirect benefits, such as increasing job opportunities decreasing poverty and inequality in park management in order to minimise conflicts of interest.

In general, there are no specific methods for zoning classification in the national parks; each national park has a specific management role, and the Indonesian government designates national parks based on the uniqueness of the area. The National Park background designations are used as the primary input in zoning classification (Thomas & Middleton, 2003). For instance, Komodo dragon protection is the main reason for the development of the Komodo National Park development, so preserving the Komodo's habitat becomes a priority in that park's zoning management. Another study explained other some important factors used in zoning classification, which includes : 1) protection of native species/high-value wildlife protection; 2) geographical features, such as slope, soil type, hydrology; 3) Accommodate various national objectives are accommodated; 4) illegal activities inside the national park are eliminated or minimised illegal activities inside the national park; 5) support for the national development policy; 6) public acceptance; 7) are in line with national land use planning; and 8) Accommodate existing local community needs are accommodated (Thomas & Middleton, 2003).

The Indonesian government regulates the zoning management of reserves and conservation areas by regulation number P.76/Menlhk-Setjen/2015. This policy was released by the Minister of Environment and Forestry to define zoning classification criteria. As outlined in table below (Table 3.1), there are at least three zones in Indonesian national parks, namely, core, wilderness and utilisation zones. Other zones might be added depending on the ecological value in specific areas, their socio-economic conditions, and existing local culture. These additional zones may include rehabilitation, traditional, religious, specific, and historical and cultural zones. This regulation defines zoning classifications in national parks into several purposes based on ecological and sociological indicators (Table 3.1).

Table 3.1 Description and criteria in national park zoning

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Source: Ministry of Environment and Forestry P.76/Menlhk-Setjen/2015

Importantly, this regulation also provides essential information on the management focus of each zoning type and some suitable activities. The park management can use the regulations to provide their guidelines for their spatial planning and the relevant policies or programmes. Precise information is needed to anticipate mismanagement in the field, or, even, with the stakeholders/communities.

The Directorate General of Forest Protection and Nature Conservation declared an updated zoning regulation in the reserve and conservation areas (P. 11/KSDAE/SET/KSA.0/9/2016). This regulation provides technical aspects for zoning classification, and includes stakeholders' involvement and their responsibilities, development stages, financial, methods, and procedures for the legalisation process. Figure 3.1 outlines the stages of official zoning development in Indonesia. The initial step is creating a working group. This group consists of national park stakeholders, such as NGOs, the local government, villagers' representatives, scientists and national park officers. The working group has responsibilities to develop the draft zoning documents and, as part in this process, the working group will collect data related to the ecology, socioeconomics, and hold focus group discussions. The working group will then analyse the data collected in order to create a draft zoning classification, including a spatial planning map. Public consultation is the next step, and in this stage, some feedback and evaluation from the national park stakeholders is delivered to the working group who then revise the zoning draft.

After the public consultation and draft revision, a letter of recommendation from the local government or authorities is needed as a compulsory requirement for legalisation from the state government, before a legalisation assessment is conducted to evaluate the zoning draft. If there is any missing information or incomplete requirements, the state government gives the opportunity to the working group to make revisions or create a second draft. The completed zoning document is approved by the state government and is then delivered to the relevant national park stakeholders. In the final stage, the national park head office follows up on the zoning document by constructing the borders of the zoning in the field.

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Source: Ministry of Environment and Forestry P.76/Menlhk-Setjen/2015

Figure 3.1 Zoning development stages in Indonesia

3.3 Geographic Information Systems

The spatial planning processes require multiple land evaluations in order to meet multiple land use objectives. This is called a multi-objective process, because it has many goals so, as a result, multiple criteria are needed because the land suitability for each zoning type is determined by a combination of several factors (Villa, Tunsei, & Agardy, 2012). These factors mainly have a geographical distribution or spatial format, which is best represented by thematic maps. In this respect, the implementation of a geographic information system (GIS) is fundamental to elaborating the multi-criteria spatial analysis, which is highly regarded in spatial planning establishment (Keisler & Sundell, 1997). This software is proven effective in providing qualitative and quantitative information for effective decision-making and is often used in multi-criteria analysis for zoning classification. GIS has the ability to examine national park areas as per the management objectives, and this is relevant for spatial planning (Villa et al., 2012). The following section will explain some of the fundamental spatial data and the ability of GIS to formulate these data into suitable spatial planning attributes.

3.3.1 Multi-criteria Analysis

Multi-criteria analysis is a widely-known method for zoning classification (Keisler & Sundell, 1997). This method has proven to be effective in providing qualitative and quantitative information for effective decision-making. The GIS software has the ability to divide national park areas for management purposes; which is relevant to spatial planning in zoning management (Villa et al., 2012). The ecological problem of increasing human populations has always been a stressor in natural resource management (Degorska, 2005). This problem is complicated by the reducing number of reserve areas, reduction in natural areas of high recreational value, barren lands for agricultural purposes, and loss of biodiversity values (Vlek & Steg, 2007). Impact assessment methods that allow data collection for large areas within a short time period is needed; these methods should be able to be carried out quickly to allow frequent updating of existing datasets. GIS is a powerful tool for identifying spatial change over a period of time, while photogrammetric images can provide the current environmental conditions. The advantages of using a combination of photogrammetry and GIS for spatial planning is the opportunity to gather readable visualisations of spatial changes and phenomena in specific areas (Markiewicz & Turek, 2014). More importantly, due to the complexity and a large number of datasets, decision-making on spatial planning may be more effectively analysed by integrating UAV images with GIS software. UAV images are useful beyond just the identification of existing developments or the analysis of land use changes. Data acquired with low-altitude photogrammetry are comparable with large-format aerial photogrammetry (Bakuła & Ostrowski, 2012). When used by the authorities, UAV data might become a tool to simplify the detailed diagnosis of development areas; thus, helping to counteract negative trends, such as land occupation.

Moreover, the detection of land cover changes is crucial for developments in the analysis of remotely sensed data (Anderson, 1977; Anuta & Bauer, 1973; Aplin, 2004; Nelson, 1983; Singh, 1989). Recently, high-resolution imagery has provided valuable opportunities for forest ecosystem monitoring (Falkowski, Wulder, White, & Gillis, 2009; Hay, Castilla, Wulder, & Ruiz, 2005; M. A. Wulder, Hall, Coops, & Franklin, 2004) and also in urban areas (Hay et al., 2005; Herold, Scepan, & Clarke, 2002). To address the need for high-resolution imagery, satellite sensors over the last ten years have become a potential source of providing high-resolution data (10-m resolution) with more advanced capabilities, such as Quickbird, IKONOS, Geo-Eye-1, WorldView-2. Those resources are beneficial for ecological studies (Fretwell et al., 2012). However, there are three main operational constraints in the application of satellite imagery: (1) cloud contamination, which can potentially obscure features of interest; (2) a high cost per scene; and (3) geometric distortion, as radiometric pixel properties and suitable repeat times are often only possible if oblique view angles are used (Loarie, Joppa, & Pimm, 2007). In theory, these surveys can be done on demand, but, in practice, data acquisition is costly, meaning that regular time-series monitoring is operationally constrained.

Several types of spatial data derived from UAVs images could be used in many land use applications, such as (Breetzke, 2015):

- Orthomosaic images: A single image on a particular area of interest. The UAV takes multiple images with an on-board camera. These images are run through the UAV's software, are georeferenced, stitched together, and a single output image of the area of interest is produced. This output can be compared with other land cover imagery for land cover changes.

- Digital surface model: It is interesting to note that UAVs mainly use photography so they can only produce a digital surface model (DSM) as the image capturing process cannot penetrate through dense vegetation.
- Contour generation: Setting the UAV flying altitude to 120 m above ground, combined with a camera focal length of 55 mm, allows ground resolutions of 3-4 cm pixels to be obtained. As a result, 3-4 cm contours can be generated. In general, a 50 cm contour generation was normally the standard interval.

3.3.2 Land Cover

As part of multi-criteria analysis, land surface information is needed to quantify the estimation of forest cover. Land cover is defined as an identifiable place on the Earth's surface, including all biosphere attributes above or beneath this surface, encompassing those of the near-surface climate, soils, terrain forms, hydrology (including rivers, lakes, shallow, marshes, and swamps), and the close to surface sedimentary layers related to groundwater preservation (FAO, 1995). Wildlife populations, the pattern of human settlement and the physical effects of past or present human activities, such as water storage, terracing, roads, buildings, and drainage structures, biodiversity losses, deforestation, global warming and increasing natural disasters, have all resulted in land cover changes and human/nature modifications (Mas et al., 2014). Ecological problems are frequently related to land cover changes. Therefore, the availability of land cover data will provide essential information for certain policies used in environmental planning and management in the future (Soni, Sandeep, Purushottam, Ashutosh, & Abhishek, 2015). The growing population and increasing socio-economic necessities create pressure on land use/land cover. This pressure results in unplanned and uncontrolled changes in land use and land cover (Brown, Daniel, Robert, Steven, & Karen, 2004).

Turner et al. (1990) mentioned that land cover is the biophysical Earth's surface and underneath area. In another definition, land cover is related to physical features of space, and the observed geographical features cover above the earth surface (Gregorio & Jansen, 1998). This definition enables multiple geographical categories to be differentiated, such as areas of vegetation (lawns, fields, trees, and bushes), bare soil (open area/critical land), and hard surfaces (building, rocks, mountains), wetlands and bodies of water (rivers, watersheds). This description has an effect on land management classification in general. The term land cover is "observed", meaning that the observations can result from various sources with different distances between the observer and the earth surface, such as aerial photographs, UAV surveys, the human eye, and satellite sensors. Natural disasters, such as landslides, floods, forest fires, severe weather, climate change and ecological processes might accelerate land cover modification. In general, human activities, agricultural systems, forest harvesting, infrastructure development, public housing and urban/sub-urban construction development affect land cover transformation today (Meyer, 1995). The motivations behind these human activities might be demographic, economic, technological or other relevant factors.

3.3.3 Factors Influencing Land Cover Change

Multiple interrelated factors over different temporal and spatial scales can influence the rate of land cover change. Several theories in natural and social science have tried to explain and describe in more detail about land cover change. Land cover change happens initially on land owned by individuals when the landowners decide to change to another land-use/utilisation as their desirable type (Briassoulis, 2000).

Cumulatively, the individual land-use change decisions create land cover changes at higher spatial levels. In the case of Indonesia, the problem is more complicated because of the overlapping policies in Indonesian land management. For instance, in Akejawi Village, there are transmigration areas that overlap with the national park area. Villagers had claimed their agricultural land and occupied park areas for land clearing purposes. This small example shows that personal motivation or individual traits could contribute to land cover changes due to economic conditions and sociological aspects, as well as a lack of government policies. On a national scale, massive forestland clearing for palm oil plantations has driven major deforestation in Indonesia. Currently, there are 14.03 million hectares of oil palm plantations, of which five million are owned by smallholders (Pusdatin, 2018). Globally, Indonesia is the world's leading supplier of palm oil and this has reached more than half of the world's production (FAOSTAT, 2015). Jointly with Malaysia, both countries supply more than 80 per cent of the global market (Pittman, Alice, Kimberly, Lisa, & Alexandra, 2013).

Both societal and biophysical factors at the macro and micro levels are independent but are also interrelated. For instance, local climate conditions are affected by the global or regional climate, and the forest ecosystem types, and soil characteristics are influenced by regional ecosystems and soil types. In the context of land clearing, individual landowners' decisions may be determined by the decisions of people or organisations at a higher level, so that land cover change often happens because of a decision from the higher level (Blaikie & Brookfield, 1987). For instance, some Indonesian people in Sumatra Island cut the forest for their oil palm plantations and, consequently, of Indonesia setting a target to become the biggest oil palm producer in the middle of 1990.

3.3.4 Land Cover Classification

Land cover identification is an important part of natural resource management. It provides essential information that affects and relates to multiple parts of the physical environment and humans. For instance, land cover change is regarded as the major variable or indicator of global changes impacting ecological processes (Vitousek, 1994) and is also associated with global climate change (Skole, 1994). It is widely recognised that there is a significant relationship between land cover changes and soil erosion on sustainable land use (Douglas, 1999) and levels of biodiversity (Chapin, 2000). As well as these facts, understanding the significance and predicting the impacts of land cover changes are fundamental parts in natural resources management or spatial planning. In general, maps/spatial form provide such data. Therefore, the ability to provide accurate data is essential (Belward, 1999). Remote sensing is widely recognised as an attractive source of thematic maps, which visualise land cover into a map. This map is a representation of the Earth's surface that is highly consistent and spatially continuous, as well as available at a range of temporal and spatial scales. Thematic mapping resulting from the classification of remotely sensed data for image classification is an important input to spatial planning (G. Foody, M, 2001). Either spatial analysis or visual interpretation could be employed to develop these data. Image classification techniques could be based on spectral similarity (unsupervised) or characterised spectrally (supervised).

The categories for land cover classifications in this study were based on the Land Cover Monitoring Guidance from the Directorate Planning Agency in the Ministry Environment and Forestry Indonesia Number P.1/VII-IPSDH/2015 on 26 May 2015 (see Table 3.2).

Table 3.2 Land cover classification based on the Ministry of Environment and Forestry

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Source: Ministry Environment and Forestry Indonesia Number P.1/VII-IPSDH/2015 on 26 May 2015

Land cover classification is the fundamental analysis in this study. Image classification is different from classifications in GIS analysis. In GIS, users create groups or classes of features from the statistical analysis of the attributes. However, in image classification, pixels with similar spectral signatures are classified using statistical measurements across several bands of an image. A group or class of pixels with the same spectral signatures can be treated as a feature in their geometric relationships. More importantly, the level of interpretive skills and knowledge of the analyst are a fundamental part of image classification. This type of analysis is a computationally intensive process and can take long periods to run.

3.4 Satellite Imagery

Land cover analysis can be carried out by the interpretation of satellite imagery. Remotely sensed data from satellites can be gathered continually over the same area, which is very useful to identify or monitor land cover changes in the conservation area, and greatly contributes to natural resource planning (Dash, 2005). Nowadays, the development of satellite technology has been growing rapidly, and imagery products vary in spectral and spatial resolution, temporal and geographic coverage, and cloud cover. As consequence, imagery product prices vary depending on their specifications and abilities (Turner, 2003). Satellite imagery can be used for several purposes and has become familiar technology not only for experts but also for lay communities. In natural resource management, satellite imagery provides essential information in resource evaluation and assessment for decision makers (Hudak, Evans, Smith, & Alistair., 2009). In addition, satellite observations may provide information about the mechanisms and features of earth information, such as pressure systems, cloud patterns, wind direction, climate predictions, and rainfall patterns (Sillmanna et al., 2017). High-resolution imagery can be used for natural resource monitoring or, even, human rights advocacy or documentation. Imagery is useful for evaluating or assessing the impact of forced displacements, violent conflicts, and another social conflicts in remote or inaccessible areas, such as Sri Lanka and Burma (AAAS, 2009). This is possible because high-resolution imagery has been developed over a period of time, so has the ability to provide information on about the impacts on the infrastructure, public spaces, and other identifiable features. This study used high-resolution satellite imagery SPOT 7 to fill the weakness of low-resolution imagery Landsat 8. A description of these types satellite imagery characteristics and specifications are discussed in the section below.

3.4.1 SPOT 7

A French company launched the SPOT (Système Pour L'Observation de la Terre) satellite in 1985. The latest version of this imagery is SPOT 7, which was launched by AIRBUS Defence and Space, on 30 June 2014, at the Satish Dhawan Space Centre, India by a PSLV launcher (Spaceflight, 2014). Technically, this commercial imagery has a resolution 1.5 metres and four multi-spectral bands (four bands), namely, blue (0.455 µm – 0.525 µm), green (0.530 µm – 0.590 µm), red (0.625 µm – 0.695 µm) and near infrared (0.760 µm – 0.890 µm). Because SPOT 7 has a resolution of ≤5 metres, this imagery is categorised as high-resolution imagery (Boyle et al., 2014).

3.4.2 Landsat 8

Landsat is free satellite imagery and is popular in scientific communities. This satellite helps to improve our understanding of the Earth, particularly by providing better knowledge of its surface features, such as tropical forests, coral reefs and glaciers. The updated version of this family is Landsat 8, which was launched on 11 February 2013, with an extended payload fairing (EPF) from Vandenberg Air Force Base, California. The Landsat 8 imagery payload includes two sensors, namely, a thermal infrared sensor (TIRS) and an operational land manager (Colomina & Molina., 2014). Both sensors provide seasonal global coverage with 30 metres spatial resolution (SWIR, NIR, visible), 15 metres (panchromatic), and 100 metres (thermal) (NASA, 2018). The 30-metre spatial resolution images are detailed enough to identify human-scale activities, such as agricultural irrigation, urban growth, road construction, and deforestation/land cover changes. By providing a baseline understanding of the Earth's surface for over forty years, Landsat allows scientists to identify and evaluate environmental changes over time. The continuous coverage of Landsat data has become an essential global reference for scientific study related to natural resources and land use. Recently, NASA and the United States Geological Survey (USGS) developed this imagery. NASA was involved in the design, launching, construction, and on-orbit calibration phases during the Landsat Data Continuity Mission (LDCM). USGS took over the operations on 30 May 2013, and this satellite is favoured, becoming Landsat 8. USGS has responsibilities for post-launch calibration measurements, operations, product generation, and data archiving in the Earth Resources Observation and Science (EROS) Centre (USGS, 2018).

3.5 UAV Photogrammetry

Beside satellite imagery, photogrammetry is an alternative method for land cover identification in the modern era. In land surveys, photogrammetry can be described as the scientific approach to making reliable measurements using digital photo imagery or photographs to locate and identify land surface information (Whydot, 2013). One reliable technique for taking above surface features is UAV photogrammetry, which is a platform for photogrammetric measurements, which operates by remotely controlled, semi-autonomously or autonomously without pilot available inside the aircraft (Eisenbeiß, 2009). In general, UAVs are equipped with a photogrammetric measurement system, including, still-video/video camera, or thermal/infrared camera system, or LIDAR system, or a combination of these systems. Some commercial UAVs, such as the Phantom 4, allow the detection and tracking of the position and orientation of the attached sensors in a local, regional or global coordinate system. Therefore, UAV photogrammetry is widely known as a new technique for photogrammetric measurements, with several potential applicable applications. The following section gives important information about UAV operation, UAV photogrammetry data collection and data processing will be used in this study.

3.5.1 Unmanned Aerial Vehicles

Unmanned aerial vehicles (UAVs) are defined as aircraft designed to be operated without a pilot on board, can be operated by remote control, and can fly semi-autonomously or full autonomously (Eisenbeiß, 2009). Initially UAVs developed for military purposes, especially intelligence and surveillance activities (Kim et al, 2015). UAV applications have grown rapidly for various civilian purposes, including transportation, agriculture, forestry, marine and leisure activities and with many potential developments in the future. The significant advantages of UAV technology compared with conventional surveys by manned aerial surveys are its relatively low cost and the ability to gather updated/real-time geographical features in a study area for further analysis (Everaerts, 2008). Despite the fact of public concerns about legal regulations and individual privacy rights (FAA, 2013), this technology is being applied more frequently. In scientific studies, UAVs can be used in a diverse range of applications, such as archaeological surveys (Bastonero, Donadio, Chiabrando, & Spano, 2014), pipeline inspections and mapping (Siebert & Teizer, 2014), river and pedestrian route mapping (Room & Ahmad, 2014), geomorphological surveys (Tonkin, Midgley, Graham, Labadz, & Jillian, 2014), geological exploration (Vasuki, Holden, Kovesi, Micklethwaite, & Steven, 2013), identification of land erosion (d'Oleire-Oltmanns, Marzolff, Peter, & Ries, 2012), and ice cover monitoring in Antarctica (Lucieer, Jong, Turner, & Darren, 2013). A recent strategy to detect land cover changes effectively addresses the limitations of conventional remote sensing approaches in forestry. UAVs may provide an accurate means for forest inventories. Several authors have already addressed the benefits of UAV-based remote sensing methods for the assessment of ecologically relevant geospatial data, in general, as they represent a new type of low-cost remote sensing platform (Grenzdörffer & Teichert, 2008).

In general, UAVs provide up-to-date imagery over areas of interest and can obtain sufficiently high-spatial resolutions for visual identification and mapping of vegetation (Ishihama et al., 2012). These aircraft can produce 5 cm resolution images that allow the detection of individual plants, types of vegetation, gaps between vegetation, and patterns over the landscape, which have not been not previously possible with standard remote sensing data (Figure 3.2) (Rango, 2009). In forest surveys, these aircraft might help the forest ranger to monitor their supervision area, or to detect illegal activities, such as the impact of illegal logging, land occupation or illegal mining. These efforts might reduce the risk to park personnel and can provide more accurate field information that it is useful for further action.

Image removed for Copyright compliance

Figure 3.2 Comparison of satellite piloted aircraft, and UAV imagery on the Jornada Experimental Range over the same area to illustrate patterns, patches, and gaps at different resolutions as adapted from (Rango et al., 2009)

3.5.2 UAV Operation to Identify Forest Structure

One of the most powerful advantages of using UAVs for forest surveys is acquiring real-time data, which give precise and current information that is useful for decision makers. The forest's structure can be measured using UAVs through a method known as structure from motion (SFM), which constructs 3D models (point clouds) from pictures taken of the mapping area from a vast number of locations and with a high degree of overlap (Figure 3.3, below).

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Figure 3.3 A 3D model produced from the structure from motion. (A) A recovering secondary forest at the left and top of the image, and oil palms at the right of the image; (B) A false colour image showing an automated ground classification, with the ground shown in brown, outliers shown in pink, and all other pixels shown in white; (C) A canopy height model produced from the 3D model by subtraction of the digital elevation model from the digital surface model (Swinfield, 2016). https://www.wildlabs.net/resources/case-studies/can-uavs-beused-measure-forest-quality

Various automated methods are suitable for analysing UAV data, and these can be applied to structure from motion (SFM). On the other hand, SFM point clouds tend to produce erroneous digital terrain models (DTM) because they tend to have far fewer ground returns than those obtained from LiDAR (Zahawi et al., 2015) (Wallace, Lucieer, Malenovský, Turner, & Vopěnka, 2016). Consequently, orthophotographs are needed to remove the terrain relief to provide geometrically correct data (Siebert & Teizer, 2014) (Kim, Lee, & Choi, 2015). The forest structure/canopy has a positive correlation with some forest quality metrics, including carbon content, biomass and successional status. It is also provides a fundamental indicator for analysing forest quality (e.g. land cover, tree size density and tree carbon counting) (Keith, Mackey, & Lindenmayer, 2009). More importantly, forest structure measurements can be used as an indicator of biodiversity (Lindenmayer, Margules, D. B. Botkin, Biology, & Aug, 2007). However, these are dependent upon the accuracy of the canopy height models (CHMs) by(Nurrochmat et al., 2014). Their study highlighted the importance of assessing the uncertainty of DTMs and CHMs, which are a function of canopy density and the mapping data (e.g. percentage of overlap).

Forest structure (composition) is another fundamental forest quality metric, which might vary independently of forest cover. UAV images or satellite data can potentially develop more precise results to predict forest biodiversity and wildlife composition (G. P. Asner & Martin, 2009) (Fricker, Wolf, Saatchi, & Gillespie, 2015). This happens through the use of multi-spectral cameras (e.g. RGB or RGB+NIR), and the resulting data from these sensors can be utilised to convert meaningful estimations of species identity or diversity. The benefit of RGB sensors is that they can produce significantly high-resolution images and, potentially, include many colour variations and textural pattern information that may be of use. Vectors of the values generated from typical image analysis convolutions can be extracted from mapping images and input alongside training information (i.e. species labels) to machine learning algorithms, which attempt to learn the best classifications for the given vectors (Swinfield, 2016).

3.5.3 UAV Operation for Aerial Survey

Principally, UAV aerial surveys are not different from the same process used by crewed aircraft or larger aircraft, but there are some specific technical features specific to UAVs. In relatively large area mapping, a UAV's flight speed is generally between 20-30 m/s with altitudes ranging from 100 m to 500 m above the ground surface (Colomina & Molina., 2014). Different types of UAV have different specifications, but, in general, UAVs will capture the image using 10-20-megapixel non-metric digital cameras (NDMC), with a range of focal lengths of between 15-50 mm. They produce good pixels of the ground (GSD) of between 5 and 20 cm (Colomina & Molina., 2014). In order to produce a correct Image orientation and colour reproduction, camera calibration is needed to reduce lens distortion (Fraser, 2018), UAV surveys could produce high-resolution multi-spectral images in relatively large areas, such as those produced by (Gini, Passoni, Pinto, & Sona, 2012). A study also showed the advantages of UAV methods to gather data at a scale of 1:1000 for regional plans in the Shanxi Province (China). The studies above underlined that the implementation of UAV technology for various purposes may produce a high-precision aerial image and has excellent prospects in future developments.

In conventional aircraft, a pilot reacts typically to conditions and controls the aircraft. With unmanned vehicles, radios, radar and cameras are used to provide a remote pilot with the conditions (Vergouw, Nagel, Bondt, & Custers, 2016). UAV sensors are a significant component for identifying the surrounding information and providing information on how the UAV is flying. The central computer then processes this information. Similarly, with humans, a UAV sensor will provide a pilot with information about the terrain and conditions to help with guiding the aircraft safely.

The UAV's computer uses software instructions telling its small motors to move above the ground surface, so the aircraft changes direction. More importantly, the computer is also gathering information about the UAV's location or where it should be, and then the computer will give directions to the aircraft to correct itself using a global positioning system (GPS) (Clarke, 2014) to provide the UAV with its location. UAVs also have different levels of autonomy depending on whether the system is autonomous or automatic. Automatic systems are defined as a pre-programmed system, which follows the pre-programmed set of instructions and also includes automatic flight stabilisation. In contrast, autonomous systems can make independent decisions by following pre-programmed settings to deal with unexpected circumstances. Automatic systems do not have this freedom of choice (Bürkle, Segor, & Kollmann, 2010).

3.5.4 The Benefit and Challenges of UAVs Aerial Survey

Unmanned aircraft development has become a hot topic in the aerial survey community. This technology has come under attention as a breakthrough technology in topographic mapping over the past ten years for four main reasons: better safety, higher product quality, lower cost, and better mobility in relatively small areas (Bloom, 2006). Some significant improvements in UAV technology have been made to obtain these advantages, such as redesigned UAV shapes, reducing UAV weight and the attached componentry, take-off and landing operational procedures, skilful and experienced UAV pilots, photography and flight licenses, and wide range signal telecommunication limits (Saadatseresht, Hashempourb, & Hasanloua, 2015).

UAVs makes aerial surveys easier and faster in small areas, such as farmland or a specific area in the forest. Other advantages and some disadvantages of UAV aerial survey are presented in Tables 3.3 and 3.4, as follows:

Table 3.3 Advantages UAV photogrammetry for aerial survey

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However, despite the advantages of UAV technology for aerial mapping or field operation. UAVs face some limitations in their application. Some of them are described below in several categories:

Table 3.4 Some Disadvantages and challenges for UAV aerial survey

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3.6 Photogrammetric Software for Data Collection and Images Processing

A proper photogrammetric software is mandatory to collect and analyse the images that resulted from the aerial survey. Some this primary software can be downloaded as a free app in play store, but license activation is required for orthomosaic software, because most of them is not open source.

3.6.1 Pix4Dcapture for Flight Planning

Proper flight planning is fundamental for photogrammetric surveys. Precise coordinates from each image should be determined in order to achieve suitable ground sample sizes and overlaps between images. UAV aerial surveys require at least an 80 per cent overlap of images to obtain dependable and accurate results (Figure 3.4) (Zietara, 2017). This is because of the use of low-cost UAVs with instability possibilities in the aircraft that can cause disruptions in the imaging process. A flight plan must also take into account the required level of ground resolution, usually referred to as the ground sampling distance (GSD). GSD is the range between two consecutive pixels centres in the correct order on the ground (Pix4D, 2018). GSD is fundamental, as it represents the resolution of the images from the aerial survey imagery. The larger the GSD number, the lower the image resolution, which relates to lower visibility or fewer details. The GSD setting is related to the aircraft position, particularly the aircraft’s elevation. The higher the elevation of a UAV, the larger the GSD number, which means a lower image resolution.

Image removed for Copyright compliance

Source: Pix4D, 2018

Figure 3.4 Illustrations of side-lapped and overlapped images in the photogrammetric view. https://support.pix4d.com/hc/en-us

The GSD can be set using flight planning software such as the Pix4D Capture application. This app is an open source platform that runs on either IOS or Android devices and is designed to facilitate taking groups of images with sufficient overlaps to allow further orthomosaic analysis. It is compatible with several DJI and Parrot manufacturer products. In DJI, Pix4DCapture is strongly recommend to use or to connect with a Ctrl+Dji app for aircraft location orientation and detection before creating a flight plan in Pix4D Capture. Pix4D Capture is a very handy app; users can set the aircraft altitude and flight plan quickly, and this app automatically informs the users about the percentage image overlap, drone battery condition, flying time estimation, and the total satellites detected. Users have the freedom to set their flight plans, but this app will give a notification if the plan is too large or out of drone coverage/performance. In photogrammetric data collection, this app shows a notification when taking each image (it sounds like bip bip) and gives a warning if the UAV loses the GPS signal or if the aircraft is facing some disruption. In addition, there are two important parts of planning the final product. First, is a navigation plan. This plan consists of a map with places where the images should be captured. This map represents the areas of interest with some potential obstacles in the flight plan. Second, is a sheet with camera parameter specifications such as flying altitude, flying speed, image scale, the dimensions of the area of interest (Kraus, 2007). These data can be achieved at the same time by Pix4D Capture application. Moreover, this app allows the users to import the list of coordinates to the system so a fully autonomous mission can be performed.

3.6.2 Drone2Map for Orthomosaic Images

Drone2Map adopts the principle of photogrammetry to convert pictures into a 3D digital surface Model (DSM), a 3D point-cloud, and orthomosaic images. An orthomosaic image is a picture of several overhead pictures and is corrected for scale and perspective, which means it has the same problem of a lack of distortion as a map (Hawkins, 2016). In the analysis process, this software initiates by keypoint identification in several overlapping images. Points of interest, known keypoints, are locations that are easily distinguished, such as a corner of a car that Drone2Map can identify in multiple pictures (Figure 3.5). Recognising the camera orientation, position and properties like focal length, it then projects a line from the camera through a keypoint (Figure 3.5). This is repeated for the next images, until a triangulated location of that keypoint in 3D space is created, which is important for creating 3D point clouds and orthomosaic images.

Image removed for Copyright compliance

Figure 3.5 How photogrammetric software calculates the location of the object by recognising matched pairs key-points between overlapping images (Hawkins, 2016)

Sufficient overlapped images are crucial, so a single key point can be used to correct four or five different images. For instance, in 14-megapixel images, Pix4D can typically identify around 60,000 keypoints and find 6,000 matched pairs of keypoints per pair of images; the more keypoints analysed, the better the level of accuracy of the projects (Hawkins, 2016). Drone2Map allows the software to evaluate the camera properties and camera positions. It can correct GPS camera positions and the camera focal length if necessary. This software can even process non-geo-tagged images. It can generate orthomosaic and a 3D point-clouds, but does not have a proper scale (ESRI, 2018). The technique applied by Drone2Map, for analysing multiple keypoints images and making corrections in the case of errors of camera position, orientation and camera properties, is recognised as modern photogrammetry.

3.7 Chapter Summary

As outlined in this chapter, spatial planning is crucial for national park development in Indonesia to define suitable land use for a number of management objectives, including accommodating local people's access to their natural resources and preserving their local knowledge. Therefore, ecology and socio-economic factors are fundamental data for zoning formulation in Indonesia (Forestry, 2015). Social economic data are related to people's livelihoods, environmental services potential, accessibility and cultural values. The ecological parameters, wildlife distribution, land use and land cover are some of the mandatory data. These data are often used as the primary input in spatial planning, so it is crucial to update these data for effective park management. In view of this, a new approach will be used in this study by combining satellite imagery and UAV aerial surveys in order to get better earth surface information. This will then be followed by a weighted overlay technique to formulate two important zoning parameter data to be used for zoning classification in GIS. GIS is a powerful tool for the spatial analyst that is often used to combine several spatial data, which are relevant to spatial planning (Villa et al., 2012). The methodology for this technique and the criteria developed to implement new park zones based on their score, value and the priority option will be further discussed in the following chapter.

Chapter 4

Research Methods

This chapter explains in more detail the research framework as a follow up to the theoretical reviews that were outlined in chapter 3. As outlined in Chapter 2, the research area focussed on the Aketajawe Block, a total area of approximately 77,794 hectares, which had aerial surveys conducted in three locations, namely, Tayawi, Akejawi and Tabanalou. This chapter begins by describing the research design, includes several stages and innovations that were used in this study to formulate the best spatial planning model for Aketajawe. This was then followed by the study's approaches for the data collection, processing and analysing data that were used to answer the research question, the model formulation for spatial planning, and the chapter conclusion.

4.1 Research Design

A new approach has been formulated in this study by integrating UAV aerial surveys and satellite imagery in order to derive better land cover and land use information for evaluating zoning in Aketajawe Block. A combination of qualitative and quantitative methods were applied in this study as this leads to improved practical and scientific results, which can gradually improve the accuracy and applicability of the models for land evaluation (Byrne & Laefer, 2016; Rosa & Diepen, 2002). This study applied multiple methods of data collection, its compilation and the analysis of primary and secondary data. The initial stage was photogrammetric analysis using a UAV. This primary stage was crucial in order to gather updated geographic information. Multiple aerial images were mosaicked together using photogrammetric software - Drone2Map version 1.3.1. The geometrically corrected images were then imported into ArcGIS 10.6 software. These images were compared with high-resolution satellite imagery from SPOT 7 and the lower resolution Landsat 8 imagery, to develop updated land use maps for Aketajawe.

In the second stage, Landsat 8 imagery was classified into the park's landcover categories. This analysis was important for gathering all land cover types in Aketajawe. Remote sensing tools and techniques in ArcMap 10.6 were used for this analysis, including image mosaicking, composite processing, raster processing, and pan sharpening to increase the Landsat 8 resolution. Maximum likelihood classification algorithms were used for this analysis. This process involved creating training samples in the area of interest followed by pixel-by-pixel classification based on spectral signatures. This was followed by a land-cover accuracy assessment using confusion matrices and kappa coefficients, and, finally, converting the raster data to vector data to calculate the total area in each land cover class.

The third phase was zoning classification. In general, there are two groups of data in this stage. First, ecology parameters including land cover, land use, wildlife distribution, altitude, slope, and rivers, are considered. Secondly, socio-economic parameters, including accessibility, cultural values, risk sensitivity and environmental services, were incorporated. While several models were developed in the course of this study, two primary models were focussed on and presented below. The majority of the input data were in the vector format, which then were converted into raster format for ease of combining. Spatial multi-criteria analysis (SMCA) was used to develop the models. SMCA is often used by decision-makers to analyse large amounts of environmental, social and economic information including the incorporation of community opinions, public policies and management goals (Kiker, 2005; Malczewski, 2006). The weighted overlay tool available in ArcMap 10.6, made it possible to implement the models and derive results. Weighted overlay is a technique for applying a general measurement scale of values to diverse and dissimilar inputs to create an integrated analysis (ESRI, 2014). Weighted overlay results were classified into three categories: high, medium and low, based on their suitability.

The last step was zoning formulation and finalisation. There are two different approaches for two zoning model (zonal model and eco-social) finalisation. The logical framework in the zonal model is that each parameter in the two zoning parameters (ecological and socioeconomic) has a different relationship or correlation with the zoning classifications (core, wilderness, etc.), and each parameter has a different weighting in each zone. In the second model (eco-social model), each assigned value for each parameter class (wildlife distribution, slope, accessibility, etc.) depended on the relationship of the zoning parameters (ecological and socio-economic) with the two primary national park objectives (biodiversity protection and people livelihood). In other words, all classes in the ecological parameters will be assigned a value that depends on their relationship in each class to biodiversity protection. In addition, all classes in the socioeconomic parameters were assigned values depending on their importance to supporting economic contributions or people's livelihoods. The weighted overlay result from zonal model was followed by reclassifications of the results in order to derive different zoning classification in Aketajawe. The photogrammetric images or satellite imagery (Landsat 8 and SPOT 7) was used as reference data to evaluate the results from this model. On the other hand, the eco-social model weighted overlay results were reformulated using coded values to eliminate any ambiguous results when the output layers were combined. Each value combination was assigned to a set of zoning categories. The result was then combined into a single layer final zoning classification for Aketajawe. The logical framework flowchart of this study is presented in the following Figure (Figure 4.1).

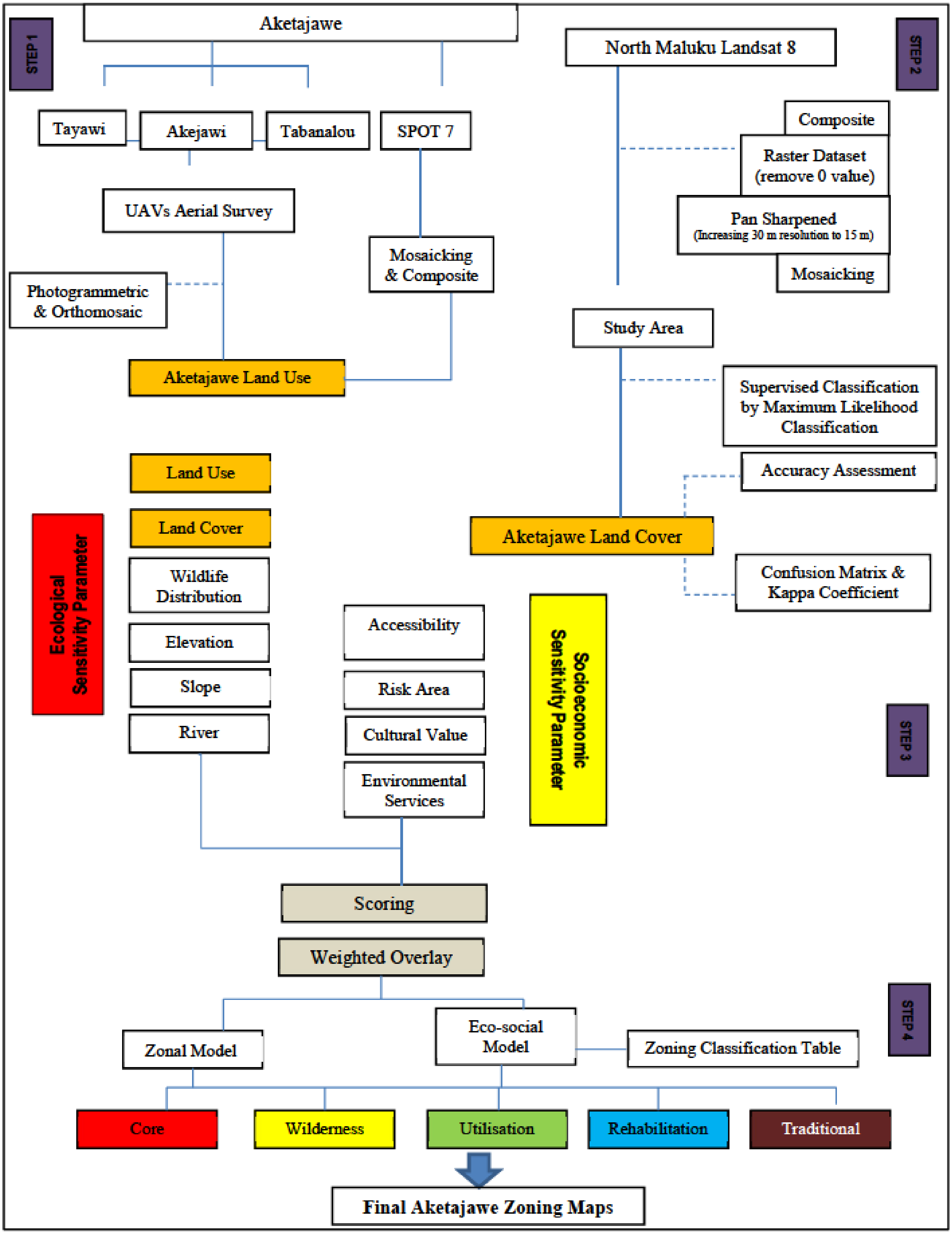

Figure 4.1 The study research framework

4.2 Data Collection

The data collection comprised both primary and secondary data. The primary data included aerial surveys data by Phantom 4 quadcopter UAV. The secondary data consisted of multiple spatial datasets relevant to spatial planning in Aketajawe, such as statistical information, demographical data, government regulations, and several remotely-sensed images. To obtain these primary and secondary data, field research in Indonesia was carried out from May to August 2018. ALNP, in North Maluku, was visited as well as the Ministry of Environment and Forestry and the Indonesian National Institute of Aeronautics and Spaces (LAPAN) in Jakarta. Visits to ALNP were arranged to collect sufficient field data for updating the land-use and land cover of ALNP and as well as some related documents about the study site. Prior to this, Google Earth image interpretation was used to identify suitable locations for aerial survey.

4.2.1 Primary Data

Primary data collection was conducted mainly for updating the land cover and land use data in Aketajawe, particularly in areas of high human interaction. Aerial surveys using unmanned aircraft were performed to locate the indigenous people's territory, agricultural land and other critical areas inside the park. The following section gives a detailed explanation about the primary data collection processes.

4.2.1.1 UAV Aerial Survey

SPOT 7 imagery was used to gather spatial information from targeted UAV aerial survey areas, particularly in areas with high human interaction. A new polygon shapefile was created for each sampling area using ArcMap 10.6 in order to create a clear boundary. This polygon was then converted into a kml file to meet Pix4D Capture's requirements. Initially, the sampling area kml file was imported to this software so the survey boundary could be easily identified. A topographic map was then used to minimise the possibility of aircraft crashes as topography information was needed to set aircraft altitude and flightpath. In theory, the UAV's altitude is the height distance between the UAV position and pilot's location on the ground, which is different from the absolute elevation on a topographic map. Based on that information, a minimum altitude for UAV height can be estimated (Pix4D, 2018). This elevation setting should be higher than the forest canopy top. Unfortunately, the topographic maps cannot be imported into Pix4D Capture, so the solution in this research was to use printed topographic maps at a (large) scale of 1:100 for the aerial survey sampling areas, followed by creating aircraft flight plans and checking the aircraft position by comparing it against the printed topographic maps.

Before take-off, there were some UAV and Pix4D Capture settings that must be taken into account as follows:

1. An adequate open area for UAV take-off positions (min 2x2 metre);
2. UAV altitude is set to a maximum of 150 meters; above this level, as image resolution decreases beyond the desired output resolution;
3. Set the side-lap to more than 80 per cent in Pix4D Capture;
4. UAV camera position set to vertical or 90° facing downwards;
5. The aircraft was placed on the landing pad in a forward-facing direction;
6. UAV's maximum speed was set to 7 m/s;
7. In this research, the longest flight distance setting was 950 metre from the take-off point;
8. The minimum number of GPS satellites used to determine the location was seven;
9. To avoid a loss of power during flights, the minimum battery capacity for RTH was set to 10 per cent

In the case of relatively large study areas such as Tayawi, the flight plan was divided into several sampling areas with a large enough percentage overlap to minimise inaccurate results. In addition, signal loss has been a big challenge for UAV surveys in forest areas, which may happen due to forest density and the different topographic conditions. Therefore, it was important to update the aircraft and remote firmware in the UAV software and to calibrate the aircraft and the remote before flights were undertaken. There are two methods for downloading images from the aircraft; first, they can be downloaded automatically in the Pix4Dcapture app to the smartphone's internal or external memory and can also be transferred manually from the aircraft/drone external memory to computers or laptops.

4.2.1.2 DJI Phantom 4

The photogrammetry survey was conducted using a popular low-cost type of UAV to acquire aerial images called DJI Phantom 4 (Figure 4.2). This is an example of a quadcopter drone and consumer-grade UAV developed by DJI and that is mainly used for entertainment and aerial photography. This type of drone also meets the fundamental criteria to apply it as a mobile mapping system. This drone is equipped with a global navigation satellite system (GNSS), inertial measurement unit (IMU) and distance-measuring instruments (DMI), which allow this UAV to perform appropriately in the automated aerial survey- and with adequate accuracy. Phantom 4 has a built-in three-axis gimbal and a built-in 4K camera, so it can capture stable images while minimising both size and weight. The complete specifications of this drone can be found in the Phantom 4 User Manual. Its producer emphasised that it was the smartest flying camera ever and was also equipped with an obstacle sensor to prevent collisions. The battery had flying performance of up to 28 minutes, which was claimed to be of a more powerful capacity than the previous Phantom generation (DJI, 2018). Figure 4.2 presented the features and shape of DJI Phantom that used in this study.

Source: DJI, 2018

Figure 4.2 Specifications of the Phantom 4 aircraft used in this study.
https://dl.djicdn.com/downloads/phantom_4/en/Phantom_4_User_Manual_en_v1.0.pdf

4.2.2 Secondary Data

The secondary data collection included a range of relevant resources from government institutions, including spatial and non-spatial data. Table 4.1 summarises all the secondary data collected. In addition, non-spatial data primarily related to the Indonesian government policies in the conservation sector, long-term and short term national park planning, relevant regulations in spatial planning, and demographic data were collated. An in-depth review of the existing national park documents, such as Aketajawe block zoning management and short-term and long term ALNP planning, was conducted in order to understand more deeply ALNP priority development, crucial issues, policy and management challenges, as well as to collect relevant information for spatial planning evaluation. These secondary data also included Indonesian Forestry Statistics, from 2014 to 2018, from the Ministry Environment and Forestry's, North Moluccas regional mid-term planning, and the North Moluccas regional statistical data in 2018 provided by BPS-Statistics of Maluku Utara Province.

Table 4.1 List of secondary data used in this study

Data or Information	Data Provider	Type of Data
Wildlife distribution	Aketajawe Lolobata National Park Office	Spatial
Indigenous people distribution	Aketajawe Lolobata National Park Office	Spatial
Village distribution in Aketajawe Block	Aketajawe Lolobata National Park Office	Spatial
Altitude	Aketajawe Lolobata National Park Office	Spatial
Slope	Aketajawe Lolobata National Park Office	Spatial
Topographic maps	Aketajawe Lolobata National Park Office	Spatial
Natural disaster risk	Aketajawe Lolobata National Park Office	Spatial
River	Aketajawe Lolobata National Park Office	Spatial
Accessibility	Aketajawe Lolobata National Park Office	Spatial
Land Use	Aketajawe Lolobata National Park Office	Spatial
Administrative boundaries of ALNP	Aketajawe Lolobata National Park Office	Spatial
Aketajawe Block zoning management	Aketajawe Lolobata National Park Office	Non-spatial
Long-term Planning ALNP 2015-2025	Aketajawe Lolobata National Park Office	Non-spatial
North Moluccas Regional Statistics Data in 2017	Indonesia Central Agency on Statistics North Moluccas (BPS Maluku Utara)	Non-spatial
Indonesia Forestry Statistics Data from 2014 to 2017	Ministry Environment and Forestry	Non-spatial
Potential Akejawi Village Data	Village Administration Office	Non-spatial

Zoning classification criteria in national park Indonesia	Ministry Environment and Forestry	Non-spatial
Technical regulation for national park zoning development	Ministry Environment and Forestry	Non-spatial

4.2.2.1 Satellite Imagery

As part of secondary data, this study used two different sets of satellite imagery: high-resolution SPOT 7, and low-resolution Landsat 8. Both sets were obtained from the Indonesian National Institute of Aeronautics and Space in Jakarta (LAPAN). This institution has authority to provide geospatial data and information to the public, including forest/land fire hotspots. For this study, SPOT 7 has four bands (RGB+NIR) with a 1.5-metre pixel resolution and data acquisition ranging from 20 August 2016 to 11 October 2017. Landsat 8 data were acquired on 6 February 2016 with a 30-metre resolution and nine bands. The Landsat 8 bands include natural colour and near infrared, located in the visible and shortwave infrared regions of the electromagnetic spectrum, plus an additional panchromatic band at 15-m spatial resolution (Jiménez-Muñoz, J. C., J. A., Mattar, & Cristóbal, 2014). A LAPAN database provided a complete list of all imagery collected by the satellite sensors, including image location, date the image was collected, and image quality information, including cloud cover percentage information. More importantly, the Landsat 8 imagery used in this study, had cloud cover percentages of lower than 10 per cent ; many remote sensing specialists agreed that imagery with a cloud cover percentage of more than 30 per cent were usually not applicable in practice (Goward et al., 2006)).

4.3 Data Processing and Analysis

This section explains several stages in the data acquired based on UAV aerial survey and satellite imagery, including some techniques and software to ensure that the data were set properly for further analysis in zoning classification.

4.3.1 Ground Sampling Distance

The first basic important step in photogrammetry survey was setting an appropriate ground sampling distance (GSD), which represented the resolution of the images from the aerial survey imagery. This can be performed by setting different aircraft altitudes in Pix4D Capture.

Interestingly, even if an aircraft was constantly flying at the same elevation, the projected images might not have the same GSD value (Pix4D, 2018). This may happen because of topographic differences or terrain elevations in the camera angle and position while shooting. However, this problem can be solved in the orthomosaic analysis since this analysis was made using camera positions and a 3D point cloud so that the average GSD number can be computed (Figure 4.3), or it can be calculated manually by using the equation below. A GSD of 4 cm means that one pixel represents, aerially, 4 x 4 cm on the ground, Figure 4.3 displays the equation parameters.

Image removed for Copyright compliance

Source: Pix4D, 2018

Figure 4.3 Ground sampling distance (GSD) calculation. https://support.pix4d.com/hc/en-us

While gathering field data, this study always set an overlap of more than 80 per cent in the Pix4D Capture application so that a single key-point can be recognised in four to five different images. The more matched pairs of key-points from the images, the higher the level of accuracy of the result in the orthomosaic process (Hawkins, 2016). This allows Pix4D to triangulate the camera properties and position, and it also allows the software to correct the GPS position of the camera and correct the focal length camera if needed.

4.3.2 UAVs Data Processing

Drone2Map has the ability to analyse UAV images automatically. Drone2Map software will automatically determine the best methods of georeferencing and mosaicking the UAV images based on their metadata. Looking in more detail at the application, there are several steps in image processing. First, images from the UAV are imported into Drone2Map and the settings, such as the coordinate system, are configured (this study used WGS 1984, as a standard geographic reference system). Then, matching pairs of keypoints in the images are identified and linked. Keypoints or interest points are defined as images unique points that must be matched and correspond with another image points (Byrne & Laefer, 2016). There are three default processing modes in Drone2Map, namely full, rapid and custom. In order to have a faster result with less accuracy, rapid assessment is the best option. This is a very useful option for verifying images collected in the field.

However, in order to prepare sufficient quality data for GIS analysis, the full mode settings were used to derive an image with high precision and accuracy though this required longer processing times. This option increases the number of keypoints used for processing and incorporates a geometric strategy to find the most consistent matches for keypoints visible on several images. In the case of the terrain or a hilly study area, a standard calibration method was used to allow external parameters optimisation using the internal camera's parameters. The final products from Drone2Map are selected based on the user's needs. The options are 2D or 3D products. In 2D products, the desired outputs are useful for further GIS analysis. Orthomosaic, digital terrain model (DTM), digital surface model (DSM) and normalized difference vegetation index (NDVI) images (if using appropriate cameras), are available. For further GIS analysis, this study mainly used orthomosaics for image interpretation and classification.

4.3.3 Satellite Imagery Mosaicking

SPOT 7 and Landsat 8 imagery contained several scenes encompassing the North Moluccas region. Image mosaicking can be performed by merging two or more images, resulting a single raster dataset (Figure 4.4) (ESRI, 2018).

Image removed for Copyright compliance

Figure 4.4 Combining satellite imagery scenes into one layer (ESRI, 2018) https://www.esri.com/~/media/Files/Pdfs/news/arcuser/1014/understanding-weightedoverlay.pdf

The new raster dataset format can be created as a stand-alone image or as a raster in a geodatabase. Data extraction and raster display are more easily transferred, and large data formats can be built easily and utilised (ESRI, 2018).

4.3.4 Land Cover Analysis by Supervised Classification

Landsat 8 imagery was used to develop the land cover classification, as shown in table 3.2 in chapter 3. In the initial step, the composite Landsat 8 imagery was clipped using the study area polygon before training sets were built. Some training samples were selected to capture certain land cover types. This was carried out by visual interpretation of the imagery at multiple scales. The number of samples depends on the amount of land cover class at minimum of 10 times bigger than the land cover class in the study area (G. M. Foody, 2002) In this study, 50 training samples were created in five different land cover classes (primary forest, secondary forest, open area, water body/river, and cloud). The samples were created using some key-elements that represented the land cover class in imagery, such as colour, pattern (a group compilation of a spatial object), texture (the colour change frequency), size, shape, and the site shadow (Lillesand, Kiefer, & Chipman, 2014).

Once all the training samples were collected, the MLC tool was used to identify pixels with similar characteristics that represent the spectral signatures of the specific land cover class to be categorised. Then, the spectral characteristics summary information from the training samples of various classes were used to assign each pixel to one of the defined types of land cover. MLC is a remarkable parametric classifier in remote sensing image classification processes (G. M. Foody, 2002). The resulting classified raster layer could be converted to a vector polygon layer for further analysis as a thematic map.

4.3.5 Accuracy Assessment

In remotely sensed data, accuracy is defined as the level of “correctness” of the classification or maps (G. M. Foody, 2002). The thematic map derived from a classification could be considered precise or accurate if it provided an unbiased land cover representative of the area it portrayed. In essence, accuracy assessment was needed to understand as the degree to which a derived image classification conformed to the real situation (Campbell, 1996; L. L. F. Janssen & Wel, 1994; Mailing, 1989). An error, in image classification, was an acceptable degree difference or discrepancy between the reality and thematic map.

In remote sensing analysis, confusion matrices are a common method used for accuracy assessment, and are also referred to as error or contingency matrices (Banko, 1998). An error matrix expresses the cross-tabulation of the actual land cover conditions shown by sample the site results and classified land cover. Different assessment and statistics can be extracted from the error matrix calculation; the basic forms of non-statistical measurements and error matrix are explained in section 4.3.5.1 and 4.3.5.2 based on binomial distributions.

4.3.5.1 Confusion Matrix

A confusion matrix table shows the values for the known land cover category of the reference data in the columns and for the classified data in the rows. The values on the main diagonal of the table represented the number of correctly classified pixels. The common layout of a table for representing the matrix value is demonstrated in Figure 4.5, below. Overall accuracy was one basic accuracy measurement, which was used in this study. This accuracy was calculated by dividing the total number of pixels checked by the total values on the main diagonal (the number of correctly classified pixels). Besides this overall accuracy, the accuracy of the classification of individual categories of land cover can be calculated in the same manner. In this analysis, two common methods were employed, namely the user's accuracy and the producer's accuracy.

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Figure 4.5 The table or layout recommended of an error matrix (Congalton, 1991)

The producer's accuracy can be calculated by dividing the value of correct pixels in one category/class by the total value of pixels as derived from the column total (Table 4.5). The producer's accuracy represented the level correctness of a specific area that had been classified. The measurements included omission errors, which represented the proportion of features observed in the field that were not classified correctly in the map. The higher the number of omission errors, the lower level of the producer's accuracy.

Another individual accuracy assessment is the user's accuracy. User's accuracy can be calculated by dividing the total number of correctly classified pixels in a category by the total value of pixels that were classified in that specific land cover category (Figure 4.5). This accuracy represented the reliability of the map. It showed the user the level of map correctness to help compare it against the actual conditions on the ground. In some cases, one land cover class in the thematic map might have two or more types of categories on the ground. The correct class, which represents the same land cover category on the ground and in the map, and the "wrong" classes, which showed that the different actual information on the ground can then be visualised on the map. These "wrong" classes were commonly referred to as commission errors. The lower the level of user's accuracy, the more errors of commission exist.

4.3.5.2 Kappa Coefficient

The Kappa Coefficient calculates the overall matrix agreement. In contrast to overall accuracy, which is derived from the total diagonal values to the sum of pixels counts in the matrix, uses the non-diagonal numbers in its calculations (Rosenfield & Fitzpatrick-Lins, 1986). Cohen developed this method in 1960 to measure the proportion of accuracy agreement. A Kappa Coefficient has a value of one when there is complete agreement between verification data and classified data (Fenstermaker, 1991). This coefficient was introduced to the remote sensing study in the early 1980s (Congalton, Oderwald, & Mead, 1983) and has since become widely used for land cover classification accuracy measurements (Figure 4.6) (Rosenfield & Fitzpatrick-Lins, 1986).

Figure 4.6 Kappa coefficient formulation and interpretation (Rosenfield & Fitzpatrick-Lins, 1986)

4.4 National Park Zoning Classification Processes

The information gathered from the UAV images and remotely sensed data was used for further analysis in order to evaluate the current spatial planning in Aketajawe and to improve decision-making. This study divided the essential factors related to zoning classification into two groups: ecological sensitivity and socio-economic value. As listed in Table 4.2 in page 66 the information about ecological disturbances or wildlife diversity was categorised under ecological sensitivity. This includes wildlife distribution, topography, altitude, slope, natural hazards, land cover, and rivers. Another category was socio-economic, which referred to some factors related to people's livelihoods and economics. Socio-economic values, risk area, accessibility, and cultural values were grouped in this category. These data were all in a spatial format, primarily derived from field surveys and ALNP management. To accomplish the zoning classification, spatial multi-criteria analysis (SMCA) was used in ArcGIS to combine the geographical data into a final layer ((Rikalovic, Cosic, Lazarevic, & Djordje, 2014), and included multiple analyses, as outlined below.

4.4.1 Reclassified Zoning into Raster Data

As part of the weighted overlay, a set of different classes for each zoning criterion must be formulated to examine the different level of relationship between zoning criteria and the resultant zonings. First, some adjustments used in this study were based on the technical guidelines from the Ministry of Environment and Forestry (Sulistyo et al., 2016), researcher expertise and the literature review. Distance criteria were addressed using the multiple ring buffer tool. All spatial data in vector format were converted to raster data using an appropriate conversion tool in ArcMap 10.6. All raster data were subsequently reclassified into three different weights with values of 1, 3, and 5. A value of 1 represents areas that are not ideal for a given zoning classification, areas classified as 3 are more ideal, and areas with a value of 5 are the most ideal. Table 4.2 provides detailed information about this general formulation and Figure 4.7 provides an overview of how the input layers were transformed as shown in the table, below. The classes shown in Table 4.2 were used to prepare all spatial data for subsequent modelling.

Table 4.2 Zoning parameter general adjustment for investigating the relationship level

Parameter	Criteria	Spatial Data Format	Buffer/Classification	Tools	Justification
ECOLOGICAL	Wildlife Distribution	Vector	0 - 1000 m	Multiple ring buffer	Ministry of Environment and Forestry technical guidelines
			1000 - 5000 m		
			> 5000m		

	Land Cover	Raster	Primary Forest	Reclassify	Ministry of Environment and Forestry technical guidelines
			Secondary Forest		
			Open Area		
			Waterbody		
	Slope	Raster	> 45°	Reclassify	Ministry of Environment and Forestry technical guidelines and researcher improvement
			25° - 45°		
			15° - 25°		
			8° - 15°		
			3° - 8°		
			0° - 3°		
	River	Vector	0 - 100 m	Multiple ring buffer	Indonesian regulations
			> 100 m		
	Elevation	Raster	1000 -1350 m	Reclassify	Ministry of Environment and Forestry technical guidelines and researcher improvement
			750 - 1000 m		
			500 - 750 m		
			250 - 500 m		
			0 - 250 m		
	Land Use	Vector	Primary Forest	Symbology	Ministry of Environment and Forestry technical guidelines and researcher improvement
			Indigenous Territory		
			Secondary Forest		
			Coconut Plantation		
			Open Area		
			Agriculture Land		
SOCIOECONOMIC	Accessibility	Vector	0 - 100 m	Multiple ring buffer	Researcher improvement
			100 - 200 m		
			> 200 m		
	Risk Area (Conflict area, natural disaster or sensitive area)	Vector	0 - 500 m	Multiple ring buffer	Researcher improvement
			500 - 1000 m		
			> 1000 m		
	Cultural Value (Indigenous and villager activity)	Vector	0 - 1000 m	Multiple ring buffer	Ministry of Environment and Forestry technical guidelines and researcher improvement
			1000 - 2000 m		
			> 2000 m		
	Environmental Services	Vector	0 - 500 m	Multiple ring buffer	Ministry of Environment and Forestry technical guidelines and researcher improvement
			500 - 1000 m		
			> 1000 m		

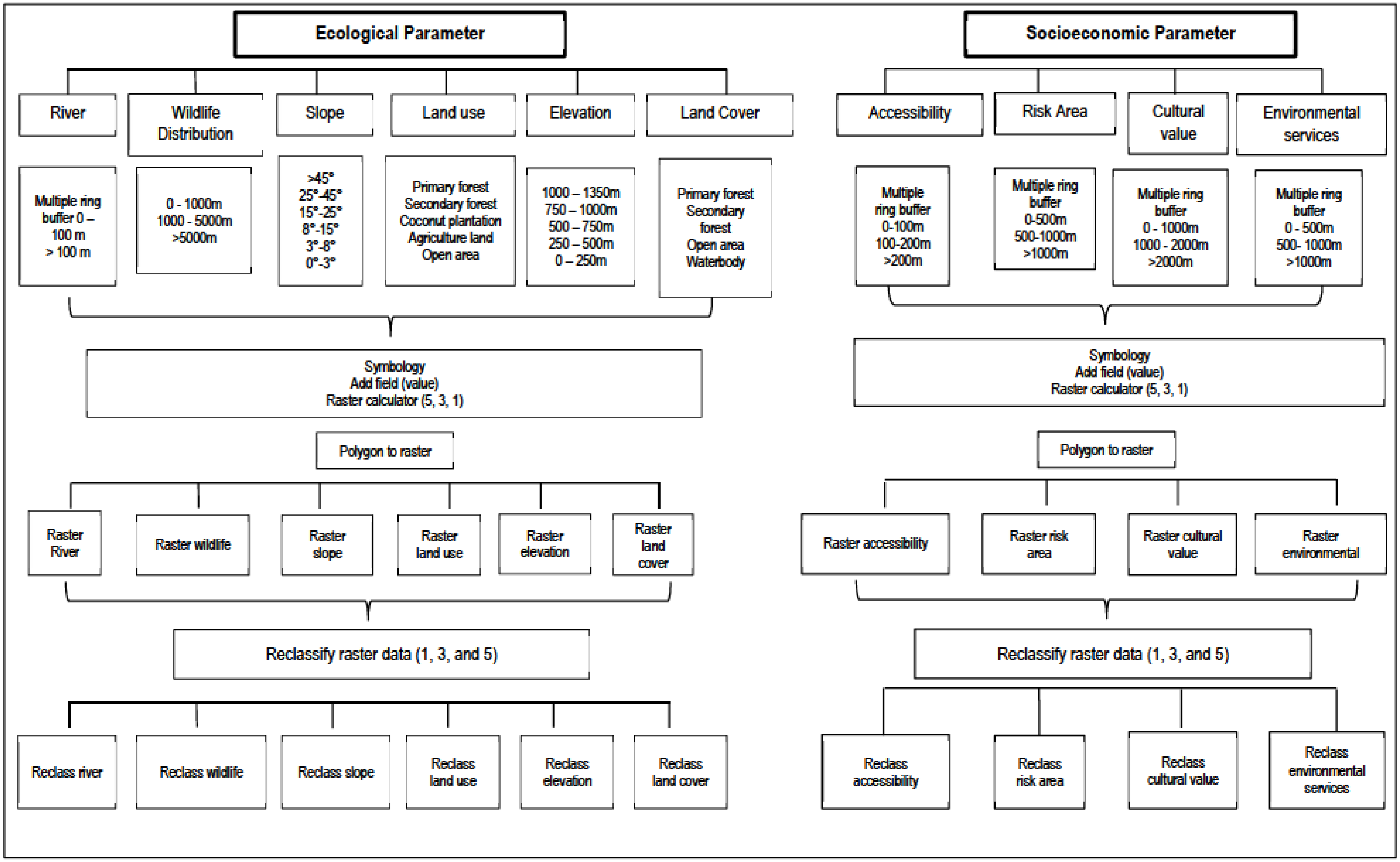


Figure 4.7 Reclassified zoning parameter processes and framework

4.5 Spatial Multi-Criteria Analysis and Weighted Overlay Technique for Zoning Classification

Multi-criteria analysis is defined as a decision-making process based on identifying a problem, and then evaluating it causes and effects and creating a set of priorities for some parameters in order to select or reject the available options/solutions (Sharifi, Toorn, & Emmanuel, 2002). This model evaluation examined some criteria based on their scores, values and the priority options. The primary objective of this analysis was to provide the best information for decision makers to make efficient and effective decisions that accommodated multiple management objectives. The expected output was an alternative zoning model appropriate to the management objectives.

Consider to the government of Indonesia policy that stated on Pemenlhk P.76/Menlhk-Setjen/2015, two of the primary objectives of a national park's are to protect biodiversity and give local communities access to their natural resources. Suitable parameters to accommodate these management purposes need to be identified. Ecology sensitivity and socio-economic value categories were used to represent the national park management's role as protector of conservation areas and biodiversity as well as their role in working with local communities. The ecological sensitivity factors studied for this analysis were wildlife distribution, elevation, slope, land use, land cover, and river/streams. In addition, the socio-economic values considered were risk areas based on social, economic activities and accessibility factors. Ranks and weights were determined for each parameter according to their level of importance in each management zone. Two weighted parameter models were developed for this study, namely a zonal model and an eco-social model. In principle, both models have a similar weighting scenario, which uses three different values, 1, 3, and 5.

4.5.1 Zonal Model

In the zonal model, the most ideal area for any particular type of zone was assigned a value of 5, then, value 3 is assigned for average suitability areas and 1 for not suitable (see detail in table 4.3). The logical framework in the zonal model was that each parameter in the two zoning categories (ecological and social-economic) has a different relationship or correlation with the zoning classifications (core, wilderness, etc.). In other words, each parameter has a different weighting depending on which zone is being considered. For instance, areas within a radius of 0-1000 metres from wildlife distributions are identified as a biodiversity hotspots, and as a result are in a core zone; this area is assigned a value of 5, which is most suitable for the core zone (biodiversity protection).When considering the traditional zone, these same areas are assigned a value of 1 (less suitable) in a separate layer, because the traditional zone is mainly for supporting people's livelihoods so it should have a low-value for biodiversity.

In addition, the weight proportion in each zoning parameter has been set by evaluating the level of importance between the zoning parameter (wildlife distribution, land cover, cultural value, etc.) and the zoning classification characteristics. For example, environmental services had the biggest proportion, at 30 per cent for the utilisation zone, because this parameter was the most crucial factor for that zone. In the zonal model, the cumulative proportion of both the ecological and socioeconomic parameters was 100 per cent. Once the weightings were set, the weighted overlay technique could be used for each type of zoning classification (Table 4.3), resulting in five output layers, one for each zone. The results from this model have been finalised based on vector data using overlay tools (Merge). Implementing the analysis covered above resulted in five output layers for this model.

Table 4.3 Weights and ranks assigned for weighted overlay in zonal model

Parameter		Variable Used	Core Zone		Wilderness Zone		Utilisation Zone		Rehabilitation Zone		Traditional Zone	
			Influence	Scale Value	Influence	Scale Value	Influence	Scale Value	Influence	Scale Value	Influence	Scale Value
ECOLOGICAL	Wildlife Distribution	0 - 1000 m	20%	5	15%	5	5%	1	5%	1	5%	1
		1000 - 5000 m		3		3		3		3		3
		> 5000m		1		1		5		5		5
	Land Cover	Primary Forest	15%	5	20%	3	5%	3	35%	1	15%	3
		Secondary Forest		3		5		5		1		5
		Open Area		1		1		1		5		1
		Waterbody		5		3		1		1		1
	Slope	> 45	10%	5	10%	5	5%	1	10%	1	10%	1
		25 - 45		5		5		1		1		1
		15 - 25		3		3		3		3		3
		8 - 15		3		3		3		5		5
		3 - 8		1		1		5		5		5
		0 - 3		1		1		5		5		5
	River	0 - 100 m	10%	5	10%	5	5%	1	3%	1	5%	1
		> 100 m		1		1		5		5		5
	Elevation	1000 -1350 m	10%	5	10%	5	5%	1	10%	1	10%	1
		750 - 1000 m		5		5		1		1		1
		500 - 750 m		5		5		1		3		3
		250 - 500 m		3		3		3		5		5
		0 - 250 m		1		1		5		5		5

	Land Use	Primary Forest	15%	5	15%	3	10%	3	20%	1	28%	1
		Indigenous Territory		1		1		3		1		5
		Secondary Forest		3		5		5		1		1
		Coconut Plantation		1		1		3		3		5
		Open Area		1		1		1		5		1
		Agriculture Land		1		1		1		5		5
SOCIOECONOMIC	Accessibility	0 - 100 m	5%	1	5%	1	15%	5	8%	5	7%	5
		100 - 200 m		3		3		3		3		3
		> 200 m		5		5		1		1		1
	Risk Area (Conflict area, natural disaster or sensitive area)	0 - 500 m	5%	1	5%	1	5%	1	3%	5	5%	3
		500 - 1000 m		3		3		5		5		5
		> 1000 m		5		5		3		1		1
	Cultural Value (Indigenous and villager activity)	0 - 1000 m	5%	1	5%	1	15%	5	3%	1	10%	5
		1000 - 2000 m		3		3		3		3		3
		> 2000 m		5		5		1		5		1
	Environmental Services	0 - 500 m	5%	1	5%	1	30%	5	3%	1	5%	3
		500 - 1000 m		3		3		3		3		5
		> 1000 m		5		5		1		5		1
Total			100%		100%		100%		100%		100%	

4.5.2 Eco SocialModel

The eco-social model has a different approach to zoning classification. Similar to the zonal model, this one also used three different values, 1, 3, and 5. The difference is that each assigned value for each parameter class depended on the contribution of the zoning parameter (ecological and socio-economic) to the two primary national park objectives (biodiversity protection and people livelihood). Therefore, all categories in the zoning parameter were set up resulting in two output layers: one for the ecological parameters and one for the socioeconomic parameters. For instance, areas within 0-500 m of environmental services was the most suitable areas for supporting people’s livelihoods because the tourism potential is high or non-timber resources (honey, dammar gum, etc.) are available, so these areas was assigned a value of 5 (most suitable).

As part of the weighted overlay analysis, the two categories are weighted independently (i.e. a cumulative total of 100% for ecological parameters and for socioeconomic parameters). For each parameter, the more a criterion has an influence on a zoning parameter, the higher its weighting. For example, wildlife distribution, land cover, and land use have 20% weights each because they all strongly influence ecological conditions. On the contrary, elevation has the smallest proportion at 10%, because ALNP is mainly for bird's protection, and elevation does not have a significant impact on the flagship species. Table 4.4 lists the weights and ranks assigned to parameters for this model

Table 4.4 Weights and ranks assigned for weighted overlay in eco-social model

Parameter	Criteria	Variable Used	Description	Value	Influence (%)	Vector Shapefile Types
ECOLOGICAL	Wildlife Distribution	0 - 1000 m	Most suitable	5	20	Point
		1000 - 5000 m	Suitable	3		
		> 5000m	Not suitable	1		
	Land Cover	Primary Forest	Most suitable	5	20	Polygon
		Secondary Forest	Suitable	3		
		Open Area	Not suitable	1		
		Waterbody	Most suitable	5		
	Slope	> 45	Most suitable	5	20	Polygon
		25 - 45	Most suitable	5		
		15 - 25	Suitable	3		
		8 - 15	Suitable	3		
		3 - 8	Not suitable	1		
		0 - 3	Not suitable	1		
	River	0 - 100 m	High	5	15	Polyline
		> 100 m	Not suitable	1		
	Elevation	1000 -1350 m	Most suitable	5	10	Polygon
		750 - 1000 m	Most suitable	5		
		500 - 750 m	Suitable	3		
		250 - 500 m	Suitable	3		
		0 - 250 m	Not suitable	1		
	Land Use	Primary Forest	Most suitable	5	15	Polygon
		Indigenous Territory	Most suitable	5		
		Secondary Forest	Suitable	3		
		Coconut Plantation	Suitable	3		
		Open Area	Not suitable	1		
		Agriculture Land	Not suitable	1		
	Total				100	

SOCIO-ECONOMIC	Accessibility	0 - 100 m	Most suitable	5	25	Polyline
		100 - 200 m	Suitable	3		
		> 200 m	Not suitable	1		
	Risk Area (Conflict area, natural disaster or sensitive area)	0 - 500 m	Most suitable	5	15	Point
		500 - 1000 m	Suitable	3		
		> 1000 m	Not suitable	1		
	Cultural Value (Indigenous and villager activity)	0 - 1000 m	Most suitable	5	35	Point
		1000 - 2000 m	Suitable	3		
		> 2000 m	Not suitable	1		
	Environmental Services	0 - 500 m	Most suitable	5	25	Point
		500 - 1000 m	Suitable	3		
		> 1000 m	Not suitable	1		
	Total				100	

The weighted overlay tools in ArcMap 10.6 were used to multiply the raster data (input) using these measurement scales and then combining all of them according to their level of importance into a single output (Belay, Islam, & Tilahun, 2015). The weighted overlay formula is described below:

$$S = W_1R_1+W_2R_2+ . . . + W_nR_n$$

Where

S = Suitable area for national park management zone
$W_{1\ldots n}$ = Weighting value of factor 1, 2, 3...to n
$R_{1\ldots n}$ = Ranking value of factor 1, 2, 3...to n [10, 11, 13]

Implementing this analysis resulted in two output layers for this model.

4.6 Modelling National Park Spatial Planning

The analyses carried out above resulted in two zoning classification models for Aketajawe. This was then followed by different approaches for the two models' final classifications to make them more reliable and easier to implement for national park management.

4.6.1 Zonal Model

As the weighted overlay in the zonal model directly examined two zoning parameters (ecological and socio-economic) in each type of zoning classification, this resulted in five zoning output layers with three classes. These data were then reclassified into two binary values, 0 and 1. Values of 0 represent unsuitable areas and values of 1 represent acceptable areas for each type of zoning. Before that, reclassification was needed for some classes resulted from the weighted overlay analysis (ecological and socioeconomic). The suitable location for any particular type of zone was represented with value 3 and 5, so these values reclassified to value 1 (suitable), then value 1 (not suitable) were reclassified to value 0 (not suitable) (see detailed in Table 4.5). In the following step, these raster (value 1 and 0) data were converted to vector data by using a conversion tool. Then, the 1 value were relabelled into specific zoning type, such as core or wilderness and values of 0 labels were relabelled as unsuitable for that zone. In order to create a single layer zoning classification, all vector layer data were combined into a single layer by applying the Merge tool (see detailed steps in Figure 4.9).

Table 4.5 Reclassification weighted overlay result

Old Classes	Classify	A New Classes
1	1	1
1-2	1-2	3
2-3	2-5	5
3-4		
4-5		

*Changing classes from 5 to 3 in the classification menu

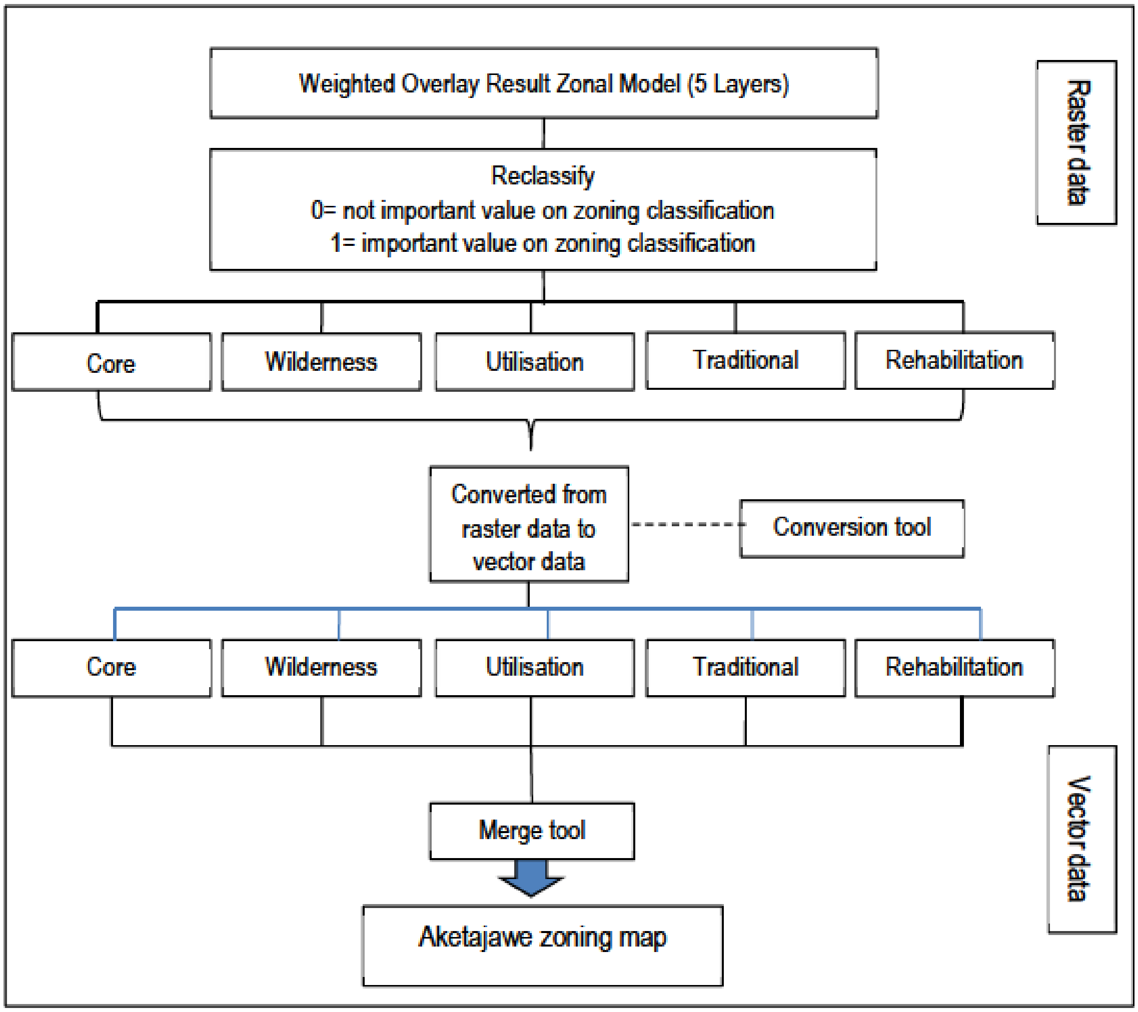


Figure 4.9 The logical framework zoning formulation in zonal model

4.6.2 Eco-social Model

As the eco-social analysis for this model resulted in two output layers, a different approach was used to reclassify the results. These raster layers were then reclassified to values of 1, 3 and 5 to simplify the raster classes (Figure 4.10). In order to create a single layer, a map algebra operation was used multiply and add, using the following equation:

Raster socio-economic*10 + reclassify raster ecological.

The raster calculator was used to recode and combine different values on the layers to reduce ambiguous results, and then the final zoning classification was determined by interpretation using table 4.6 to interpret different values resulting from model B.

Table 4.6 Zoning formulation in eco-social model

	Value	Ecological		
		5	3	1
Socio-economic	50	Wilderness (55)	Utilisation, traditional (53)	Specific, traditional (51)
	30	Wilderness, rehabilitation (35)	Wilderness, utilisation, traditional, rehabilitation (33)	Traditional, rehabilitation (31)
	10	Core (15)	Core, wilderness (13)	Rehabilitation (11)

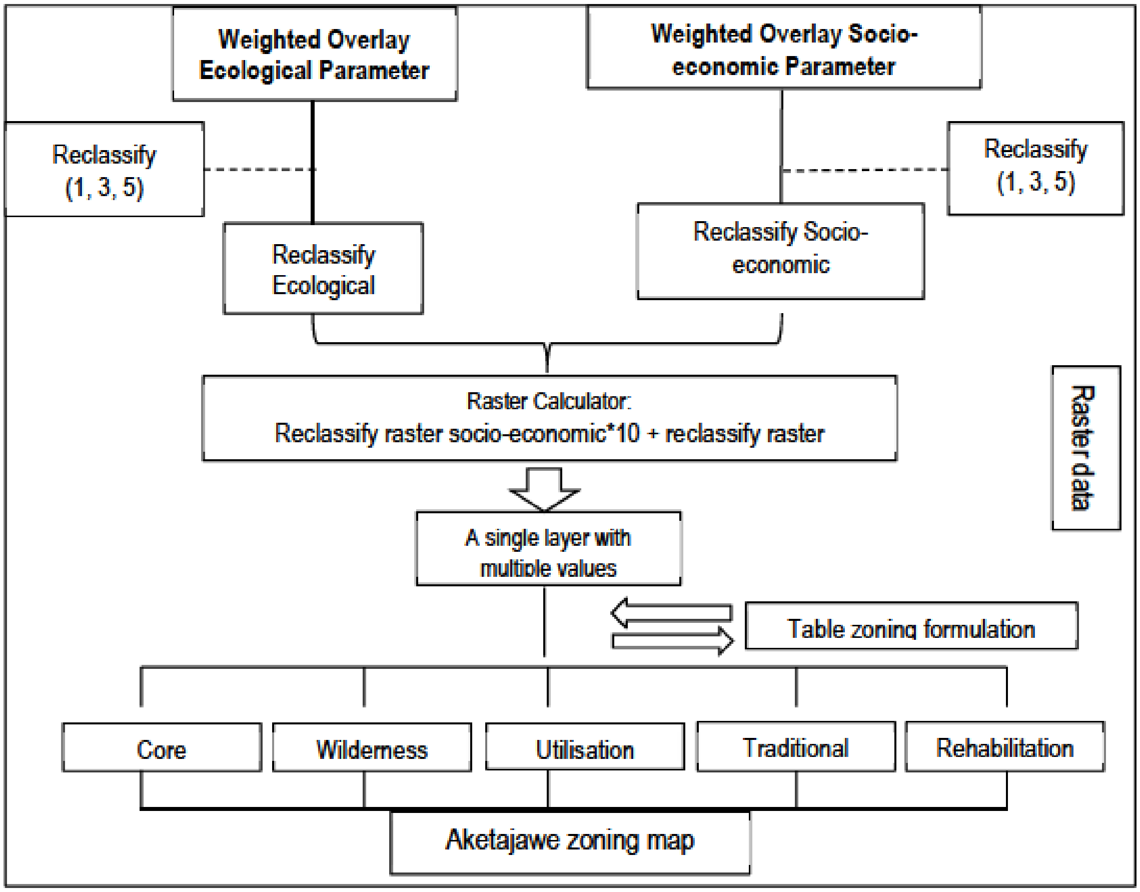


Figure 4.10 The Logical framework for final modelling eco-social model

The eco-social zoning formulation (table 4.6) is classified based on criteria stated in zoning regulation number P.76/Menlhk-Setjen/2015 by the Ministry of Environment and Forestry. This regulation described a set of zones criteria for national park management and block management in protected or sanctuary areas and tourism areas. More detailed guidelines from the Directorate of Natural Resource Conservation and Ecosystems, Ministry of Environment and Forestry regulation number P.11/KSDAE/SET/KSA.0/9/2016, then described the technical guideline for zoning classification or block management in reserve nature areas and conservation areas of Indonesia. This study used an updated ALNP border map; this border was launched in 2014 by the Ministry Forestry declaration number SK.11919/Menhut-VII/KUH/2014, which mentioned that the total area of the Aketajawe Block increased by 693, 95 hectares from 77.100 hectares to 77,794 hectares.

4.7 Chapter Summary

The combination of photogrammetry and satellite imagery analysis provided an alternative approach to national park zoning, which provided more reliable land cover and land use information. These data were integrated with several other spatial data (ecological and socio-economic) in a spatial multi-criteria analysis that offered various opportunities for the decision-making processes, such as national park spatial planning. By the application of weighted overlay techniques in GIS, a different value assigned that allowed several levels of sensitivity to be examined to help decision-makers obtain more robust spatial information about the consequences of using different perspectives, and how the methodology can fit within the Indonesian government regulations and were applicable, for real management situations.

It was important to ensure that this approach yielded practical results and provides something meaningful to park management. This is a crucial part of science. The methodology used in this study was formulated based on the actual management problems in the context of land use allocation in Indonesian national parks. A national park is not just about biodiversity protection it is also important for supporting people's livelihoods. The two models were implemented by using GIS software in order to obtain the best-fit pattern for land allocation in the ALNP. The results of the photogrammetry and satellite imagery analysis, and some GIS analyses are presented in the following chapter.

Chapter 5

Results

The results of the analyses undertaken in this study are presented in this chapter. They cover the photogrammetric measurement results based on the aerial surveys, the satellite imagery analysis for land cover and land use classifications, and also the spatial analysis results for spatial planning modelling.

5.1 UAV Aerial Survey

In total, there were 3,865 images collected and an estimated 678 hectares mapped from 31 flights over three sampling areas. The most extensive flight was carried out in the *Tobelo Dalam* resin harvesting area in Tayawi with an aerial coverage of 118 hectares; the most distance between the aircraft and the remote controller was around 950 metres on one Phantom battery. Over the 31 flights, the total flight time, from take-off to landing was 4 hours 19 minutes and 10 seconds (see detailed information in Table 5.1). Most of the time, data collection was performed without internet or mobile network connections, so the study area base map was downloaded during flight planning and combined with topographic data to determine the correct altitude of the aircraft.

Table 5.1 Aerial survey summary using Phantom 4

Sampling Areas	Number of Images	Flight Path (km)	Total Area Mapped (ha)	Flight Time
Tayawi	1621	53.94	302.4	2.28’33”
Akejawi	1914	45.83	264.45	1.16’43”
Tabanalou	330	12.73	111.020	33’54”
Total	3865	112.50	677.87	4.19’10”

5.1.1 Ground Sampling Distance (GSD)

The GSD can be calculated based on the focal length, camera height, image resolution and sensor size of Phantom 4. The aircraft’s camera had a focal length, field of view (FoV), of 94° 20 mm (35 mm format equivalent), a real focal length of 4 mm, a sensor width of 6.17 mm, and an f/2.8 focus at ∞, a 1/2.3" CMOS sensor with 12.4 M effective pixels, and an image resolution of 4000 x 3000 pixels. Moreover, higher altitude images usually resulted in lower resolutions than for lower altitude images. This is reflected in Table 5.2, where the aircraft height was set to 75, 100 or 150 metres, depending on the topographical conditions. In relatively flat areas, a 75 or 100 metre height was used, with 150 metres being used in hilly areas. The following table shows the GSD numbers for three different aircraft height settings (75, 100 and 150 metres) used to ensure a more than 80 per cent overlap.

Table 5.2 GSD and distance parameters as a function of flight height for Phantom 4 Standard

Aircraft Height (m)	GSD (cm/pixel)	The distance covered on the ground by one image in width direction (m)	Height of single image footprint on the ground (m)
75	2.89	116	87
100	3.86	154	116
150	5.78	231	174

For instance, the camera dots in Figure 5.1 below indicate the positions of each image captured from a height of 75 metres with an overlap of at least 80 per cent at the Parrots Sanctuary site.

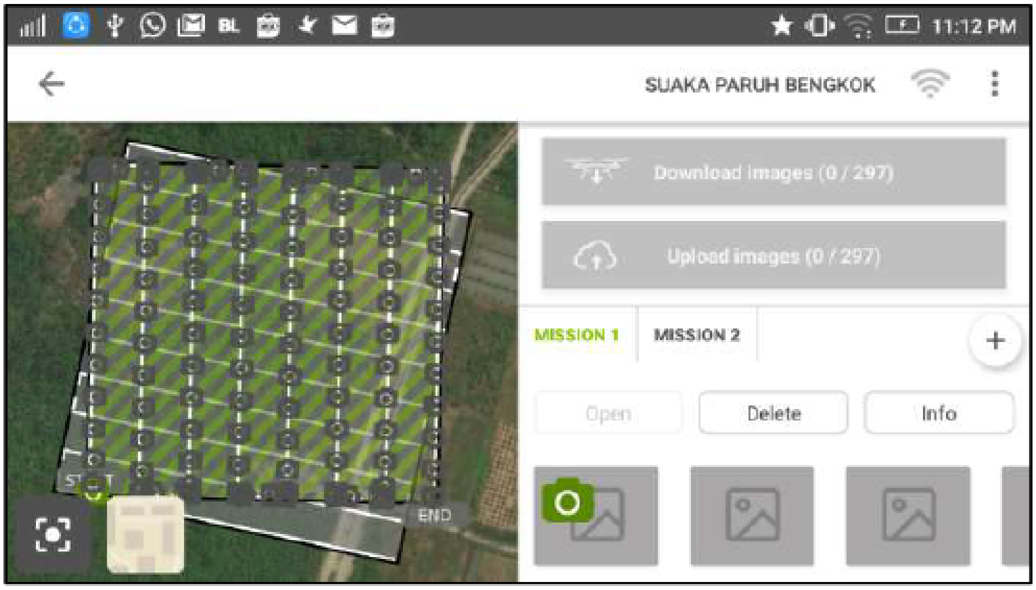


Figure 5.1 The image's position by DJI phantom 4 in Pix4D capture Software

5.1.2 Drone2Map Application for Image Interpretation by Orthomosaic Process

Drone2Map uses photogrammetric analysis to transform images into a 3D digital surface model (DSM), and a 3D point-cloud and an orthomosaic images. The orthomosaic processing was performed with an Intel (R) Core (TM) I7-4790 CPU@ 3.60 GHz with 16 GB RAM. The detailed orthomosaic results are described in the following section.

5.1.2.1 Tayawi

The aerial survey at this site focused on the indigenous people's (*Tobelo Dalam*) activities, mainly in their settlements and when carrying out their livelihood activities. The ALNP boundary changes in 2014 had a major impact on the *Tobelo Dalam* community. This community's settlement is not inside the ALNP territory, which can be seen clearly in Figure 5.2, but, as they are a nomadic group, this community has several temporary shelters inside the park, mainly for hunting and agricultural purposes (Figure 5.2).

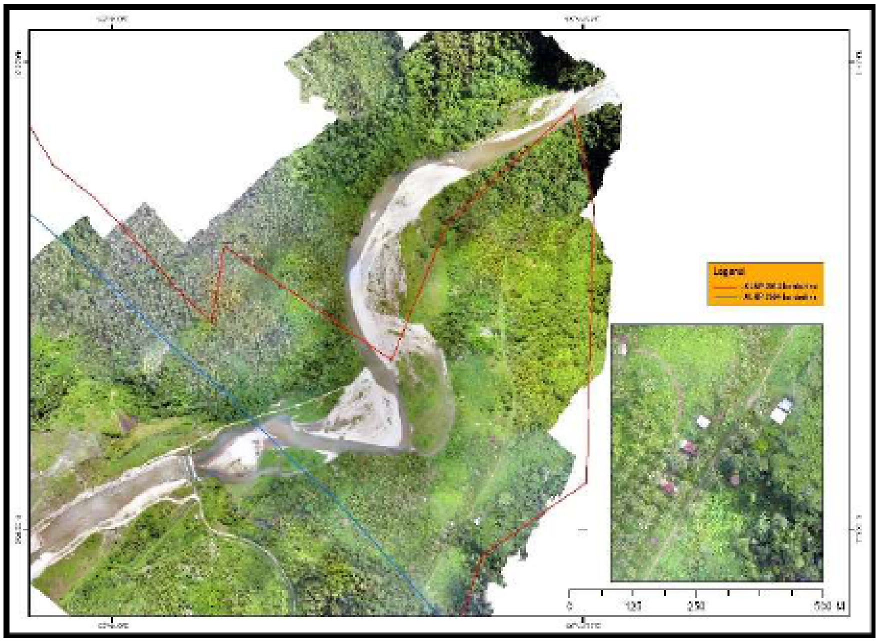


Figure 5.2 *Tobelo Dalam* **main settlement (DJI Phantom 4, 26 May 2018 data acquisition)**

The blue line represents the ALNP border in 2004, and the red line is the present park border, with an estimated 40 hectares of the community's land area reduced due to this new government policy. Within the scale of this image (1:50), the aerial survey detected 11 houses, 1 church, 1 community school, 1 park site office and a coconut plantation. Interestingly, this area had previously been converted from a national park into limited forest production; as a result, it might pose more challenges for future park management to keep the forest intact (North Maluku Spatial Planning 2013-2033). The second image from this site indicated dammar-gum harvesting activities (Figure 5.3). This community has a designated area for maintaining their local traditions, including how to prevent confrontations among the different *Tobelo Dalam* groups as the harvesting process was one of their primary income streams.

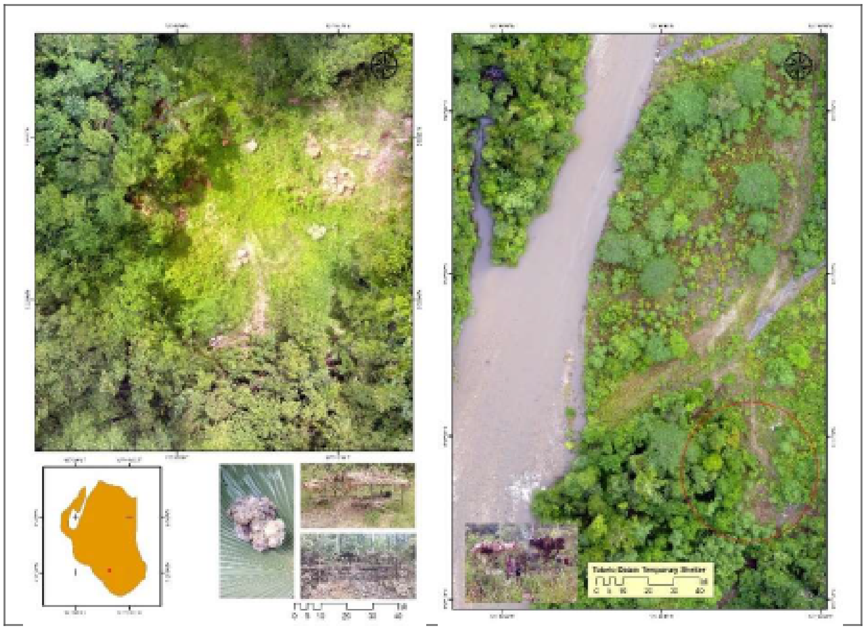


Figure 5.3 (a) *Tobelo Dalam* shelter for resin harvesting; and (b) their shelter for hunting inside the national park from the DJI Phantom 4 aerial survey

5.1.2.2 Akejawi

Land tenure conflict was the biggest issue at this site as the village's agricultural land overlapped with the national park area. This problem had been identified since ALNP development began in 2004 as an impact of the transmigration programme by the Ministry of Agriculture in the mid-1980s, which relocated Javanese people to expand new farming areas in Halmahera Island. The aerial survey focussed on this overlapping area to understand the existing field conditions. In total, the aircraft flew for 1 hour 16 minutes and 43 seconds to collect information about geographical features from 264.45 hectares. The aircraft focussed not only on agricultural land but also on farm infrastructure, settlements and the park's forest. As part of the analysis, Quickbird imagery, that was acquired in 2010, was used to compare the land use changes over the eight years from 2010 to 2018 (Figure 5.4).

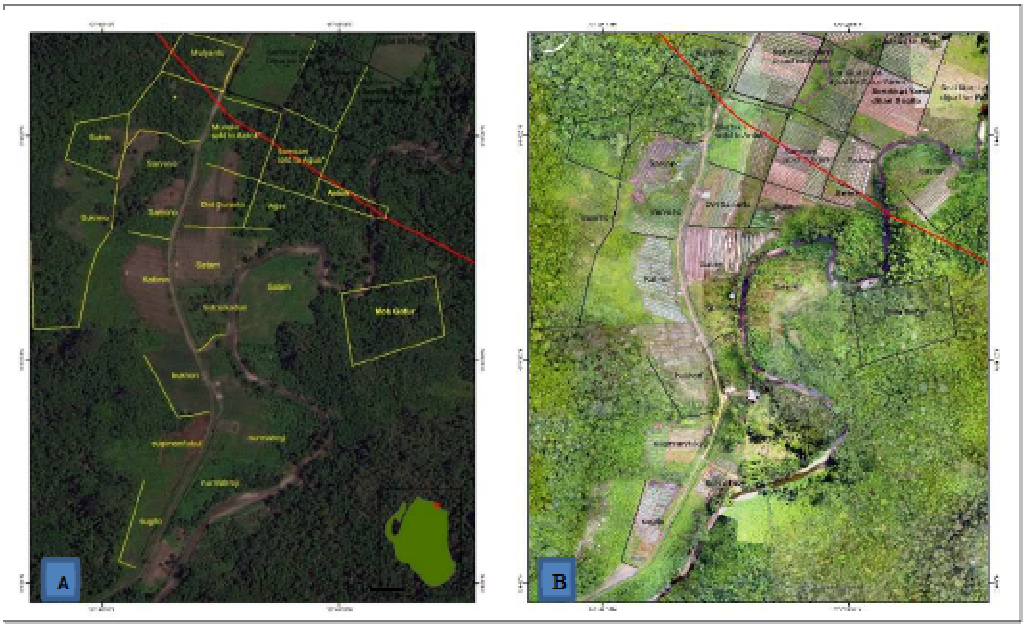


Figure 5.4 Comparison of land-use changes between: (a) Quickbird imagery; and (b) UAV images over eight years (2010 and 2018)

The orthomosaic images indicated that there had been no significant land use changes at this location. In total, there were 21.2 hectares of agricultural land inside ALNP. A small number of land-cover conversions from forest to agricultural land have happened in the Saryono, Agus and Antok farms with a total area of around 2.9 hectares, which were mainly concentrated near the river. These data suggested that the Akejawi people respected the ALNP territory, as shown by their farms remaining outside the park boundary, and by the park management allowing people to access their local natural resources.

5.1.2.3 Tabanalou

Tabanalou village is adjacent to the northern boundary of the park. The local people have been highly resistant to the park because some of them claim that ALNP has occupied their ancestral lands. As a result, park officers have limited access to this area. For these reasons, insufficient data have been collected from this area. The drone survey and ground truthing process found agricultural activities inside the park, such as coconut production and dammar-gum harvesting. An aerial survey was carried out to identify the existing land use. In total, 111.02 hectares area were mapped with a total flying time of 33 minutes and 55 seconds. The aircraft flew over the national park border and the existing road, as the aircraft needed an open landing area for take-off. The coconut farm, which is around 17.06 hectares, is apparently located inside the park (Figure 5.5-yellow polygon); However, due to the UAV's flight-time limitations, this study assumed that the real coconut farm total area was more extensive than this imagery indicated. As a part to mitigate massive land occupation, The Ministry of Forestry Revised the ALNP boundary in 2014 by relocating the park border about 450 metres deeper inside the park area as an effort to give enough national park buffer zone (see figure 5.5). The current ALNP border is represented by the red line (after 2014), while the blue line shows the ALNP border in 2004.

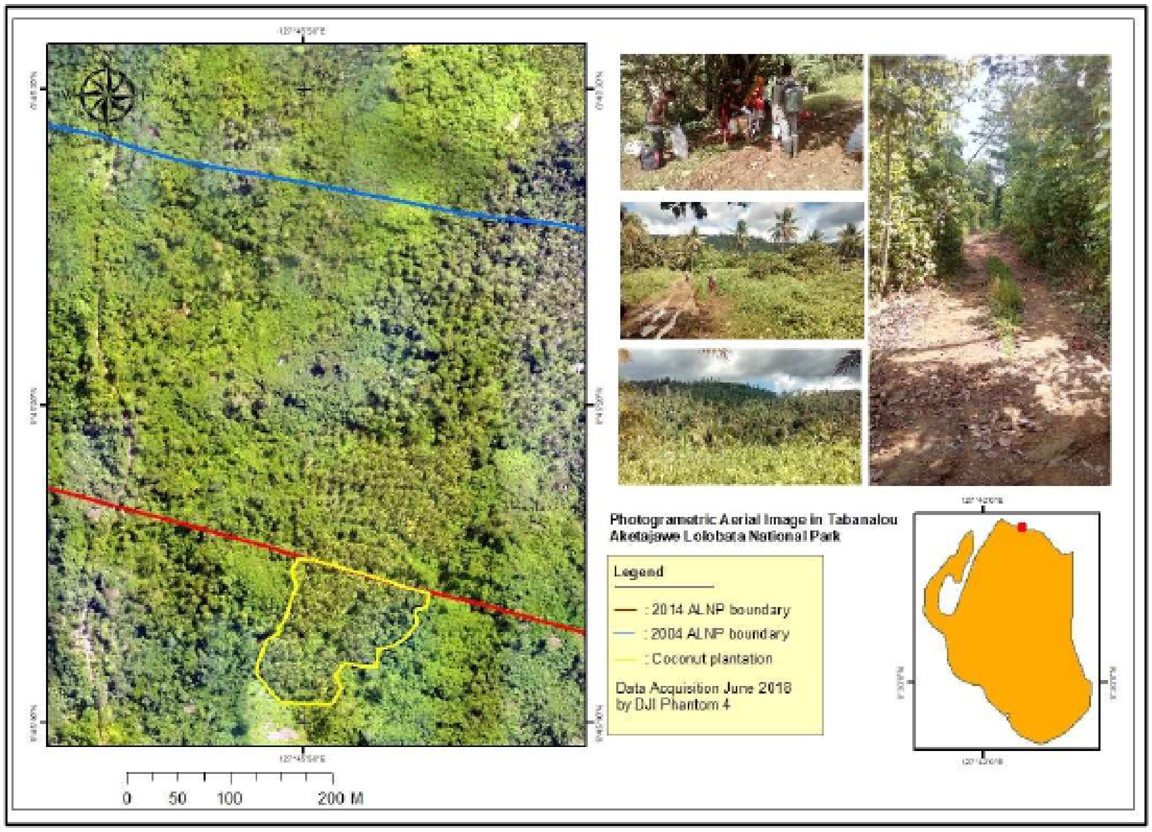


Figure 5.5 Existing land use conditions based on an aerial survey in Tabanalou

5.2 Landsat 8 Land Cover Classification

Up-to-date land cover data were essential for better national park spatial planning. Initially, SPOT 7 with 1.5-metre pixel resolution (acquired in 2017), gathered from the Indonesian National Institute of Aeronautics and Space (LAPAN), was used for this study, but due to a high cloud cover percentage in the research area, this imagery was used for land use classification and combined with orthomosaic images. Alternatively, imagery from the Landsat 8 OLI and Landsat Enhanced Thematic Mapper Plus (ETM+) with lower pixel resolution (30-metre) was used. Both imagery sets were freely downloaded from the United States Geological Survey

(USGS) website (http://glovis.usgs.gov/). Landsat 8 has an additional panchromatic band with a 15-metre resolution by using band 8 and Pansharpening tools in Arc Map 10.6. The Landsat 8 OLI imagery (path 59-60 row 110) was acquired on 6 March 2016 and used in this study because it has a low (less than 10 per cent) cloud cover. More recent Landsat 8 imagery was available on the USGS website, but most images had high cloud cover percentages and were unsuitable. Detailed information about satellite imagery processing to provide land cover has been outlined in a flowchart in appendix A.

The supervised maximum likelihood classification (MLC) technique was used for identifying land cover classes in Aketajawe Block, based on land cover categorisations by the Directorate Planning Agency, Ministry Environment and Forestry Indonesia Number P.1/VII-IPSDH/2015 on 26 May 2015. The MLC results showed that in general, Aketajawe's land cover could be categorised into four categories; primary forest, secondary forest, open-area or critical land and water bodies (river). All these classifications are presented in Figure 5.6. Once the MLC had been completed, the Calculate Geometry tool was used to estimate the total area in each land cover class. The analysis specified that primary forest has the largest proportion, at 84.32 per cent, with a total area of around 65,590 hectares. On the other hand, water bodies had the smallest area and proportions, at 396 hectares (0.5%) (See table 5.3 for a more detailed breakdown). The total area of Aketajawe land cover classifications, as presented in table 5.3 was 77,780.84 hectares; this number was not significantly different from the official Aketajawe area by the Ministry of Forestry decree number SK.1919/Menhut-VII/KUH/2014, where the total area in Aketajawe is listed as 77,793.95 hectares.

Table 5.3 The total area and proportion of land cover classification in Aketajawe

No.	Land Cover Classification	Total Area (ha)	Proportion (%)
1.	Primary forest	65,590	84.3
2.	Secondary forest	9749	12.5
3.	Open area	2046	2.6
4.	Waterbody	396	0.5
	Total	77,781	100

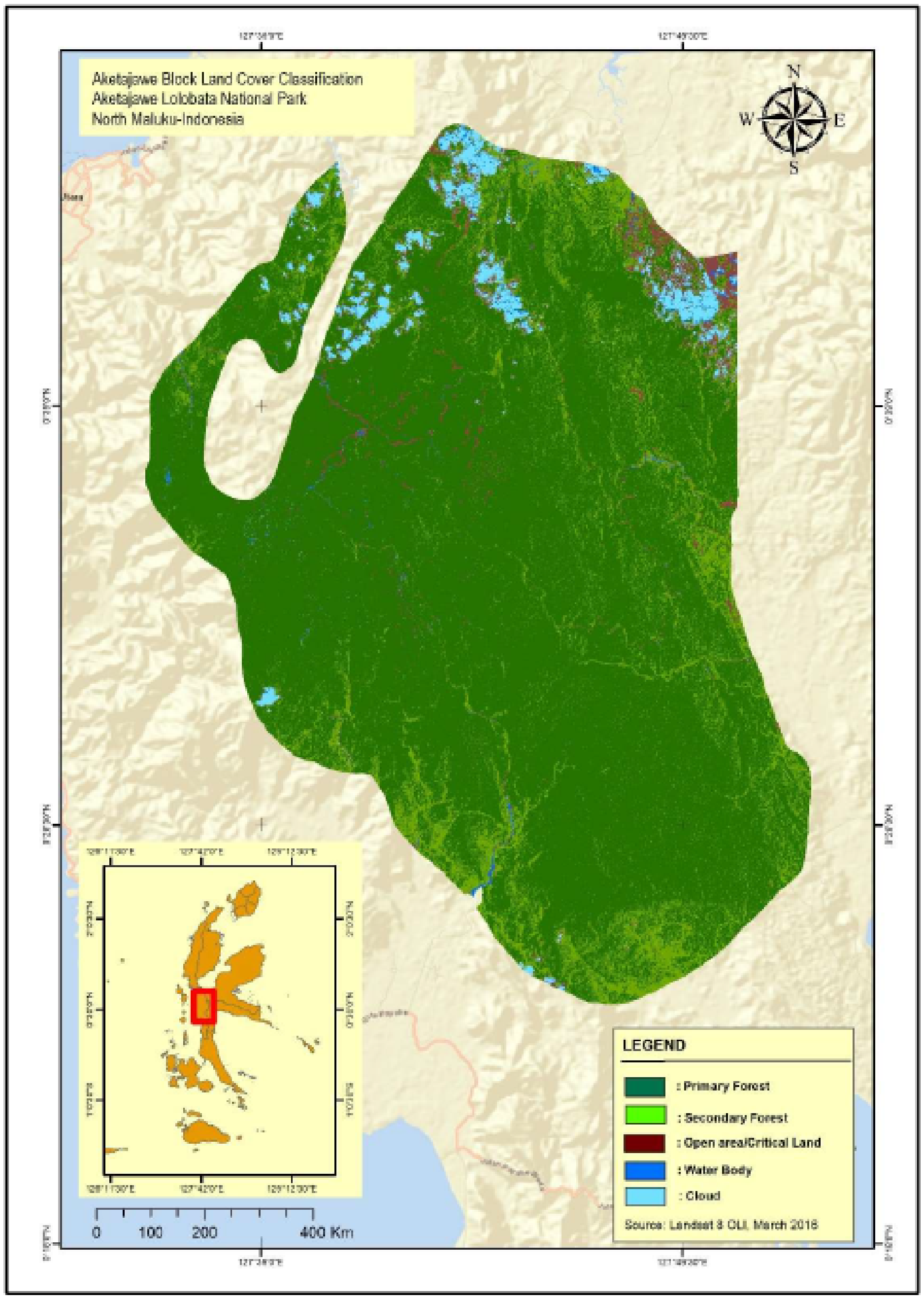


Figure 5.6 Land cover classification Aketajawe region map based on Landsat 8

As a conservation area, the main ALNP management objective was to protect the intact forest, including their biodiversity and local people's livelihoods. Therefore, the data provided in table 5.3 are used as the main components of this study for further analysis.

5.2.1 Cloud Cover Issues in Landsat 8

With remote sensing in humid tropical areas, cloud cover was the biggest obstacle and the most apparent problem in the land surface spatial analysis (G. Asner, 2001). This issue was found in both the SPOT and Landsat imagery. During data collection, the Earth Explorer database over the period from 2016 to 2018 was inspected for the research area. The results indicated that all Landsat 8 imagery scenes in the North Maluku region experienced cloud coverages of greater than 20 per cent. The best data with the lowest cloud percentages were two scenes that were acquired on 6 March 2016 and were used for the land cover classification. The MLC result estimated the total cloud cover at 2221.8 hectares (2.86%); with no earth surface information underneath. SPOT 7, which was acquired in the same year, was used to interpret the land cover for the areas covered by clouds. A new polygon was created about the cloud areas in the Landsat 8 imagery and this polygon was then overlain on the SPOT 7 imagery to interpret the land surface characteristics. SPOT 7 has a higher resolution than Landsat 8, at a 1.5-metre pixel resolution. With a higher pixel resolution, this suggested that the result were more reliable; accordingly, the cloud areas were identified as primary forest as interpreted from the SPOT 7 image.

5.2.2 Accuracy Assessment of Remotely Sensed Data

Once the land cover classification had been performed, it was important to check the accuracy of the results. Two types of assessment were conducted to measure the level of accuracy of the MLC results and also the producer's accuracy and the user's accuracy. The assessment focused on a clearly identified area in the satellite imagery (Landsat 8 OLI). There were 50 points created in each type of land cover class, so in total 250 points were used in this study. The producer and user accuracies were then calculated using the formulae in section 4.3.5, and are tabulated in table 5.4, below.

Table 5.4 Theoretical error matrix, tabulation of producers, users, accuracy assessment

Land Cover Classification	CLASS					Total	Correct Sampled	Producers (%)	Users (%)
	1	**2**	**112**	**146**	**190**				
Cloud	50	0	0	0	1	51	50	100	98.04
Primary forest	0	49	0	2	0	51	49	98	96.08
Secondary	0	1	47	0	0	48	47	94	97.92
Open area	0	0	0	41	6	47	41	82	87.23
River	0	0	3	7	43	53	43	86	81.13
Total	50	50	50	50	50	250			

The user's accuracy varied from 81.13 per cent to 98.04 per cent, while the producer's accuracy ranged from 86 per cent to 100 per cent. The variations in the accuracy percentages indicated a confusion in the open area class with other land cover categories, but this was not significant. The producer's accuracy reflected the level of reliability of predictions in each particular category. The user's accuracy contrasted the pixel numbers from the classified images that matched the reference data. This reflected the reliability of the land cover classification for the user. As a result, the user's accuracy is generally a more useful measurement of the classification in the actual utility of the field. Overall, the user's accuracy in this study was more than 80 per cent, so was reliable for further analysis as the primary and secondary classes had high percentages of accuracy, at more than 95 per cent (Congalton, 1991).

The overall accuracy of the results was 92 % and with 90 % for the overall Kappa statistics (Table 5.5). In a map derived from Landsat 8 or satellite imagery, the number of overall classification accuracy measurements at 92 per cent indicated that the map classes were properly differentiated using the classification method applied (Landis & Koch, 1977). In addition, the overall Kappa measures for accuracy classification was 90 per cent (refer to Figure 4.5 in page 64) suggesting an almost perfect agreement between verification data and classified data (Fenstermaker, 1991).

Table 5.5 Overall and kappa accuracy assessment

Land Cover Classification	Commission	Omission	Overall (%)	Kappa (%)
Cloud	0.02	0		
Primary forest	0.039	0.02		
Secondary forest	0.021	0.06	92	90
Open area	0.128	0.18		
River	0.189	0.12		

The commission error describes the number of pixels that were incorrectly classified in a category they did not belong in. For example, the highest commission errors were in the river category, which meant that they had the highest number of pixels (10) which were incorrectly classified as river. Similarly, the number of omission errors reflected the number of pixels that were incorrectly classified into their correct category (land cover classification). For instance, the open area category was 0.18 with a total of 9 points (Table 5.4 and 5.5), which actually belonged to this class but were not classified in this category. The Kappa Coefficient assessment in this study was calculated at 90 per cent, which meant the level accuracy of the land cover classification was close to perfect (refer to Figure 17 in chapter 4. Apart from overall accuracy, the individual parameters above show a highly reliable output from model performance of the particular category or class in this study area. Overall, the accuracy assessment indicated that this supervised classification result was reliable for further use.

5.3 Integration of Orthomosaic Images and SPOT 7 and Landsat 8 for Land-Use Classification

A new approach to land use identification by combining orthomosaic images and land cover classification was initiated in this study. This approach performed well for reducing the Landsat 8 limitations in terms of lack of pixel resolution in order to derive the present land surface. There were significant differences in pixel resolution, whereas the orthomosaic images had a resolution of 4.4 cm, while SPOT 7 and Landsat 8 have 1.5 m and 15 m pixel resolutions, respectively. As an example, the MLC classified Akejawi as an open area because this area has a brown colour in Landsat 8. However, the actual conditions in this area was agricultural land (see detail in Figure 5.7).

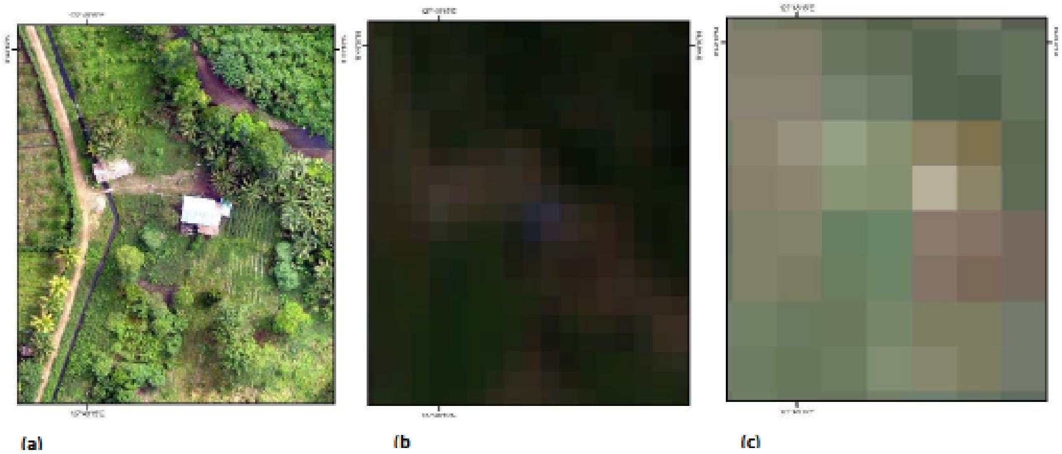
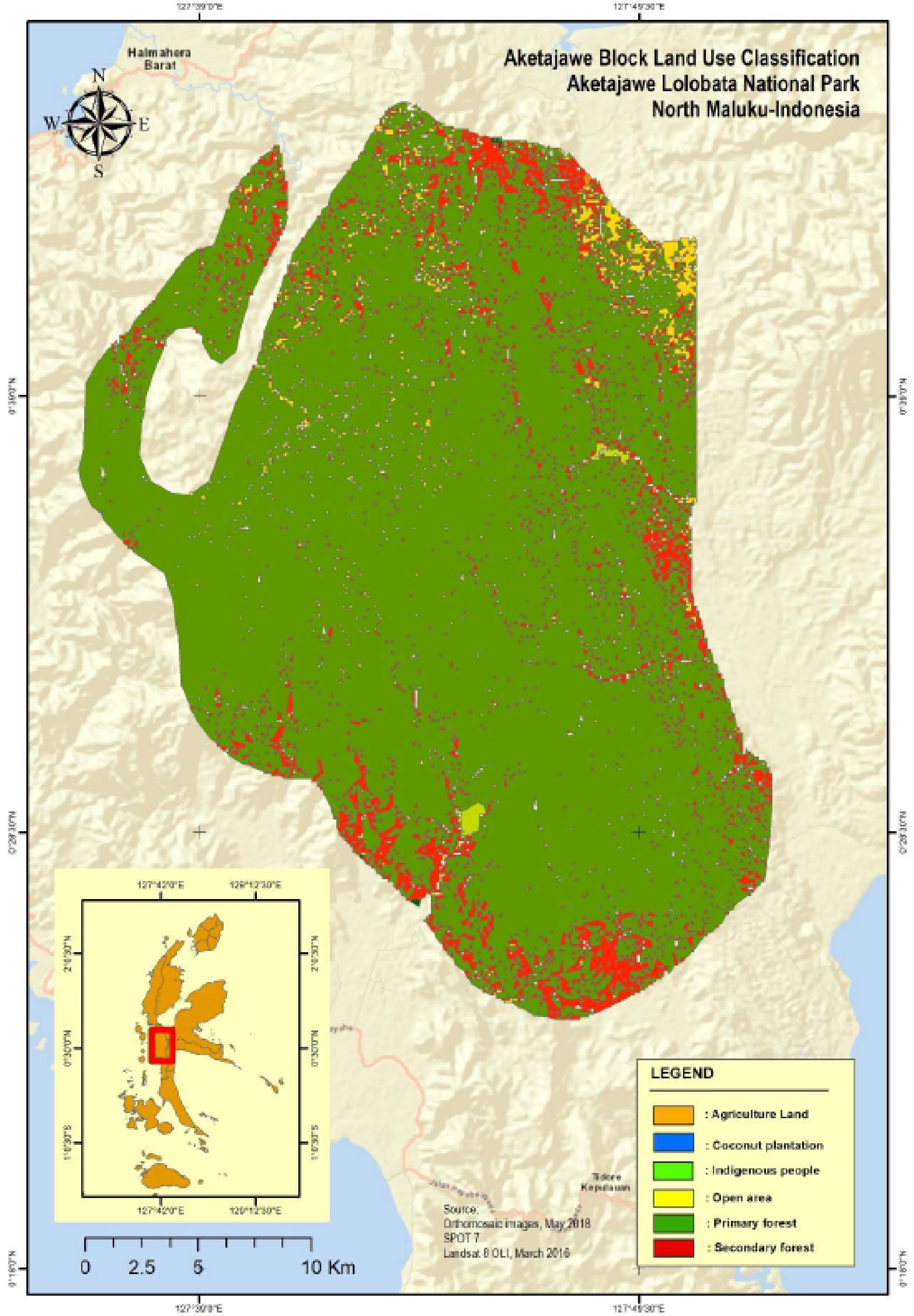


Figure 5.7 Agriculture land in Akejawi Spotted by three different tools:
(a) orthomosaic image; (b) SPOT 7 imagery; and (c) Landsat 8 imagery (scale of 1: 10 m)

The images, above, demonstrate the gaps between the UAV images and the SPOT 7 and Landsat 8 imagery. The UAV imagery provided significant additional information for Aketajawe land use classification. Therefore, to incorporate the photogrammetric survey in section 5.1.2 into the land use classification, a new features class was created in the UAV mapped area, and a specific land use class was added to the attribute table before it was merged into the land use polygon. This layer was then converted into a raster format. The resulting land cover layer showed that primary forest has the largest land use proportion, at 87.3 per cent, and agricultural land has the smallest proportion, at 0.01 per cent, (Table 5.6). Figure 5.8 presents a map of the classified land covers.

Table 5.6 Land use classification with the proportion in each category in Aketajawe

No	**Land Use**	**Perimeter (km)**	**Area (m^2)**	**Total Area (ha)**	**Proportion (%)**
1	Secondary forest	1,732,779.5	76,922,284.3	7692.2	10
2	Open area	497,257.7	18,695,371.7	1869.5	2.43
3	Primary forest	2,199,954.9	671,468,625.2	67,146.9	87.3
4	Coconut plantation	4,270.9	253,666.9	25.4	0.03
5	Agriculture land	1,975.5	138,147.6	13.8	0.01
6	Indigenous people	11,976.6	1,643,928.9	164.4	0.21



Source:
Orthomosaic images, May 2018
SPOT 7
Landsat 8 OLI, March 2016

Figure 5.8 Land use classification in Aketajawe

Aerial surveys bring valuable information to complex spatial planning evaluations, which help to understand land surface characteristics from the actual conditions. The orthomosaic images from the three sampling areas provided high-resolution information that would be very difficult to determine from satellite imagery, such as the *Tobelo Dalam* house distribution and the extent of agricultural land. Despite the weakness of battery performance, UAVs offered more advantages to identify more specific or sensitive areas in land management, including national park spatial planning.

5.4 Application of Multi-criteria Spatial Analysis into GIS Software

Both the raster and vector processing tools in Arc Map 10.6 were used to examine multiple spatial parameters and investigate a suitable model for Aketajawe spatial planning. As explained in table 4.2 and Figure 4.7 in chapter 4, GIS analysis involved integrating several spatial layers including: multiple ring buffers, finding distances, reclassifying and converting data formats, raster processing and overlaying techniques. Overlay analysis was used to evaluate suitable areas for particular zoning types, and the weighted overlay technique was performed to understand the level of importance weights had on zone criteria. Then SMCA Provided information in smaller, more understandable, parts. Parameters were analysed separately and then integrated into a logical framework. This section described information about the results from the reclassification and weighted overlay analysis.

5.4.1 Reclassified Zoning Parameters

As described in table 4.2, it was important to create some new raster layers before carrying out the weighted overlay analysis. Once this analysis was performed, reclassification was necessary to give a new value to each zoning parameter class. These represented the levels of importance between the zoning parameter classes and the zoning types. The reclassification process was executed based on formulations from the zonal and eco-social models (tables 4.3 and 4.4). The principle scheme used a value of 5 for the highest level of correlation, 3 for moderate level and 1 for the lowest level. This reclassification process was performed based on national park technical guidelines, which mainly protected natural ecosystems or biodiversity and accommodated local people's needs (Dudley, 2008). The reclassification results are explained, below, in detail:

5.4.1.1 Zonal Model Input Layers

In total, 30 layers resulted from the reclassifying process for ecological parameters and 20 layers for socioeconomic parameters (see details in appendix B). This reclassification process was carried out for each type of national park zoning (core, wilderness, utilisation, traditional, and rehabilitation) and was formulated based on Table 4.3. In total, there were 38 classes in each type of zoning: 26 classes for ecological parameters and 12 for socioeconomic parameters (appendix 2).

5.4.1.2 Eco-social Model Input Layers

Table 4.4 was used as a reclassification guideline in this model. In total, six layers resulted from the ecological parameters and four layers from the socioeconomic parameters. All classes of ecological parameters were formulated based on the level of their relationship with biodiversity protection; so, the biodiversity hotspot areas and protection areas have values of 5 (10 classes were accounted for in this value). A similar processing analysis was formulated for values of 3 and, in total, there were 16 classes for values of 3 and 1 (eight classes for each value). In summary, value 5 had the highest number of classes over value 3 and 1, so this result might represent the actual conditions in Aketajawe as this area placed a high value on biodiversity. Similar reclassification processes have been formulated for the socioeconomic parameters; all classes focussed on their level of relationship to economic contribution and local culture. In summary, there were four layers resulting from this analysis with 12 classes having values of 5, 3, and 1 (four classes for each value). The following images present the results from the eco-social model reclassification process (Figures 5.9&Figure 5.10).

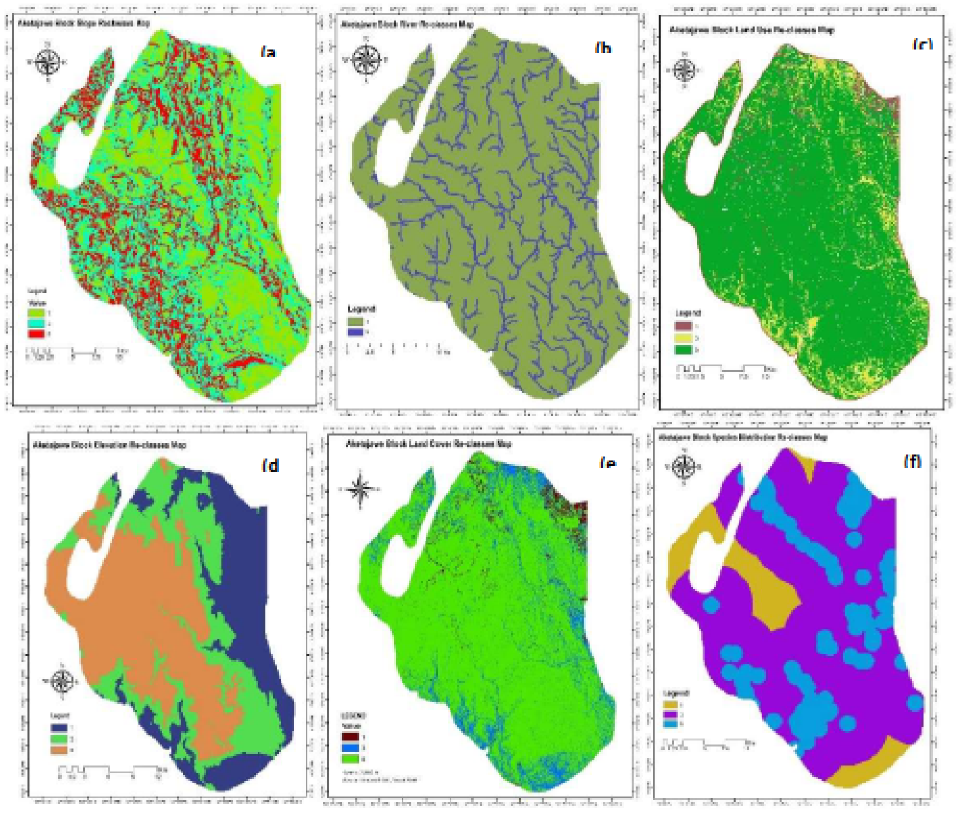


Figure 5.9 (a) Slope reclassification layer; (b) River reclassification layer; (c) Land use reclassification layer; (d) Elevation reclassification layer; (e) Land cover reclassification layer; (and f) Wildlife distribution reclassification layer.

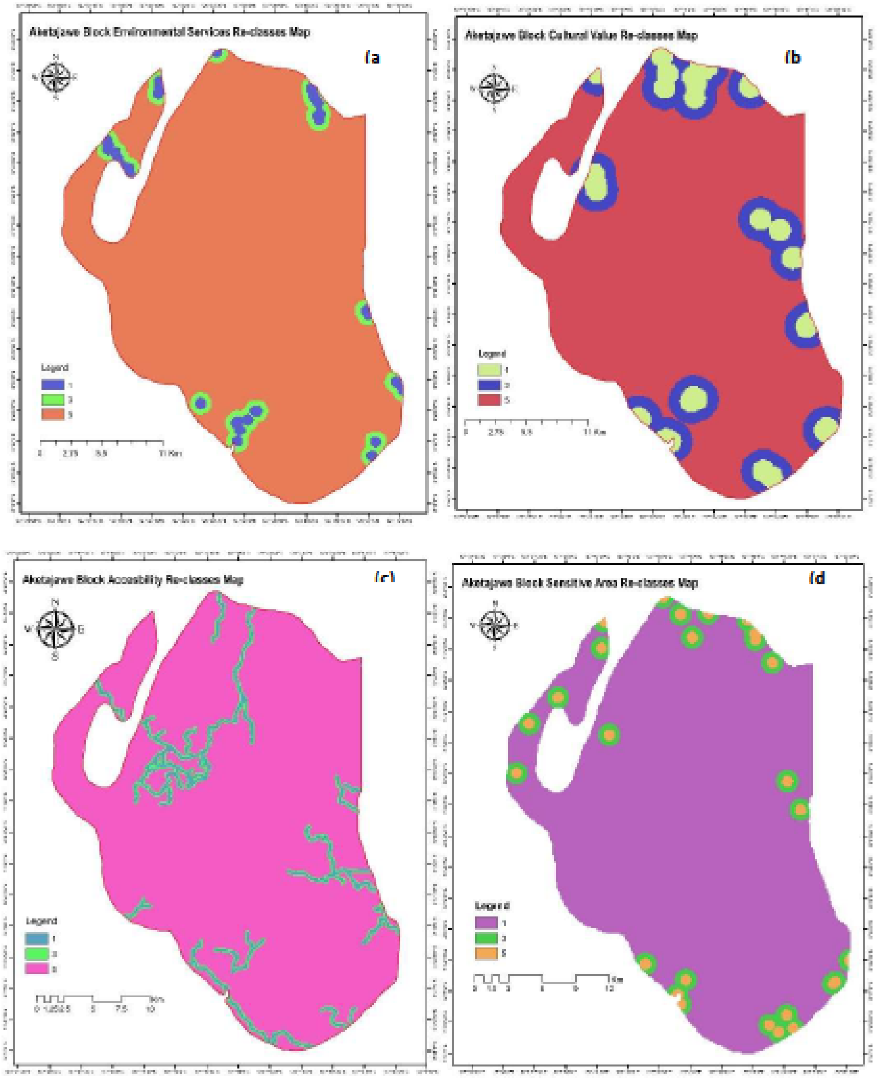


Figure 5.10 (a) Environmental services reclassification layer; (b) Cultural value reclassification layer; (c) Accessibility reclassification layer; and (d) Sensitivity area value reclassification layer (socioeconomic parameter)

5.4.2 Weighted Overlay Results for the Zonal and Eco-social Models

Once the reclassification process was finished, the new raster layers were ready for weighted overlay analysis. A set of weighting values was used to define the levels of correlation between the type of zoning and the zoning parameter — this set of weights is presented in table 5.7 for the zonal model and in table 5.8 for the eco-social model.

5.4.2.1 Zonal Model Results

A set of zonal model parameter raster data was used as input data in the weighted overlay tools, followed by inputting the important weighting percentages. In total, there were five resulting layers; one for each type of zone. Each layer had five different classes of value (1 to 5, see details in Figure 5.11). Further investigation was needed to evaluate information for each value by interpreting the real field conditions and spatial analysis results. This was carried out by evaluating each attribute table value and their position in the real world (against SPOT 7 and Landsat 8 imagery). As a result, this study focused on values of 4 and 5 because these values represented the most important type of zoning and provided a suitable location for any particular type of zoning. Boolean Analysis was used for the next stage.

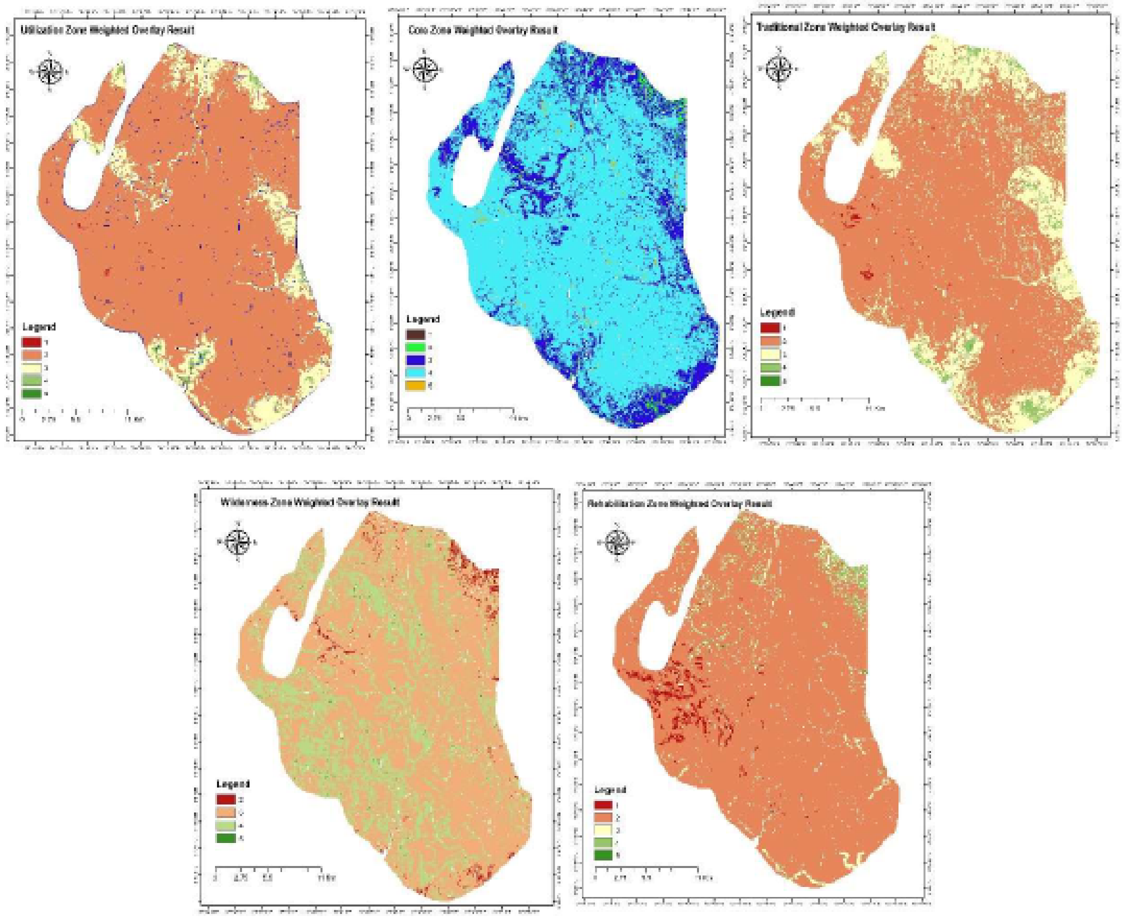


Figure 5.11 Weighted overlay analysis zonal model results

Values of 4 and 5; were reclassified to a value of 1, which meant suitable areas for any particular type of zoning. Other classes (1, 2, and 3) were reclassified to a 0, representing areas not suitable for a particular zone type. For easier visualisation, values of 1 were given a colour while 0 values were made transparent in Figure 5.12.

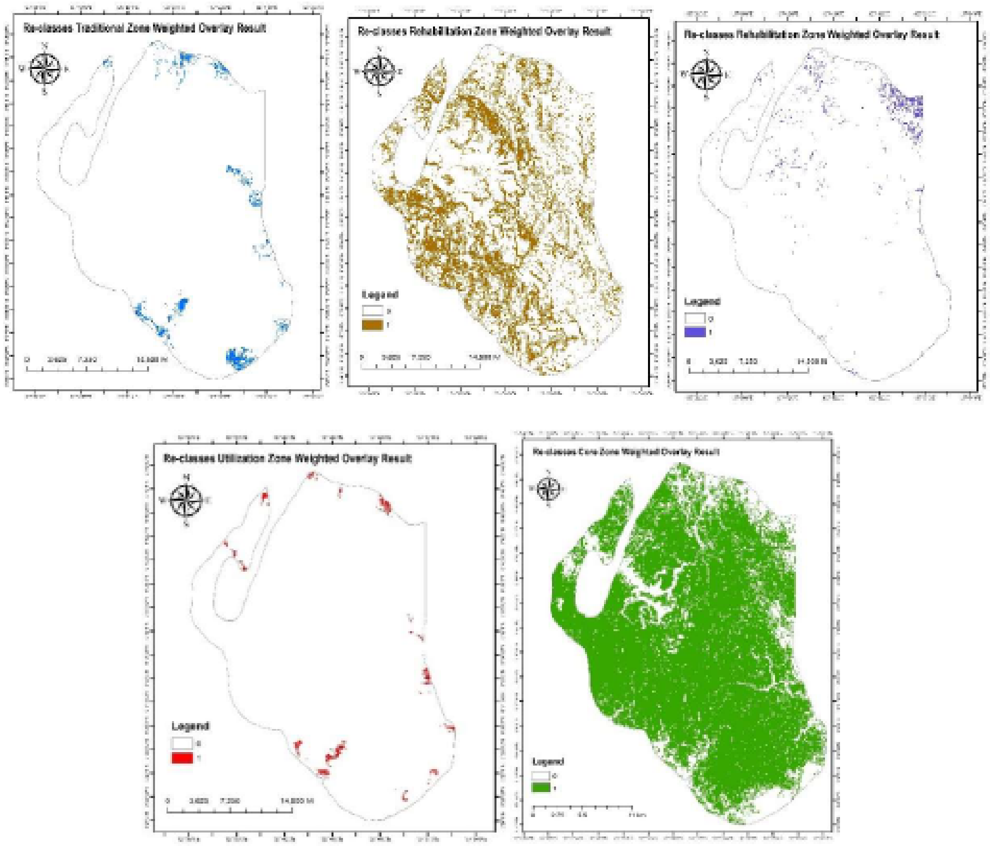


Figure 5.12 Re-classified weighted overlay zonal model result using Boolean logic for the Zonal Model

5.4.2.2 Eco-social Model Results

The weighted overlay method was also used to combine the ecological and socioeconomic parameters in the eco-social model. As a result, two raster layers resulted from this model; namely, raster ecology and raster socioeconomics. Table 12 was used as a guideline to formulate each class. This table shows that all classes of ecological parameters have been set mainly for biodiversity protection, with community welfare and local cultural protection having second priority. This table also described the differences in level between each zoning class. For the ecological parameters, it was noticeable that wildlife distribution, slope and land cover have the highest proportion, at 20 per cent, and elevation was the lowest, at 10 per cent. Elevation had a small proportion because Aketajawe mainly promoted bird conservation, and most of these species have higher elevation ranges. In the socioeconomic parameter, cultural value had the highest proportion, at 35 per cent. This high proportion represented the park management's objective of accommodating local people's needs. Some indicators have been used to represent cultural values, including indigenous people's settlements and their territorial areas, local people's activity, including their plantations so, by attributing the biggest proportion, this can give enough space for local people to keep their traditions or activity to use the natural resource in spatial planning. The weighted overlay eco-social model result is presented in Figure 5.13.

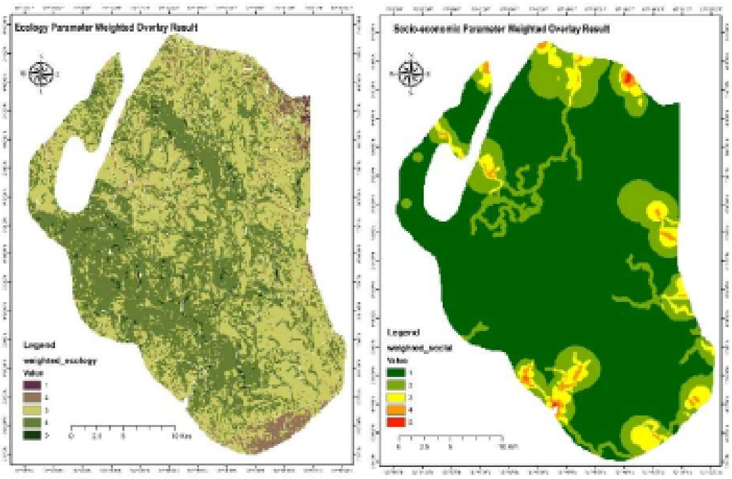


Figure 5.13 Results of the weighted overlay analysis for the eco-social model

In Figure 5.13, it is clear that five classes (1, 2, 3, 4, and 5) resulted from the weighted overlay analysis. However, it was difficult to interpret these values, so reclassification was needed to simplify these values into 1 (not suitable), 3 (suitable) and 5 (most suitable) as in this study's evaluation scheme. Reclassifications are important to set raster values for math algebra operations, so was conducted by reclassifying the spatial analysis tools, and using the raster data (weighted ecology and weighted social) as an input layer. In the reclassification tool, three output classes were defined for output classification then a new value was (1, 3, or 5) assigned to each class correctly (Table 5.7) — this result is provided in Figure 5.14.

Table 5.7 Reclassification weighted ecology and weighted socioeconomic

Old Classes	Classify	A New Classes
1	1	1
1-2	1-2	3

2-3	**2-5**	**5**
3-4		
4-5		

*Changing classes from 5 to 3 in the classification menu

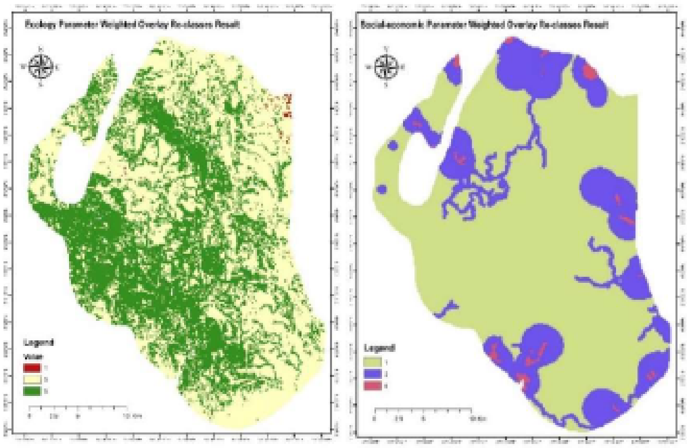


Figure 5.14 Results of the reclassified weighted overlay analysis for the eco-social model

5.5 Zoning Parameter Formulation for Aketajawe Spatial Planning

Optimising multiple uses of land or forest was a big challenge for today's land managers and governments. To achieve this, the park managers needed to evaluate their park areas for their economic, environmental and social importance and then derive suitable spatial planning measures and appropriate legislation. In national park management, these spatial planning measures must meet expectations for various demand land uses, while supporting the optimum protection of natural resources. Through two different schemes, this study has attempted to encompass multiple land use objectives in park management into a single comprehensive spatial planning or zoning map. Section 4.5 presented two different methods, which have been tested in order to formulate several vital factors in zoning classification, and the results are described as follows:

5.5.1 Zonal Model

The biggest challenge in this model was how to combine all five different zoning layers into a single map without removing any essential values. Therefore, the Merge tool was used. Each raster-zoning layer was first converted to a polygon layer (vector data). A new attribute was then added to each layer and given a value of 1 or 0 depending on whether it represented a particular zoning type or not. In the final step, all polygon layers were combined using the Merge tool and the layer legend was changed to reflect the unique zoning types, as shown in Figure 5.15.

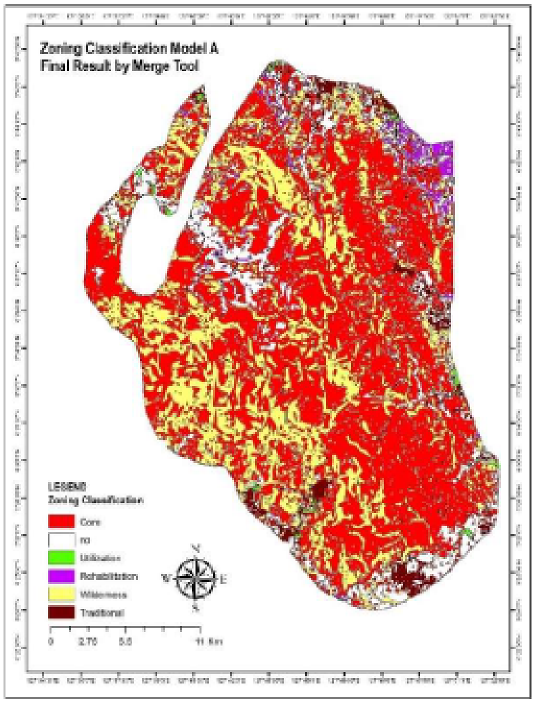


Figure 5.15 Zonal model result using the Merge tool

Figure 5.15 shows the different areas for the zoning classifications. In principle, the zoning formulation analysis was finished, but the next essential stage was to make the map easier for decisionmakers to understand.

5.5.2 Eco-social Model

Figure 5.13 highlighted the crucial step of combining raster ecology and raster socioeconomic layers, and, as a part of this stage, Figure, 5.14 explained the importance of reclassifying these raster data. Three class values (1, 3, and 5) in both zoning parameters represented the level of sensitiveness/importance of Aketajawe area from the zoning criteria, so this value combination was needed for further analysis. A map algebra operation used suitable coding in order to make the outputs easier to interpret. To begin, each class of socioeconomic parameter was multiplied by ten and this new value was then added to the raster ecology layer using the raster calculator. The formula is as follows: Eco-social model = raster social-economic*10 + raster ecology so, in total, nine coding groups resulted. Each coding represents a suitable area for any zoning classification as presented in Table 5.9 and Figure 5.16, as follows.

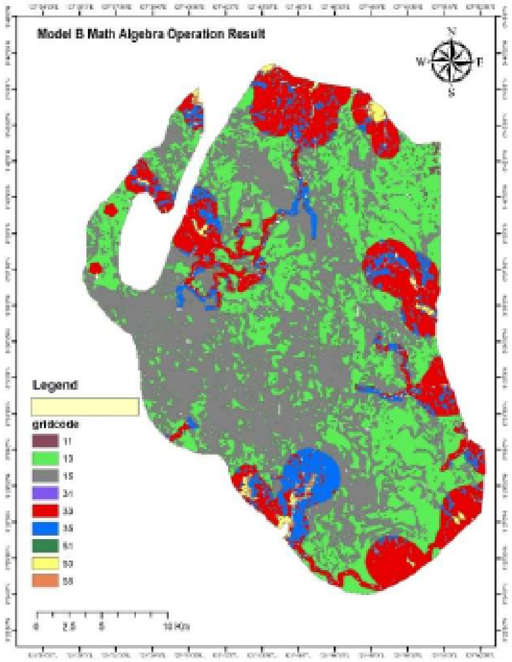


Figure 5.16 Map algebra eco-social results

A single layer with nine new classes resulted from this formulation. Each class reflected a combination between the ecological and socioeconomic parameters based on the spatial analysis, while the layer coding can be used to interpret the suitable classification of zoning types. It was performed by matching the coding formulation in table 5.6 (section 4.6.2). These raster data were converted into the polygon format and Calculate Geometry was used to calculate the total area in each coding, as presented in table 5.8.

Table 5.8 Eco-social model total area calculation based on math algebra operation

Coding	Zoning Formulation	Colour	Total Area (ha)
11	Rehabilitation	Dark brown	145.72
13	Core/Wilderness	Green	27,551.33
15	Core/Wilderness	Grey	29,055.49
31	Traditional/rehabilitation	Purple	21.83
33	Wilderness/utilisation/traditional/rehabilitation	Red	13,702.74
35	Wilderness/rehabilitation	Blue	5,061.98
51	Specific/traditional	Dark green	1.49

53	Utilisation/traditional	Yellow	650.48
55	Wilderness	Brown	201.99

However, from the park management's perspective, the results from the math algebra operation were not easy to interpret and were similar to the zonal model Merge result. Therefore, final adjustments were made to create a result that was easier to understand and implement.

5.6 Final Adjustments for the Spatial Planning Classifications

Further refinements were formulated in this final stage to create a map for each model. Indonesian regulation number P.76/Menlhk-Setjen/2015, P.11/KSDAE/SET/KSA.0/9/2016, and ALNP planning documents were used as technical guidelines with some key information used for final adjustment, as follows: (1) The core zone was buffered so that this zone was not adjacent to the national park border area; (2) Four-wheel drive roads identified from the satellite images were buffered and classified for rehabilitation as they were not suitable for the core zone; (3) Wilderness zones were positioned adjacent to the core or utilisation zones; (4) Accessibility to the utilisation zones was enforced; and (5) Public infrastructure was designated for the specific zones. Figures 5.17 and 5.18 present the final maps for the zonal model and eco-social model, respectively.

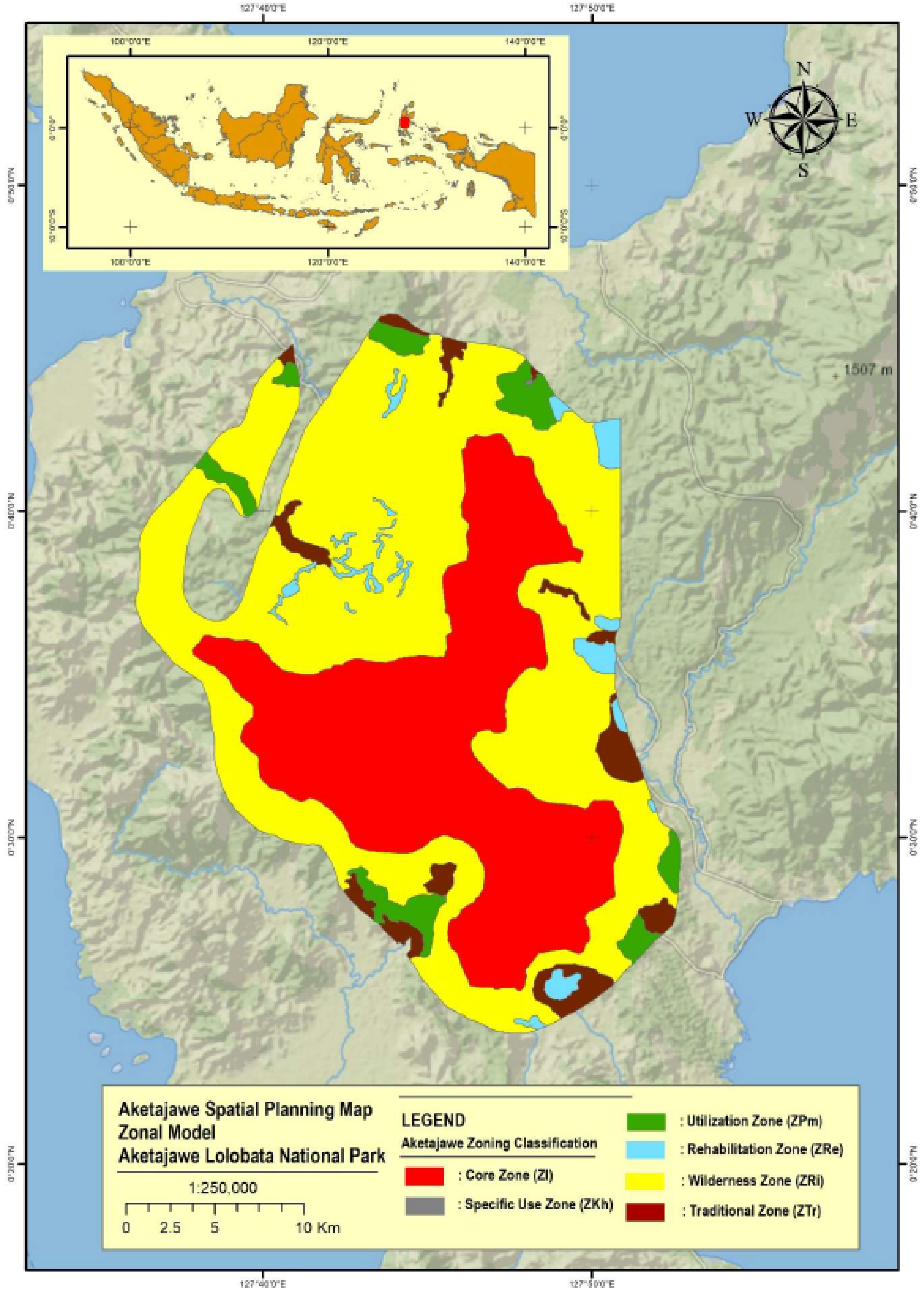


Figure 5.17 Results of the Aketajawe spatial planning zonal model

From this map, it was obvious that the wilderness zone has the biggest proportion, at 54.49 per cent, with a total area of 42,397.8 ha, and this was followed by the core zone, at 34.74 per cent, with a total area of 27,026.963 ha. Detailed spatial planning results for a zonal model can be seen in table 5.9.

Table 5.9 The proportion zonal model results

No	Zoning	Code	Shape Length	Shape Area	Total Area (ha)	Proportion (%)
1	Specific use	ZKh	1,207.28	95,098.041	9.510	0.01
2	Core	ZI	119,803.89	270,269,628.75	27,026.963	34.74
3	Traditional	ZTr	117,626.13	33,361,169.70	3,336.117	4.29
4	Wilderness	ZRi	417,968.75	423,978,044.71	42,397.804	54.49
5	Rehabilitation	Zre	114,817.16	19,259,059.42	1,925.906	2.48
6	Utilisation	ZPm	79,101.28	30,980,370.34	3,098.037	3.98
	Total				77,794.337	100.00

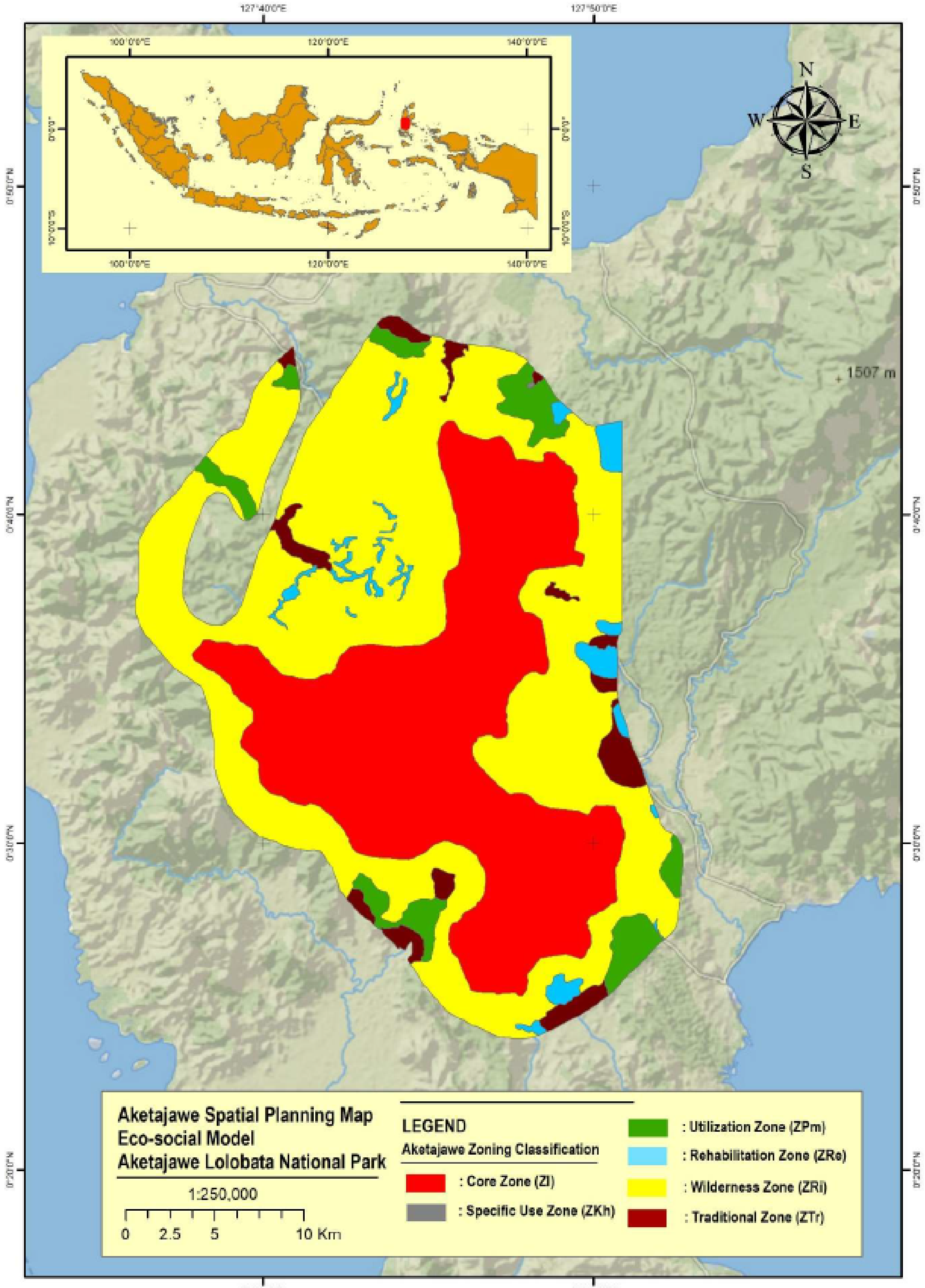


Figure 5.18 Results of the Aketajawe spatial planning eco-social model

The image, above, shows the spatial planning results based on the eco-social model. In general, the final map did not appear to be significantly different from the zonal model; however, some differences can be detected in the core zone (north region, nearby the traditional zone in Tabanalou), and in traditional and rehabilitation zone in the south and east regions of Aketajawe. In total, the area calculations showed that the wilderness zone is biggest at 40,772 ha (52.41%) and this was followed by the core zone, with a total area at 29,159 ha (37.48%). The complete information about this model is presented in table 5.10, below.

Table 5.10 Results of the proportion eco-social model

No.	Zoning	Code	Shape Length (m)	Shape Area (m)	Total Area (ha)	Proportion (%)
1	Specific use	ZKh	1,207.28	95,098.03	10.00	0.01
2	Wilderness	ZRi	420,829.33	407,721,678.39	40,772.17	52.41
3	Traditional	ZTr	87,673.76	23,700,253.57	2,370.00	3.05
4	Rehabilitation	Zre	115,118.00	19,365,526.78	1,937.00	2.49
5	Core	ZI	122,699.94	291,588,155.17	29,159.00	37.48
6	Utilisation	ZPm	86,097.34	35,470,414.74	3,547.00	4.56
	Total				77,795.17	100.00

5.7 A Chapter Summary

The analyses carried out, above, resulted in two models with suitable spatial planning for Aketajawe. It was notable that GIS had the ability to combine not only multiple spatial data but also incorporate government regulations relating to zoning management in national parks. Several stages in zoning development were carried out systematically using GIS as this software offered various tools with several beneficial applications. They included the ability to examine orthomosaic images from UAV aerial surveys and several satellites imagery resources. Comparisons between the two models are discussed in the following chapter, including the strengths and challenges, applications of aerial survey and satellite imagery for forest monitoring. Some weakness of photogrammetric surveys by unmanned aircraft will also be presented in order to improve this technology for further research applications.

Chapter 6

Discussions

In this chapter, the study results are discussed in relation to other studies, government policy, and the existing literature as well as the study's objectives. As part of a critical insight, the benefits and advantages of the application of satellite imagery and UAV technologies in forest surveys are presented, including its potential as part of national park management. The chapter also considers the value of GIS software as a powerful tool to examine various types of spatial data to improve decision making in natural resources management. In spatial planning, both models' results have been considered, to figure out the strengths and weaknesses of each model. This, then, is followed by the best suggestions in zoning classification formulation based on this study, including its potential implications and re-evaluation of the current ALNP zoning management. In the final section of the chapter, some applicable approaches have been suggested to bring these studies' positive aspects into the national park management system, and also provide future research directions for the application unmanned aircraft for forest surveys and GIS analysis in park management.

6.1 Value of UAV Aerial Surveys and Satellite Imagery for National Park Spatial Planning

The results from the interpretation of the UAV and satellite imagery showed that updated land cover and land use information could make significant contributions to national park spatial planning. These data provided meaningful information about the earth's surface characteristics, such as indigenous people's territory, the extent of their agricultural land and their temporary shelters. The intact and extensive tropical forests in ALNP were crucial for biodiversity protection on Halmahera Island as the total area of the park represented only 7.5% of the total mainland, and was located in the centre of the island (Susanto, 2009). Therefore, improper ALNP spatial planning may lead to a decreasing ability to sustainably manage forest resources. As a result, the need for frequently updated land cover and land use data was essential for effective national park management, as suggested by Walther (1986). As mentioned in the research methods and results chapters, this study primarily investigated the benefits of satellite imagery and UAV aerial surveys in order to create useful national park spatial models, which are discussed in the following section.

6.1.1 Satellite Imagery Strengths and Weaknesses in Providing Earth Surface Information

The application of remotely sensed data in spatial modelling and as the primary source of input data for spatial planning, has been widely recognised in modern land survey approaches (Geneletti, 2001; Keisler & Sundell, 1997). Satellite imagery provides spatial information from different sensors and various platforms at different times, making remote sensing the best source of land information for relatively large areas and its application. This advantage is demonstrated in Figure 5.6 and Table 5.3, which show the land cover classifications for the Aketajawe region developed using image classification. This result showed that Aketajawe is covered mostly by primary forest, at 65,590 hectares (84.32%), followed by secondary forest, at 9,749 hectares (12.53%), open areas, at 2,045 hectares (2.62%), and water bodies, at 396 hectares (0.5%). Technically, the high ecologically sensitive areas (primary and secondary forests) are suitable for biodiversity protection, which are represented as the core and wilderness zones in national park spatial planning in Indonesia (Perdirjen KSDAE No.11 in 2016). Looking specifically at the open areas, the number of critical areas in Aketajawe decreased from 3,409 hectares, in 2012, to 2,045 hectares, in 2016. This may have been due to restoration programmes or natural regeneration over the last five years. However, it is clear from the imagery that logging roads still exist after twenty years of ALNP management, as can be seen in the Landsat 8 (2016) and SPOT 7 (2017) images. This is not currently accounted for in ALNP planning. The imagery suggested that natural regeneration cannot accelerate the succession process and may need human intervention. As a result, this study encourages establishing a rehabilitation zone for the existing ex-logging roads.

A crucial finding of this study has been the identification of a new solid open area of around 444 hectares in the northeast Aketajawe region. This was identified by comparing different satellite imagery over the last three years, as shown in three different satellite imagery sets (Digital Globe (2014), Landsat 8 (2016), and SPOT 7 (2017)) in Figure 6.1. To date, the park management has not been aware of this open area, and its identification has been greatly facilitated by the use of satellite imagery allowing the undertaking of immediate action.

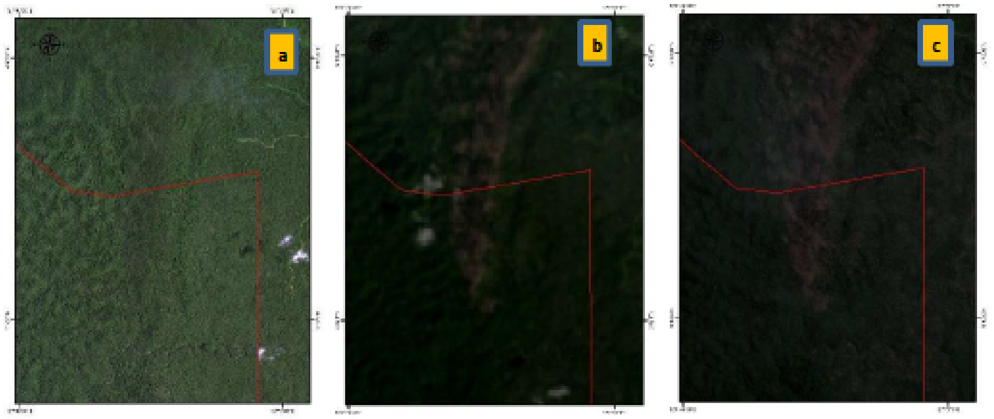


Figure 6.1 Land Cover Changes from 2014 to 2017: (a) Digital Globe, in 2014;(b) Landsat 8, in 2016 (b), and SPOT 7, in 2017 (c) with a 1: 240 scale

Figure 6.1 illustrates one of the strengths of satellite imagery for forest monitoring. Due to a lack of personnel and the challenging topographic characteristics over a relatively large area, it was almost impossible to conduct forest patrols regularly for the whole Aketajawe block. At the same time, illegal activity can happen at any time. Satellite imagery, such as from Landsat or SPOT, can be used as a tool to provide a visual time series of changes to the earth's surface over large areas. First, the initial information from this imagery can be used by decision makers and park managers to target further investigation. Secondly, we can interpret which factors generated this open area based on spatial information, such as accessibility. Typically, this critical land alteration was driven by large scale logging operations because extensive land clearing had been carried out by cutting machines to harvest the trees; which was different from illegal logging by villagers that was often conducted selectively in relatively small areas. These findings showed that satellite imagery could, potentially, also be used to investigate deforested areas. Deforestation is the broad term for describing the condition of a fragmented forest (Resosudarmo, 1996). In Indonesia, many factors cause deforestation, mostly related to commercial plantation businesses, infrastructure development, transmigration, mining activities or commercial logging and forest fires (Verchot et al., 2010).

On the other hand, there are limitations in the use of satellite imagery, mainly relating to pixel resolution and cloud cover percentages. The Landsat 8 imagery used in this study had a 15-metre resolution. This imagery may provide incorrect details about land use information in small areas, which could be crucial for the park's management. ALNP also experienced a related problem in 2010 when the park management agreed to establish a restoration programme in Akejawi. Based on the interpretation of Landsat imagery this area had a brown colour, which was assumed to be an open area. However, in reality, it was agricultural land. Figure 5.7 on page 88 demonstrates this limitation. Besides, Landsat 8 imagery may require expertise, skill, experience and knowledge for its proper interpretation. Alternatively, understanding the Landsat interpretation guidelines was necessary to minimise false information, as suggested by Leboeuf in 2016.

Another significant problem relates to cloud cover. Landsat 8 can be freely accessed and provided imagery at different points in time, but this imagery tended to have a high cloud cover percentage, particularly in tropical regions, a problem experienced in this study. Looking at the Landsat 8 imagery over the period from 2017 to 2018 for the North Maluku region on the Earth Explorer website, cloud percentages were seldom less than 20%. The best option was data acquired in March 2016 that had less than 20% cloud cover.

Even though SPOT 7 has much better pixel resolution at a 1.5-metre spatial resolution, this imagery experienced a lot of cloud cover problems over the area of interest. As SPOT 7 is not free and is difficult to acquire, researchers do not have many options to choose different time data acquisition, which is entirely different from Landsat 8. In Indonesia, LAPAN has the authority to release this imagery to the public for special purposes (e.g. research, disasters or the military), and some private providers also offer a range of SPOT data, but budget limitations may limit the amounts that can be acquired. Considering these limitations, SPOT 7 was not used for the full spatial analysis in this study. As SPOT 7 provided better land surface information, this imagery was used for imagery comparisons to identify land use patterns in Aketajawe. Overall, cloud cover problems were hot topics on GIS and remote sensing fora, and several approaches have been attempted to establish suitable techniques for reliable cloud removal, although further development was still required.

6.1.2 UAV Aerial Surveys as Alternative Solutions for more Effective Forest Monitoring

The limitations of remotely sensed imagery drive innovation in land survey techniques. Several improvements have attempted to acquire land information quickly, reliably and efficiently. These concerns encourage innovations in UAV technology for aerial survey applications for multiple purposes. In forest inventories, the benefits of UAV-based remote sensing for ecological assessments have already addressed by many GIS analysts, which is demonstrated in various applications of land use surveys, spatial planning, and zoning classifications (Keisler & Sundell, 1997; Geneletti, 2001; Grenzdörffer & Teichert, 2008; Villa et al., 2012(Grenzdörffer & Teichert, 2008; Keisler & Sundell, 1997).

A primary advantage related to time allocation in that UAV aerial surveys might decrease the total time needed for data collection significantly compared to traditional field surveys using GPS. As described in Table 5.1 (page 78), the UAV surveys took 4 hours 20 minutes, in total, to collect data on 677 hectares. In a traditional field survey using GPS, this could take several days depending on the topographical conditions, which was not as big of a problem for a UAV. Technically, the aircraft will follow the pre-set instructions from the software, including the flight-plan, camera settings and side-lap and overlap settings. In conventional surveys errors are more likely as there is a heavier reliance on human capacity. The most significant constraint in UAV surveying relates to battery life (Hartley, 2017). Different UAV types perform differently; in general, fixed-wing UAVs have a better and longer battery life with more extended aerial coverage than quadcopter UAVs. The Phantom 4 used in this study performed well in a range of topographical conditions with the biggest area mapped being 117.55 hectares for one battery; which is still more powerful than a 20-minute manned survey. Three back-up batteries were used in this study to anticipate the limitations of the Phantom 4 battery.

Another advantage of a photogrammetric survey is the ability to create high-resolution orthomosaic images from raw data. This is the most significant advantage of the UAV surveys, and is useful for land cover identification (Ishihama et al., 2012). Figure 5.7 (page 88) presented this advantage compared with the Landsat 8 and SPOT 7 satellite imagery. The orthomosaic images have a clear resolution even at a 1:50 scale; where it might be useful for land use classification and visual interpretation in Aketajawe. For instance, Figures 5.2 and 5.3 (pages 79 and 80) showed clear information about the *Tobelo Dalam* territory and their activity areas in Tayawi. Figure 5.5 on page 83 provided an aerial image of Tabanalou villager's coconut plantations and Figure 5.4 (page 82) displayed detailed information about the extent of agricultural land in Akejawi.

The differences in image resolution are not trivial and can lead to significant differences in the classification of land use or land cover and produce patch-level metrics (i.e. wildlife corridors, indigenous people’s territories) (Boyle et al., 2014). These discrepancies could likely affect the ability to interpret landscape fragmentation patterns. In park management, it can have direct impacts on ecosystems and species conservation management plans. Various types of satellites offer different levels of high-resolution imagery for conservation practitioners but the biggest challenge is to obtaining these data are due to its high cost and budget limitations (Xie, Sha, & Yu, 2008). This issue can be solved by using a UAV application for land surveys in focussed areas, such as the specific areas this study focussed on areas (indigenous people’s territory and agricultural land). High-resolution information is critical for the detection of small and narrow forest fragments (see, for example, Figure 5.5 page 83). In areas of high human intensity, land use patterns could be affected periodically, which would be difficult for park managers to be aware of due to time and personnel constraints. The orthomosaic images could be used as tools to evaluate human activities in this fragmented area, and to prevent deforestation from becoming more extensive. In critical areas, these high-resolution images bring significant benefits. Lower resolution images cannot provide such detail about small area land features, such as the stages of natural succession, the distribution of pioneer species and landscape formation. This limitation can be tackled easily with images sourced from UAVs. These images provide detailed information about the current vegetation stages and landscape features with the added benefit of including digital surface models and digital terrain models, which can be used to provide a more informative working plan base map. In tourism development, a high resolution is also crucial for more precise environmental impact assessments and the evaluation of infrastructure development.

A further advantage of an unmanned aerial survey is the ability to provide real-time, on-demand land surface information that is of a significant benefit compared to conventional surveys (Everaerts, 2008). The user has full control over when to undertake field data collection, which is almost impossible with satellite imagery due to technical, operational and its restricted licenses. This ability brings national park management more closely into the ‘real' field situation, so faster and better decision making is possible. As an example, if a forest fire happens, a UAV can be used to detect the central fire location so a faster response can be conducted. More importantly, the users have more freedom to select the best-fit drone specifications for their particular research or topic of interest. On the other hand, satellite imagery is a product that has been developed by large corporations, so there are some limitations regarding specifications and requirements for a specific user's request.

Overall, this research showed the importance of the application of satellite imagery and UAVs for spatial planning and land evaluation in ALNP. The benefit of remotely sensed imagery to present land surface information over a relatively large area is indisputable and the availability of the observed time series data offers a great range for potential study in park management. Satellite imagery limitations, such as its high cost, low resolution, high cloud cover percentages and the potential for out-of-date data are the biggest challenges in satellite imagery applications. However, these limitations can be minimised by UAV aerial survey applications in focussed areas. As a powerful tool in a specific area, UAV technology can provide almost real-time information with high-spatial resolutions in areas of interest. In principle, it is also a low-cost technology for land surveys (Grenzdörffer & Teichert, 2008). This study encourages unmanned aircraft applications to investigate some sensitive areas inside the ALNP boundary and the use of this technology as a valuable input for development, such as forest patrols, infrastructure surveys and ecological assessments.

6.2 Importance of GIS in National Park Spatial Planning

The benefits of applying MCA using spatial data and GIS-based decision support systems in national park spatial planning have been widely recognised by various researchers (Campbell, 1996; Day, 2002; Villa et al., 2012). An innovation in this study was to use two different scenarios for national park spatial planning as separate objectives. This implies several stages of multi-criteria analyses, followed by zone allocation, which also included determining suitable data coding at several phases in the process. At these stages, some decision-making processes were divided into several parts that can be formulated, analysed, presented and evaluated periodically, as needed. Re-evaluation is advantageous as the content and spatial data quality can be updated and reviewed at any time. The zoning criteria/parameters with several objectives can be updated and the analyses repeated with new parameters and indicators, as well as new sets of updated weight assignments.

The weights for each zoning criterion in the two models (zonal model and eco-social model) are clearly stated, and the different levels of sensitivity of the weights can be tested. In this way, the management of ALNP can be improved with the addition of new and high-resolution spatial information related to the consequences of implementing different management scenarios. In some cases, these analyses may suggest the capture of new data, such as when the impact of activities/policies/programmes is not clear. Alternatively, there may be conflicts of interest among stakeholders in areas where valuable resources are found, such as in Akejawi, Tayawi and Tabanalou. This can make park managers aware of the need to obtain more detailed data or understanding on that specific issue.

Finally, this research presents another perspective on spatial planning in Aketajawe that resulted from two different weighted models. It is notable that GIS has the ability to integrate multiple spatial data layers related to spatial planning. This suggested that ALNP management needed to improve its spatial database capacity and reliability. Without reliable and robust data, GIS analyses may not produce accurate results. With high-quality spatial data, this study illustrated that the different weighted models used in the GIS analysis showed similar final results. High-resolution UAV data collected for this study found that fragmentation has happened over the last three years in areas with high human interaction in the traditional and rehabilitation zones. These results suggested that these zones needed more attention from ALNP management to prevent more extensive deforestation in the future.

6.3 Comparison between the Zonal Model and the Eco-social Model in Aketajawe Spatial Planning

Zoning management is the general pattern of national park establishment for defining spatial land use purposes, imposing land use limitations and regulating natural resources use (Portman, 2007). Territorial planning is needed to ensure adequate areas for biodiversity protection to accommodate indigenous people’s livelihoods and support regional economic development. The benefits of spatial MCA and GIS in park spatial planning have been examined in several studies (Geneletti, 2001; Keisler & Sundell, 1997; Villa et al., 2012). An innovative approach in this study was the formulation of two different models (the zonal model and the eco-social model) for GIS-based spatial analysis in national park territorial planning. This implies that several approaches using multi-criteria analyses are possible, which include multipurpose land allocation and the level of relationship analysis at several stages of the process. The Indonesian government regulates national park zoning management into multiple classifications, namely, core, wilderness, utilisation, traditional, rehabilitation, specific use, historical, and religious, which are based on the individual national park’s characteristics. The results, limitations and opportunities arising from the two models are discussed below.

6.3.1 Influence proportion and Weighting Scheme between the Zonal Model and the Eco-social Model

The two models used in this study, set ecological and socioeconomic parameters as two primary forms for national park spatial planning, which is reflected in the Government of Indonesia's regulation No.P.76/Menlhk-Setjen/2015. Principally, both models used the same ranked values: 1 for not suitable, 3 for suitable and 5 for most suitable. However, the models developed were formulated based on two different approaches: first, it was about the percentage of influence allocated according to its importance, and, secondly, the weighting scheme.

As outlined in Tables 4.3 and 4.4 in chapter 4, the proportions of influence factors allocated for each zoning parameter are different. In Table 4.3, which represented the zonal model, the total proportion of the two zoning parameters was 100%. Logically, this model set the ecological and socioeconomic parameters as interdependent factors in national park zoning classification; as a result, they have a cumulative portion at 100%. While the more important zoning criteria (slope, land use, etc.) in any particular zone, have higher influence percentages. For example, wildlife distribution has the highest proportion, at 20%, in the core zone. The greater influence affecting the factors in spatial analysis, the higher the proportion assigned (Elbeih, 2007). As each zone classification has specific management objectives: zoning parameter reclassification and influence percentages have been formulated based on each specific zone objective. In the weighted overlay analysis, the zonal model provided distinct information for zoning classification, which represented five different layers, namely, core, wilderness, utilisation, traditional, and rehabilitation.

A different approach was conducted in the eco-social model. As outlined in Table 4.4, this model was examined by set ecological and socioeconomic parameters as independent factors, so each parameter had a 100 % influence factor in total. By having equal proportions in the total, this implies the "spirit" of national park management in Indonesia, in which biodiversity protection and economic contribution had been set as the two primary factors. This, then used the weighted overlay technique to combine these parameters into a single spatial data (Figure 5.16) for zoning formulation. Technically, this was entirely different compared to the zonal model (5 layers, Figure 5.12). One big challenge in the eco-social model that resulted from the weighted overlay, as presented in Figure 5.16, was by not clearly providing distinct zoning classification information. As a result, Table 4.6 in page 76 was used to interpret the final results. It is suggested that zoning expertise is needed to help identify the proper coding formulation (Table 4.6).

Another difference was the weighting scheme in the zonal model, as ten criteria in the zoning parameters (ecological and socioeconomic) were interdependent factors, and both parameters had been formulated based on the specific zone type characteristics (five zones). Technically some zone criteria were more superior than others depending on their level of importance to the zone's objectives. For instance, in the traditional zone, the area related to people's livelihoods and their traditions had been assigned value 5, so this implies that this area has less biodiversity sensitivity from its relatively flat topography. Therefore, in the wildlife distribution and slope weighting process, this area of more than 5000 metres from the biodiversity hotspot and with a slope range of 0° - 15° has value 5. The zonal model illustrated that each zone criterion had a relationship with each other, and every zone's objectives became a "benchmark" for these criteria in the zoning classification.

In contrast, the eco-social model has a different approach for zoning formulation. This model set the zoning parameters as separate primary factors, because they were a dependent group. As a consequence, each zoning criterion had been examined based on their relationship to ecology or socioeconomic factors. This model's logical framework reflected national policy in that the Indonesian government manages national parks for biodiversity protection as well as supporting their economic contribution to local and regional development. Technically, each zoning criterion in the ecological parameters had been examined for their relationship to biodiversity protection so, in the weighting scheme, the area has a high value of biodiversity, such as 0 – 1000-m (wildlife distribution), primary forest/waterbody (land cover), 24° - 24°/>45°(slope), 0 – 100-m (river), and 750 – 1000-m/1000 – 1350-m (elevation) so are assigned value 5 (most suitable area for zoning protection). Also, in the socioeconomic parameter, each criterion had been formulated based on its value to the economic contribution and people traditions so, in the weighting scheme, the area has high potential economic resources, such tourism hotspots, non-timber production, an accessible area, and a high cultural value and so were assigned value 5 (most suitable).

The combination of these parameters (ecological and socioeconomic) gave meaningful information for national park spatial planning. As dependent factors, both parameters have an equal portion to contribute to a suitable land use pattern for any particular zone type.

6.3.2 Results, limitations and challenges

The discussion, above, explained the different logical frameworks between the zonal and eco-social models, which had been formulated based on Tables 4.4 and 4.5 in chapter 4. The results in these models exposed some meaningful spatial information and challenges that will be described in the following paragraphs.

An area that represents high-value natural resources and serves as the water-reservoir area is called core where tourism activities are prohibited. Figures 5.17 and 5.18 show the core zones as a red colour and these lie in the inner areas of Aketajawe with high slopes and elevations. As estimated in the zonal model, an area of around 27,027 hectares was suitable for the core zone in the ecological model and covered 34.74% of the total Aketajawe area. In the eco-social model, this proportion was slightly bigger, at 37.48%, with an estimated total area of 29,159 hectares. The core zone was the centre of ALNP that was usually rich in biodiversity. Therefore, the Indonesian government decreed that no development should occur in this zone.

Areas that provide biodiversity protection, education and research activities, including limited nature-based tourism, fall under the definition of wilderness zone. In Figures 5.17 and 5.18 this is shown as a yellow colour. This is a buffer area for the core zone, so the locations generally surround the centre of the national park. This area has varying degrees of slope and elevations, from moderate to high, and this has better access than in the core zones. The zonal study model estimated the area as suitable for the wilderness zone and was around 42,398 hectares, which was 54.44% of the total Aketajawe land. In the eco-social model, the total area was not significantly different, at 40,374 hectares, or 51.90% of the total Aketajawe area. Areas that offer a great range of outdoor opportunities and tourism facilities/activities are under the definition of the utilisation zone and are represented as green in Figures 5.17 and 5.18. This area offers various tourist spots and has easier access and is relatively close to the communities. Most of this area has a low slope and elevation so visitors can more easily access it. In the zonal model, the area suitable for this zone covered 3,098, hectares or 3.9% of the total land. This number was slightly bigger than in the eco-social model, where it was estimated to be around 3,547 hectares (4.56%). This main difference is located in Sidanga (the southern part Aketajawe region). The eco-social based zoning formulation formulated some areas in Figure 5.16 as area suitable for the utilisation zone beyond what was identified in the zonal model.

On the other hand, the Boolean and merge analyses in the zonal model produced values of 0, which are not suitable areas for any zoning type in this area (Figure 5.15). These are shown as no colour (hollow) in this figure. Any recreational building is suitable for the utilisation zone, but, as it is a reserve area, an environmental impact assessment is compulsory before construction starts.

In Indonesia, national parks are also managed for indigenous people's protection, including their livelihoods, and any historical, traditional and cultural values. In the zoning classification, these areas are accommodated in the traditional zone. This zone is shown as a brown colour in Figures 5.17 and 5.18. The entire traditional zone in the zonal model comprised 3,336 hectares and covers 4.25% of the Aketajawe land. This total area decreased to 2,764 hectares (3.55%) in the eco-social model. The two-model map comparison shows this difference is mainly in Kobe and Kobe Kulo villages. In the eco-social model, there are missing raster data along the Akejira River; local people used this area as their plantation area, which was suitable for the traditional zone. Allocating adequate traditional zones in national park spatial planning was necessary. As a developing country, many Indonesian people have a high dependency on natural resources, especially those living near forests. Without traditional zones, people do not have legal access to use their natural resources; as a result, this can increase the number of national park conflicts.

Before national park management started, some of the ALNP area was part of a forest company concession, as indicated by the presence of some logging roads and logging areas inside the park boundary. This area designated as critical land. The zoning formulation identified some critical areas as rehabilitation zones, and these are shown with a blue colour in Figures 5.17 and 5.18. This recovery area is not only scattered around the park border but is also near the centre of the Aketajawe region; and is mainly ex-logging roads. In the zonal model, the total critical land was around 1,926 hectares (2.47%), and this needed to be recovered. This number was almost the same, at 1,937 hectares (2.49%) as the eco-social model. Technically, these data can be used as a reference; ground truthing is necessary to ensure the real total recovery area and to investigate the ecological conditions at these locations. In this case, the UAV survey might suggest a useful method of rehabilitation. Tree planting can accelerate forest recovery, as well as biodiversity (MS, GB, & Durigan, 2014) and carbon storage (Laganiere, Angers, & Pare, 2010), and gives economic benefits to local communities (Knoke et al., 2014). Alternatively, forest recovery might depend on the intensity of natural regeneration.

In Aketajawe, the Indonesian government has built some public infrastructures, such as farm irrigation and a dam to support Akejawi people's livelihoods inside the park area. The specific use zone is an area that accommodates any public infrastructure development, so this specific area is not included in this study's zoning formulation analysis. The only adjustment was conducted in the digitising process to ensure there was no gap or overlap polygon between the traditional, specific use and utilisation zones. In the zonal model, the total specific use zone was 9.5 hectares, and it slightly increased to 10 hectares in the eco-social model, which covered 0.01% of total Aketajawe area.

In summary, there were no major differences in the final spatial planning formulation between the zonal and eco-social models. The location and distribution of the core, wilderness and rehabilitation zones were relatively similar, even though the total area was slightly different, possibly due to the digitising process. However, in the spatial planning relating to indigenous protection and livelihoods, there was a different distribution of the traditional and utilisation zones in the eastern and southern parts of the Aketajawe region. The results for the zonal model was relatively similar to the actual field conditions. This was possibly due to all zoning classification parameters being formulated to focus on this zone's criteria; as a result, the traditional zoning component has a higher weighted factor than for the others. Based on this study result, a combination of zonal models and eco-social model techniques can be used for better national park spatial planning. In the case of the missing raster value, a comparison between these two models might give valuable spatial information. Therefore, these combined model results can be more accurate and more similar to the real field conditions.

6.4 Implications for National Park Management

Based on this study's results, there are two points to emphasise for ALNP management. First, there was the potential for further contributions of UAV aerial surveys tor the implementation of new spatial planning. Secondly, evaluating the current park zoning against new data could lead to more effective park management. Both of these are discussed below.

6.4.1 Further UAV Applications

Spatial planning is often related to land use patterns, which are often used as some of the primary data inputs. Typically, satellite imagery is used for land use classification in national parks, because this imagery can provide spatial information over a relatively large area. However, updated land use patterns are often difficult to gather from satellite imagery because of technical satellite operation, such as the timing of orbits and the level of the sensors. In countries where people have high natural resources dependency, land use changes tended to occur frequently and more extensively, such as in Indonesia.

Consequently, satellite imagery sometimes fails to provide updated spatial data in specific areas with high human interactions. This limitation can be easily tackled with photogrammetric surveys using UAVs. With their ability to collect data on demand, UAV surveys can be used to derive land use patterns at any time, which can then be applied to more focussed objects, such as indigenous people's settlements, tourism spots, logging areas, and the derivation of general land use patterns, such as the extent of agricultural land, existing roads/accessibility, or people's residences. This effort proved effective in this study's final results for both models. The UAV aerial surveys gave positive inputs for updating the land use classifications; so, a more updated traditional zone has resulted when compared with the present official Aketajawe zoning classification in chapter 1. By updating land use data periodically, the park managers have reliable information as part of the national park programme or for policy evaluation.

Therefore, there is scope for the further use of UAVs with respect to traditional and rehabilitation zone development, because of the level of importance of these zones as they are most affected by deforestation or land use pattern changes. Land use analysis using a combination of satellite imagery and UAV aerial surveys provided more useful and updated land information. The aerial based survey in this study provided detailed land use patterns inside the park. The area with high human sensitivity and critical areas around the national park needed to be evaluated regularly. These sensitive points should be updated and maintained correctly in order to maintain an accurate ALNP database. Considering conventional survey limitations in regard to time requirements, high costs and the resulting reliability, UAV surveys can be used as an effective method for forest surveys. The ability of UAVs to produce up-to-date information with high precision is significant.

Consequently, more reliable and faster data can be presented to park managers, resulting in more effective and timely policies. The aircraft type can be adjusted with the management objectives or the size of aerial coverage. In the case of the larger areas to be covered, fixed-wing aircraft may be more suitable, but if the survey location is in a remote area with multiple elevations, quadcopter UAVs are a better option.

6.4.2 Current Zoning Re-evaluation

Looking over the official Aketajawe spatial planning in Figure 1.1 and Table 1.1 of chapter 1, there are some different zoning distributions and total area estimates between this study results that differ from the official spatial planning map of Aketajawe. The first difference is in the core zone. The core zone was a highly sensitive ecological area mainly for biodiversity protection, and the primary forest was dominant in this zone. As a result, this area should be protected from any illegal activities and remain relatively inaccessible. The ex-logging roads in the north and centre inside the park boundary were not suitable for the core zone along the 200-metre buffered road areas.

On the other hand, some logging roads are positioned in the core zone in the official Aketajawe zoning map. In this study, these areas are classified as both rehabilitation zones and wilderness zones. This area was interpreted by satellite imagery (SPOT 7 and Landsat 8) for additional justification. As a result, the total number of recovery areas in this study almost doubled, from 1,009 hectares in an official document, to 1,937 hectares in this study's eco-social model. The increase was due to this study finding a large critical area in the northeast of Aketajawe that was not represented in the current, official Aketajawe zoning document. The other significant difference was the location of the traditional zone. This study suggested that the indigenous people's area in Tayawi and Kobe Kulo should be designated in the traditional zone. This included coconut plantations in the South Aketajawe region and alongside Akejira, which were not represented in the official Aketajawe zoning document.

Improper land allocation in spatial planning could increase the number of stakeholder conflicts and ineffective national park policies. The gap between the planning documents and the real situation may lead to misunderstandings among the national park stakeholders, especially as people may use their natural resources at any time, and the national park has limitations on patrolling these areas at all times. Building trust, respect and loyalty are essential to keeping the forest intact by mutual understanding between stakeholders. As a result, the local people can ensure their livelihoods, as well as help the national park management to protect biodiversity. In addition, these incorrect zoning classifications indicate a disagreement between the national zoning policy and local spatial planning; which is not conducive to effective management.

6.5 From Science to Management

How to incorporate science into the national park management system has been a big challenge over the last two decades for conservation practitioners. Typically, science is likely to be thought of as an 'ideal' condition whereas management is more familiar with an 'accommodative' approach. Even though this study methodology was not aimed at answering this question, it is interesting to discuss this issue in order to find the missing link between managers and scientists so they can work together.

The problems between science and management have been addressed in several studies (Roux, Rogers, Biggs, Ashton, & Sergeant, 2006; S Postel & Richter, 2003) and various solutions and opportunities have been discussed, but this problem persists (Cullen, Victor, & Stephens, 2001). In developing countries like Indonesia, the application of science into government systems is not easy, particularly in natural resources development, which is politically complex and has budget limitations.

While it was often not easy to bring science into management, some possible approaches can be suggested based on this research. First, is the need to understand the fundamental problems in the field. In park management, forest surveys are essential and should be regularly scheduled. These include forest patrols, forest inventories, and land use assessment. This is a big task, and the problem is mainly a lack of human resources and budget limitations. This study results, presented in Figures 5.2, 5.3, 5.4, 5.5 and Table 5.1, illustrate the benefits of UAV aerial surveys, which are easy to interpret and understand. The agricultural overlap problem in Akejawi is an excellent example that represents this idea. One of the crucial factors causing this unsolved problem is agricultural land mapping and border reconciliation.

Previously this issue was difficult to approach because it needed expensive satellite imagery for updating the base map. However, this was not such a big problem for UAV surveys. In addition, it provided a low-cost approach with the ability to provide high-resolution information; this technology can produce real-time data that are essential for proper management. Several potential further applications can be communicated easily to park management, including ex-logging roads surveys, critical recovery and deforestation area mapping.

More importantly, this study illustrated how science offered several approaches for deriving better land information that was increasingly more accurate and reliable. This benefit brings the national park management closer to real 'field' conditions, by allowing them to understand problems better and provide up-to-date data.

To sum up, it is not easy to incorporate science into a management system and ensure they can work well together. The number of conflicts of interest is growing rapidly, and high public expectations on the national park management often makes this mutual relationship more complicated. However, this study illustrated the 'power' of science to provide more reliable and updated field conditions, which can improve the decision-making process in park management. Science cannot remove the complexity of the decision-making process, but this study suggested some possible ways to incorporate science into park management, by understanding the basic field problem and initiating science-based pilot projects.

6.6 Future Research Directions

This study outlined the development of a low-cost unmanned aerial vehicle (UAV) in forest surveys to evaluate national park spatial planning. UAV photogrammetry is a remarkable technique in modern aerial survey. This study documented that the use of UAVs in land surveys have a variety of challenges that need further attention. To use UAV methods effectively in forest surveys, unanswered questions and potential disadvantages should also be addressed in future research.

First, losing the drone signal randomly during data collection can happen due to a technical error in the drone itself or the environmental conditions. A UAV itself used several advanced technologies in their componentry, including a GPS system, a motor or engine, a computer system, radio communications and camera operation. These complex technologies work together to support drone operation using several applications. UAVs might work well in relatively flat areas or urban spaces; however, they are more challenging to use in hilly areas and remote areas, such as a dense forest. Signal loss can frequently happen due to different terrain conditions and forest density. This study experienced several lost signal incidents, mainly when carrying out data collection in the primary forest. For instance, even though a take-off position was in a relatively open area of four m^2 near a river, signal loss frequently occurred when the UAV flight exceeded 350-600 metres from the starting point. The forest canopy and topographic conditions could possibly be the main reasons for the signal interference in these cases. An additional antenna extender or a signal booster may work well to anticipate this problem in the aerial survey, but this requires further research.

Secondly, challenges related to managing flying height stability. Quadcopter UAVs have good manoeuvring ability; this type of UAV was suitable for flying in relatively remote areas, such as tropical forests. However, different contours and varied elevations may become significant obstacles in forest surveys. Ideally, a UAV pilot should have good visibility to see the aircraft during the flight mission to anticipate the plane crashing. However, it was almost impossible in tropical forests, due to forest density. In the case of this study, the UAV pilot could not see the aircraft or even hear the propeller sound with only the remote-control screen as an indicator of the flight's status. Therefore, it is essential to have a good topographical knowledge in the study area; without that, it makes flying the aircraft a gamble. Improving the aircraft obstacle sensors also is crucial. In Akejawi, the obstacle sensors performed well in avoiding unexpected barriers (trees, rocks or hills). The Phantom 4 will automatically avoid these obstacles, which are visible on the in-flight indicator screen. However, the obstacle sensor positions were only in the front of the aircraft, meaning that if there were unexpected objects on the aircraft's sides, the sensor will not detect them. Therefore, it will be a big improvement if UAVs have an all-sides obstacle sensor.

Thirdly, replaceable camera and battery performance can limit UAV flights. The Phantom 4 is claimed to be the smartest UVA DJI produces. The built-in camera and battery specifications have been well developed over its previous generations. Nevertheless, the dedicated camera was not replaceable, which would be a limitation for research that needed a specific camera, such as a thermal camera or a multispectral sensor. In addition, the use of a lithium polymer as the battery material has a limitation of 25-28 minutes flying time (DJI, 2018), which may not be adequate for aerial surveys of more than 200 hectares per flight. A longer flying time was necessary because it can increase the mapped area coverage. An innovation of battery charging technologies that allowed faster power transfer and reduced charging time would be important to reduce the number of backup UAV batteries and make UAVs more affordable (Galkin and DaSilva, 2018).

Lastly, the need to develop proper weighting overlay models for specific national park management purposes, such as tourism infrastructure development area, habitat suitability, and tower development for forest patrols, etc. In principle, after the zoning classification was established, the park management should continue to implement more detailed programmes or policies in each zone. For instance, in the utilisation zone, this area focussed on tourism development as well as local people's livelihoods. Business activities or stakeholders' involvement were allowed in this zone. Consequently, investment in infrastructure was possible in the utilisation zone. As part of this, proper infrastructure planning was mandatory, because the construction methods/strategy in conservation areas were different, compared to the urban areas. Similar to this study, several spatial data can be formulated to develop a suitable spatial model for infrastructure development. In that situation, the park management has the freedom or full control to examine several parameters, including the weighting scheme to analyse these data or even examine and evaluate any possible scenarios in order to develop the best spatial model, if necessary. As spatial data can be updated at any time, the zoning parameters or the influence of the percentage allocation can be evaluated as management needed. All of these scenarios can be tested by GIS software. Besides, there are many topics or future research directions in weighted overlay applications for national park management, as this technique has been employed to examine several topics related to natural resources management, the redesign of natural reserve modelling (Bojórquez-tapia et al., 2004; Keisler & Sundell, 1997), land use strategies for developing park buffer zones (Hjortsø, Stræde, & Helles, 2006), different strategies in wetland management (R. Janssen et al., 2005), and land prioritisation for different stakeholder group preferences (Strager & Rosenberger, 2006). As time goes on and, with an increasing human population, human pressure was happening more frequently in the national park, and this made park management more complex; therefore, the use of the best strategies was fundamental; and the use of weighting scheme as part of GIS techniques can be used as useful to tools as part of the decision making process.

Chapter 7

Conclusions and Recommendations

7.1 Introduction

In the course of this study, questions arose as to the best strategy or method for obtaining updated land surface information for better decision making in the Indonesian protected area context. From the national park manager's point of view, reliable land surface information is essential for multiple management objectives, such as national park spatial planning and protecting indigenous people’s livelihoods. In order to address this need, a new approach was formulated in this study by integrating the photogrammetric technique and satellite imagery in order to derive better land cover and land use information for zone management in Aketajawe Block, ALNP. A comprehensive GIS analysis has been conducted to examine the use of remotely sensed data (UAV and Satellite-based), as well as multiple spatial datasets that identified areas of great ecological importance and social value. The study was completed by incorporating relevant government regulations in order to establish a more applicable framework for spatial planning in Aketajawe. The following conclusions and recommendations for future research are based on the key findings generated by this study.

7.2 Conclusions

Indonesian forests provide a “home” for over a thousand species of wildlife and a unique cultural heritage, as well as for Indonesian indigenous people and local tribes. As a response to protect these valuable resources, the government of Indonesia has designated some biodiversity hotspots as nature reserves, often as national parks.

ALNP is one of 54 national parks in Indonesia, which has a role in conserving forest resources as well as maintaining people’s livelihoods and traditions and contributing to economic development. Therefore effective spatial planning is fundamental for park management that defines spatial land use purposes, imposes land use limitations and regulates natural resource use (Portman, 2007). Government of Indonesia regulations divides national parks into several zones, namely protected (core), wilderness, utilisation, rehabilitation, traditional, historical or cultural, and religious zones, (Forestry, 2015). In spatial planning, the availability of updated land cover/land use data is crucial in environmental planning and management (Soni et al., 2015). Accordingly, this study focused on the evaluation of Aketajawe spatial planning by integrating UAV technology and GIS analysis to acquire an update land cover and land use data for evaluating existing zone classifications and develop new ones.

In principal, UAV provides a cost-effective and speedy method to collect and update spatial information in specific areas, such as indigenous people's territory, degraded land, and agricultural areas. Satellite imagery was used to gather spatial data in the relatively large area of Aketajawe-(77,794 hectares). These data were combined with ecological parameters (e.g. slope, wildlife distribution, elevation and river proximity). Another set of spatial data related to a socioeconomic parameter (e.g. people's livelihoods and economic variables, such as accessibility, risk areas, cultural values, and environmental services) was developed. These two parameter sets were combined into two spatial zone models (the zonal and eco-social models) to examine the best spatial planning outcomes for Aketajawe.

Principally, there are two major differences between the zonal and eco-social models presented in this thesis: influence percentage allocation and weighting scheme. In the zonal model, the total influence percentage between ecological and socioeconomic parameters was at 100%. Each criterion was assigned a value of 1, 3, or 5 based on their relationship to each particular zone objectives (core, wilderness, etc.) in the weighting scheme methods. In the eco-social model, by contrast, each set of zoning parameters had total influence of 100% (i.e. ecological = 100% and socioeconomic = 100%), the all spatial data in each zoning parameter were examined with respect to two primary national park development goals (biodiversity protection for the ecological group and economic contribution for the socioeconomic group). Once formulated, all models were analysed by using weighted overlay tools in GIS software.

The primary and secondary data analysis in this study showed several interesting key findings. The photogrammetric survey using UAVs has been shown to be effective for capturing reliable forest surface information in specific areas. As shown in this study, 687 hectares area were mapped with a total flight duration of 4 hours 19 minutes and 10 seconds. This is significantly faster than conventional surveying methods using GPS. Better land use information illustrated in this study's orthomosaic images (Figure 5.2, 5.3, 5.4, and 5.5) over satellite imagery, because they have higher spatial resolution and the images represent the more up to date field conditions from when the satellite data were collected. The most significant advantage of UAV aerial surveys compared to satellite imagery is the ability to provide real-time, on-demand land surface information. The user has the freedom to undertake field data collection when needed, which is almost impossible with satellites due to technical and operational limitations. This ability allows national park officers to work more closely with the real conditions.

Satellite imagery is a powerful tool over a relatively large area, which can present the whole "picture" of Aketajawe Block. A crucial finding of this study has been the identification of a new solid open area of around 444 hectares in the Northeast Aketajawe region that was previously undocumented. These data were then used to update land cover information over Aketajawe based on Landsat 8 data acquired in March 2016 using the maximum likelihood classification technique. Then the combination of orthomosaic images from the photogrammetric survey and satellite imagery (Landsat 8) presented land use classifications for Aketajawe, which is composed primary forest (87.3%), secondary forest (10%), open area (2.43%), agriculture land (0.01%), coconut plantation (0.03%), and indigenous people territory (0.21%).

A further GIS analysis to examine the best spatial planning outcomes in Aketajawe based on two model formulations (the zonal and eco-social models) resulted in relatively similar zoning classification total areas. In the zonal model, this model is structured including core zone at 27,027 (34.74%), wilderness zone at 42,397 ha (54.50%), traditional zone at 3,336 ha (4.29%), utilisation zone at 3,098 (3.98%), rehabilitation zone at 1,926 ha (2.48%) and specific use zone at 9.5 ha (0.01%). In addition, based on eco-social model formulation, the Aketajawe spatial planning composition included the core zone at 29,159 ha (37.48%), wilderness zone at 40,772 ha (52.41%), traditional zone at 2,370 ha (3.05%), utilisation zone at 3,547 ha (4.56%), rehabilitation zone at 1,937 ha (2.49%) and specific use zone at 10 ha (0.01%).

Overall, there were no major differences in term of total area and zone distribution in both model zoning classifications. This may indicate that, even though different spatial logic was used in to formulate these models, there is a correlation or relationship between ecological and socioeconomic parameters when identifying similar areas for each particular zone classification. With high-quality spatial data, this study illustrated the differently weighted models used in the GIS analysis showed similar final results.

In summary of this study, the following conclusions can be drawn:

- UAV has been proven to provide real-time, on-demand high-spatial resolution land surface information that is a contrast benefit compared with the conventional surveys by GPS or human survey;
- GIS has been effective in examining several remotely sensed data resources, such as UAV and satellite data for generating the spatial model in the national park zoning classification;
- GIS offers a variety of spatial analysis techniques that can be updated or reviewed at any time as management needs as well as quantify the impact of human intervention in the conservation area and developing management's strategies in ALNP;
- As Indonesia is a developing country with the fourth largest population in the world (BPS, 2018), Indonesian forests have struggled to meet people's basic necessities and have been used as "economic objects" by the Indonesian government to raise more income. Consequently, forest degradation and deforestation is an ongoing problem. Improved information about the national park zoning management is crucial to lead more transparency forest management, which limit future over-exploitation of these resources that have been proven in this study by application of UAVs survey and satellite imagery into GIS spatial analysis.

7.3 Recommendations

The focused recommendations from this study are mainly related to how satellite imagery and photogrammetric surveys using UAVs can be incorporated into national park management, and the application of GIS as the part of the national park decision-making process and what can be done in the future based on this study result. The benefits and weakness of satellite imagery and UAVs photogrammetry have been well discussed in this study. Their combined use offers a great opportunity to develop a range of spatial data, such as land cover, land use, open areas, logging areas, and indigenous people's territories that are fundamental in park management. This offers several further research applications in biodiversity evaluation, monitoring tourism development and forest restoration. This potential has not yet emerged in ALNP, because of the lack of management efforts to strengthen the spatial database capacity and reliability, including the GIS users and ancillary equipment. As suggested in this study, there are many ways and options for gathering satellite data. Of course, there is a case for using high specification satellite data, which provides several advantages in terms of wider spatial extent, better spatial resolution and more spatial analysis potential. However, freely available satellite data, such as Landsat, is also available and easy to access. The more applicable photogrammetric survey has been developed using UAVs. Low-cost UAV systems have been used in this study, demonstrating the applicability of this technology in park management. As a result, the use of satellite data and photogrammetric images in park management is reasonable and possible. The combination of these technologies brings the national park management to work more "closely" into the real field condition with good data reliability and visibility.

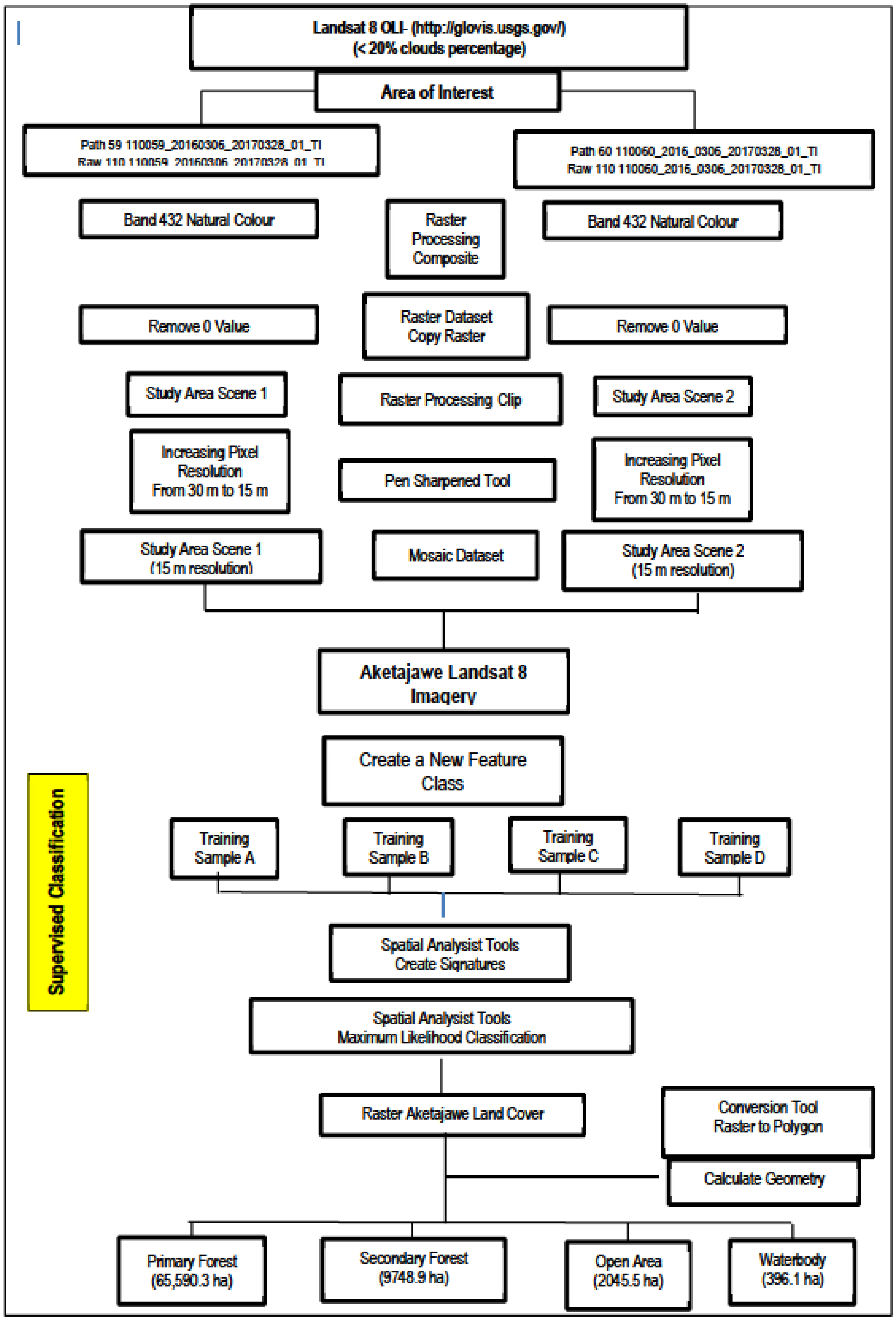
Nevertheless, without a good GIS system and suitably qualified users, the discussion above is useless. GIS is a reliable software in natural resource management. Reliable spatial data is meaningless without good support with GIS environments. Incorporating GIS into park management is crucial, where a lot of management strategies, actions, programmes, and planning in a national park are always related to spatial data — for example, managing overlapping agricultural land and national park area in Akejawi. Keeping forest intact is the top park management priority, but at the same time, deforestation happens continually due to population growth. As a result, field conditions are always dynamic, and an innovative strategy is needed to manage these problems. Through the application of GIS, more comprehensive data and information can be analysed systematically to provide more transparent forest resources management to decision makers, consequently the policymakers have a better understanding to prevent any detrimental impacts of human interventions as well as promoting the potential of the national park for sustainable and more collaborative national park management in the future.

Moreover, the spatial planning data based in this study analysis can be used as a reference to make a more detailed programme or policy decisions in each zone. As national park management needs stakeholder participation in supporting park development, public involvement or private investment could be implemented in ALNP. Consequently, more detailed or specific spatial planning is essential, such as infrastructure planning, tourism development strategies, or forest rehabilitation programmes. This study result could be used as a primary reference to identify suitable locations for developing more specific spatial planning. Zoning classifications can be used as a “general” land use allocation followed by master planning or detailed engineering designs (DED) for further national park development.

The connectivity between these spatial planning documents is important in helping maximise forest integrity, which will ultimately contribute to the future sustainability of these critical natural resources and provide the widest possible benefits to the diverse human and non-human communities who are dependent on Indonesia's national parks.

Appendix A

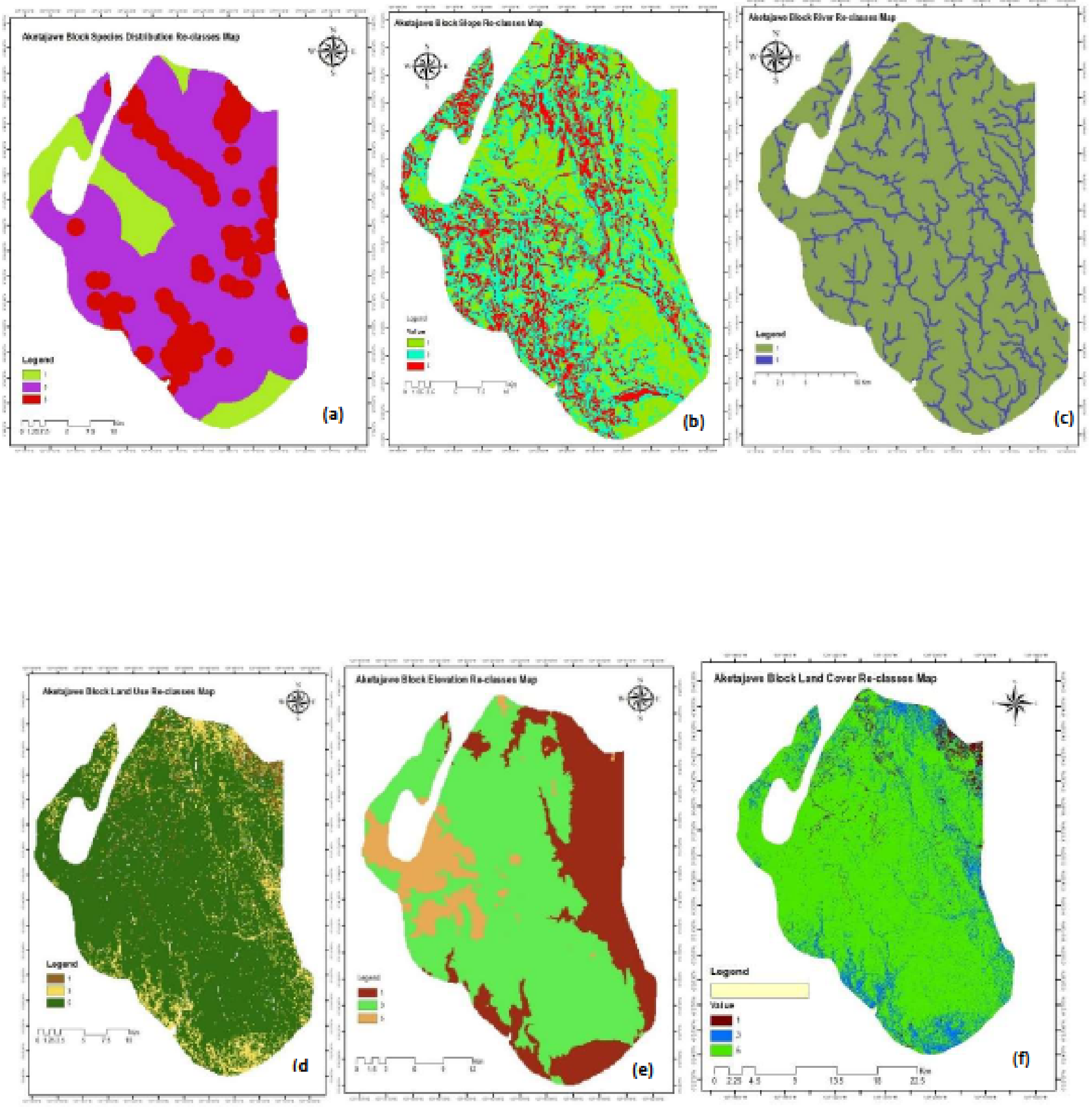
Maximum Likelihood Classification Flowchart



Appendix B

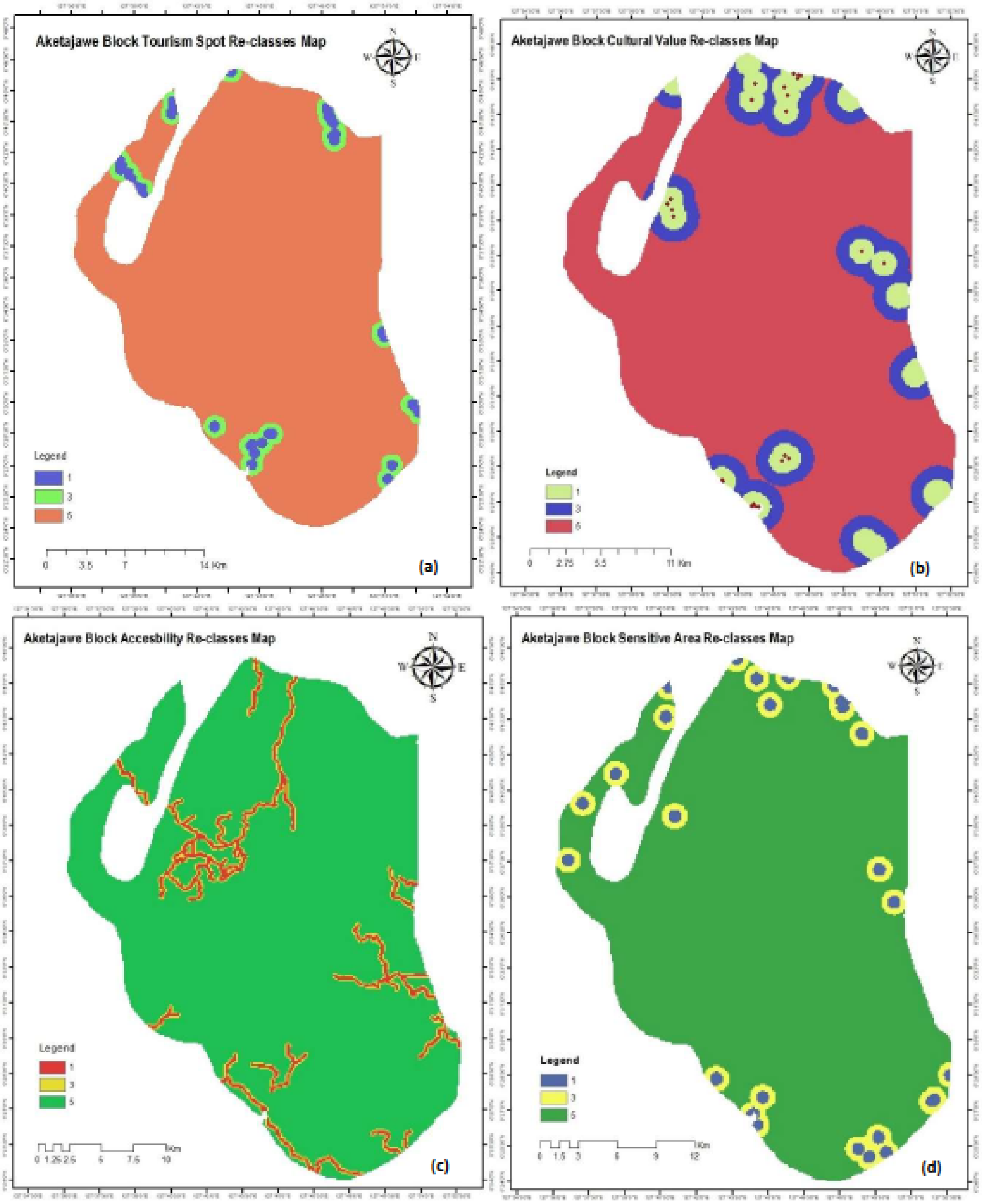
Zonal Model Reclassification Map

B.1 Core Zone



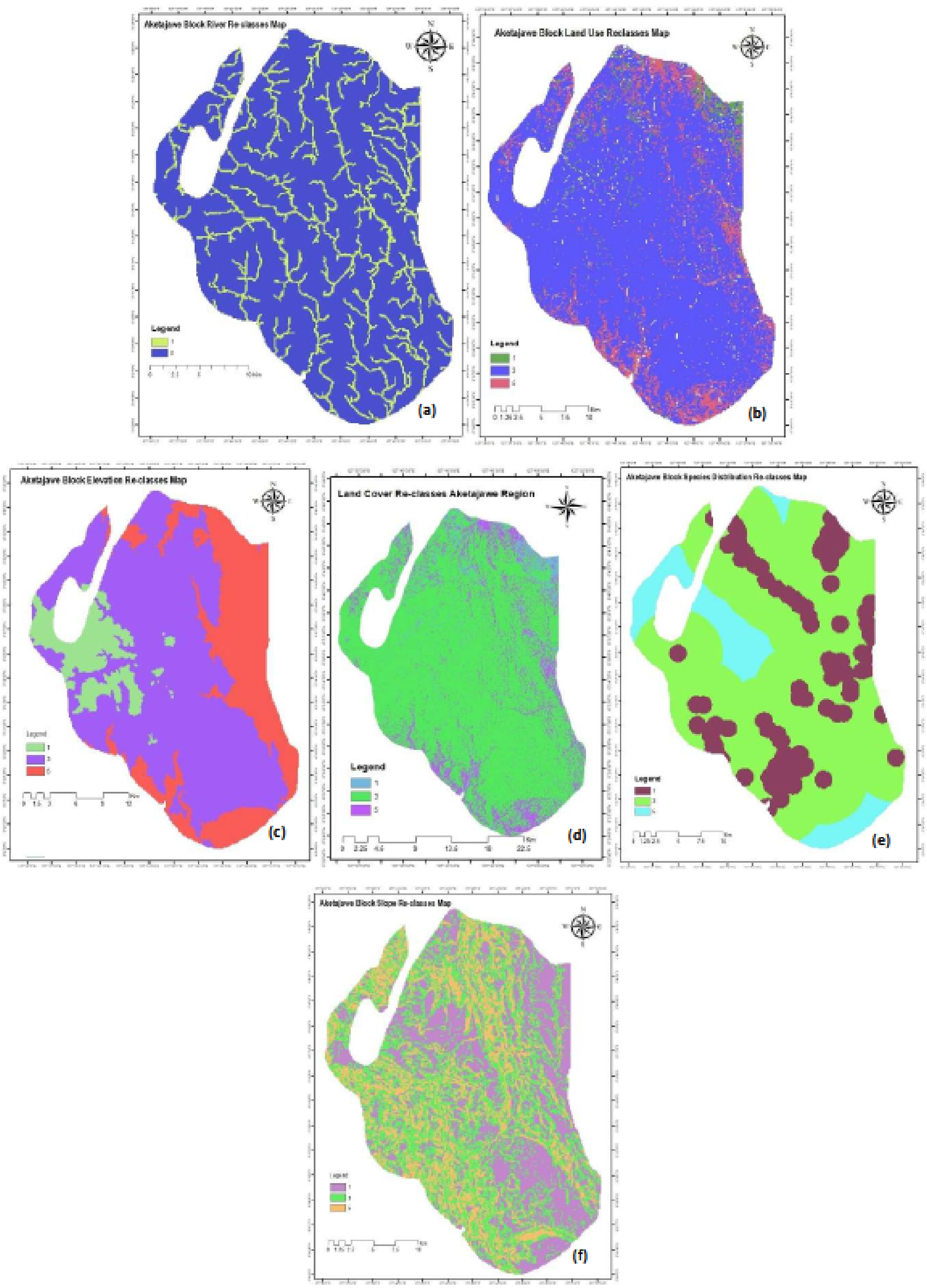
(a) Wildlife distribution reclassification layer, (b) Slope reclassification layer, (c) River reclassification layer, (d) Land use reclassification layer, (e) Elevation reclassification layer (f) Land cover reclassification layer

Ecology Parameter



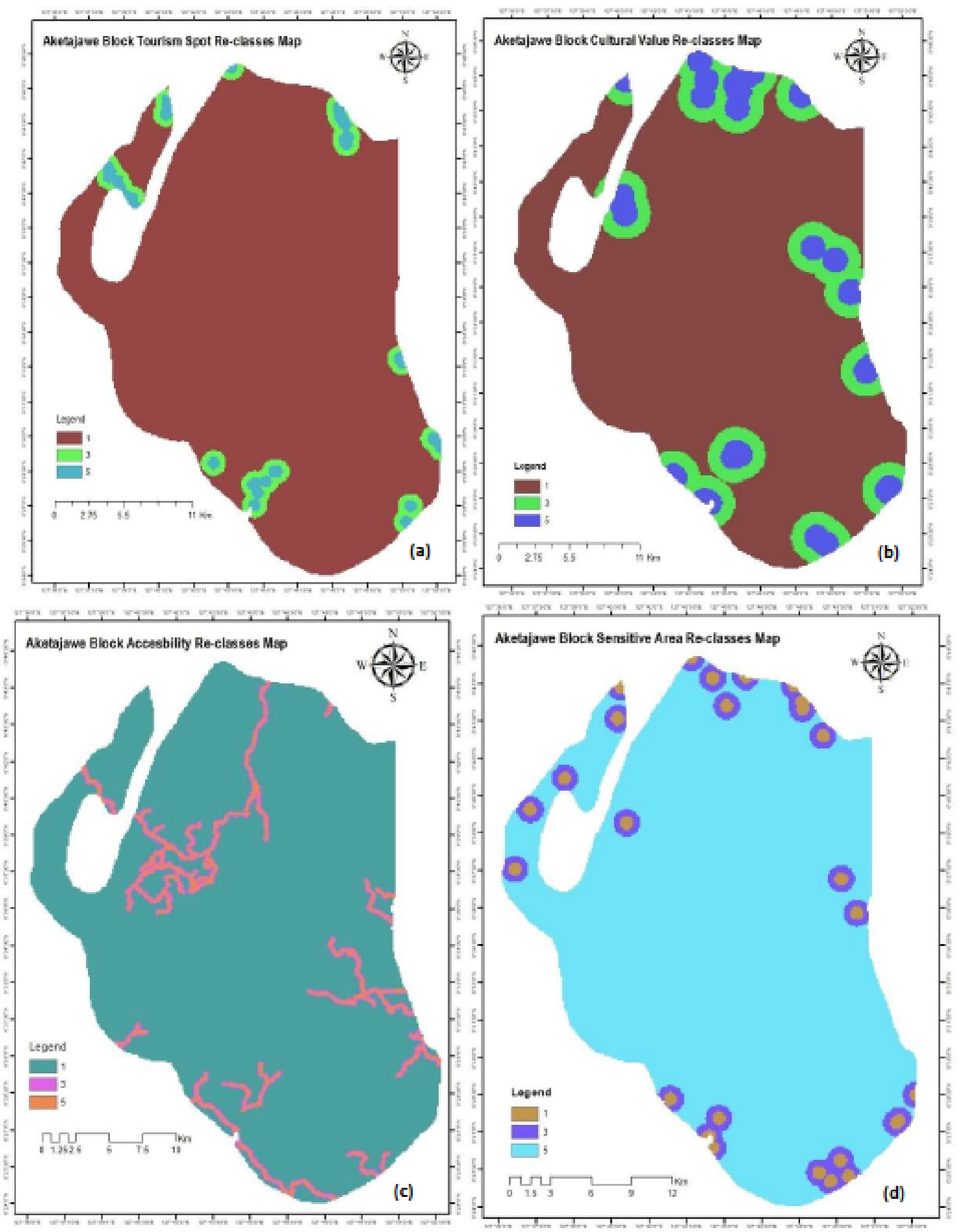
(a) Environmental services reclassification layer, (b) Cultural value reclassification layer, (c) Accessibility reclassification layer, and (d) Sensitivity area value reclassification layer (Socio-economic parameter)

B.2 Utilisation zone



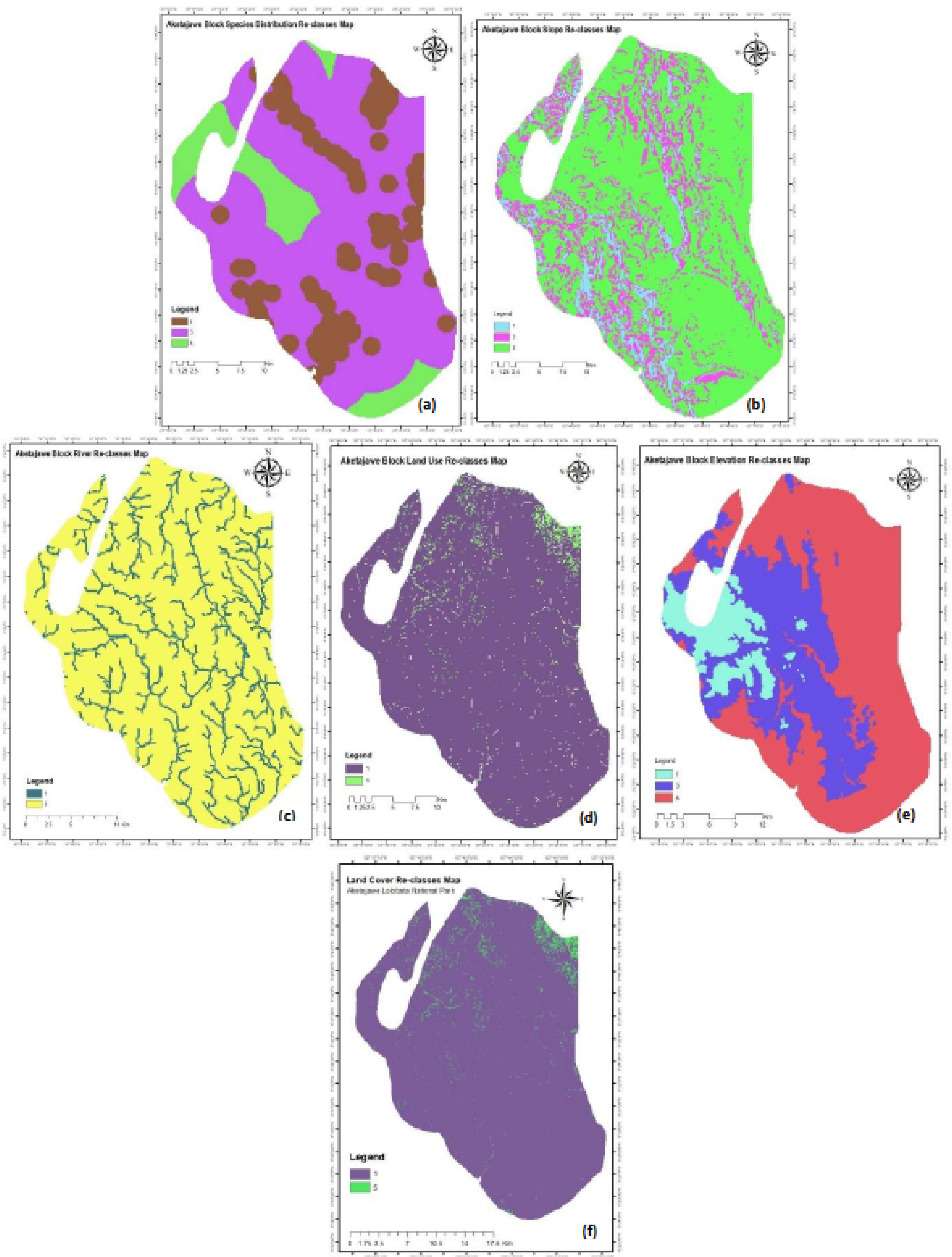
(a) Wildlife distribution reclassification layer, (b) Slope reclassification layer, (c) River reclassification layer, (d) Land use reclassification layer, (e) Elevation reclassification layer (f) Land cover reclassification layer

Ecology Parameter



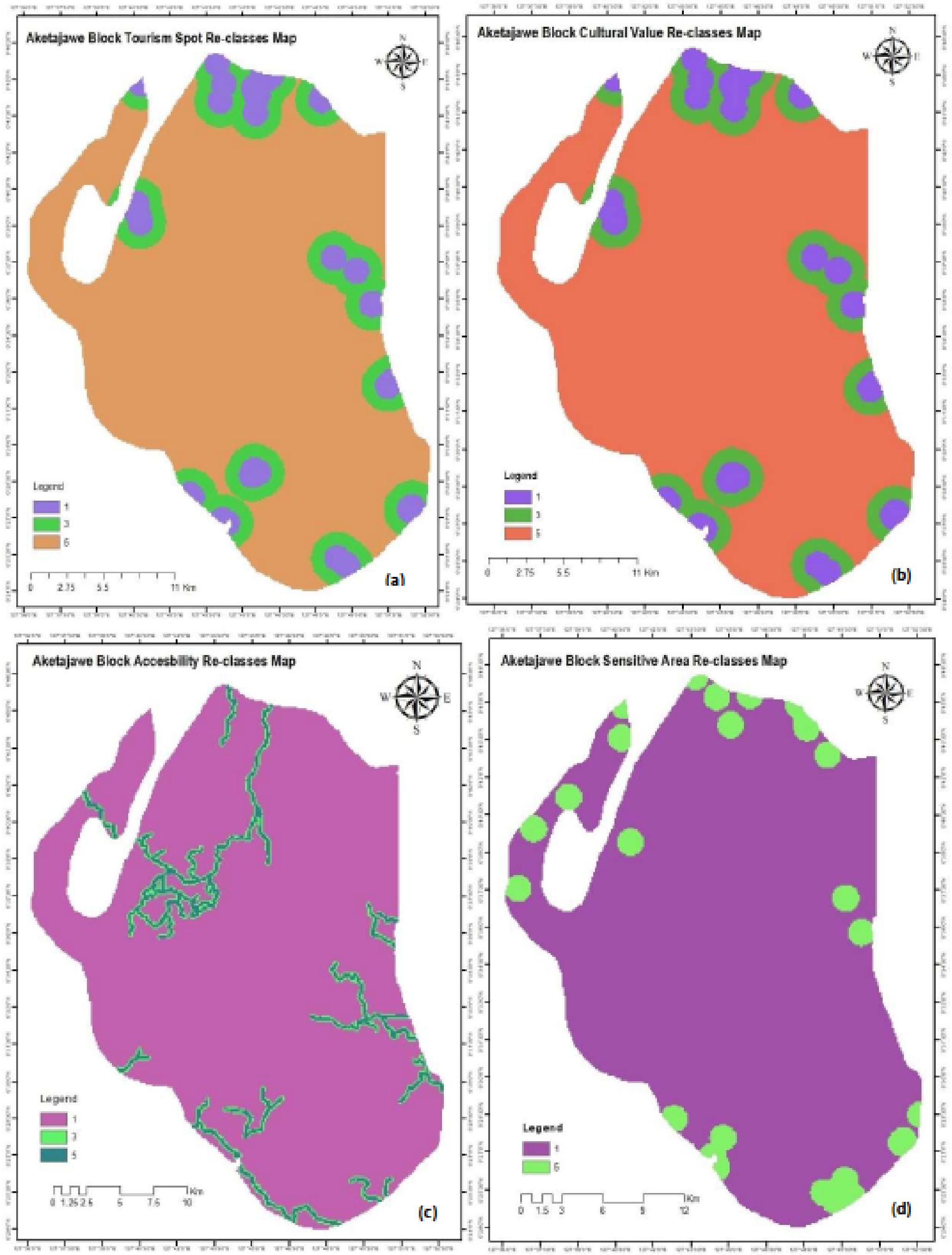
(a) Environmental services reclassification layer, (b) Cultural value reclassification layer, (c) Accessibility reclassification layer, and (d) Sensitivity area value reclassification layer (Socio-economic parameter)

B.3 Rehabilitation zone



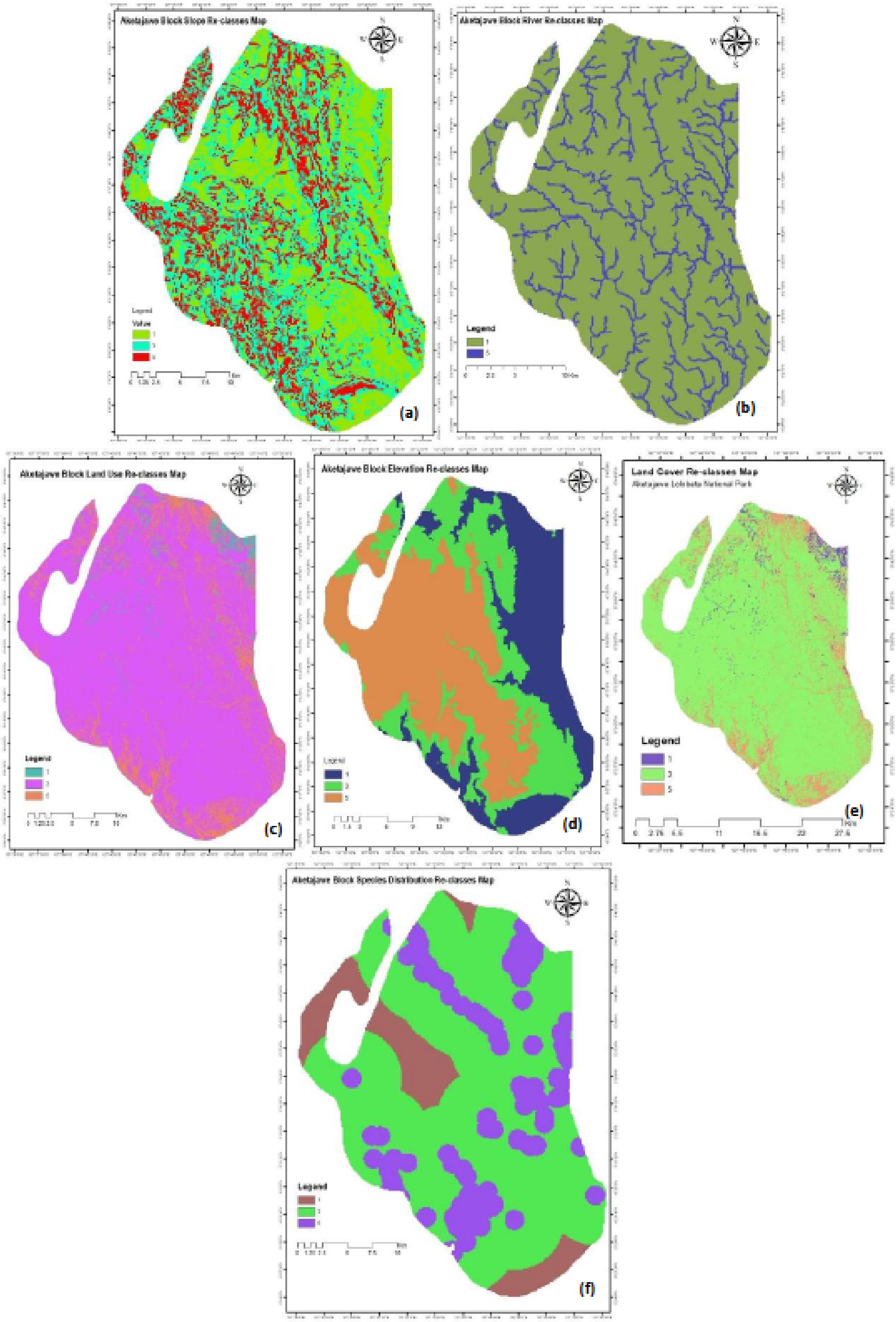
(a) Wildlife distribution reclassification layer, (b) Slope reclassification layer, (c) River reclassification layer, (d) Land use reclassification layer, (e) Elevation reclassification layer (f) Land cover reclassification layer

Ecology Parameter



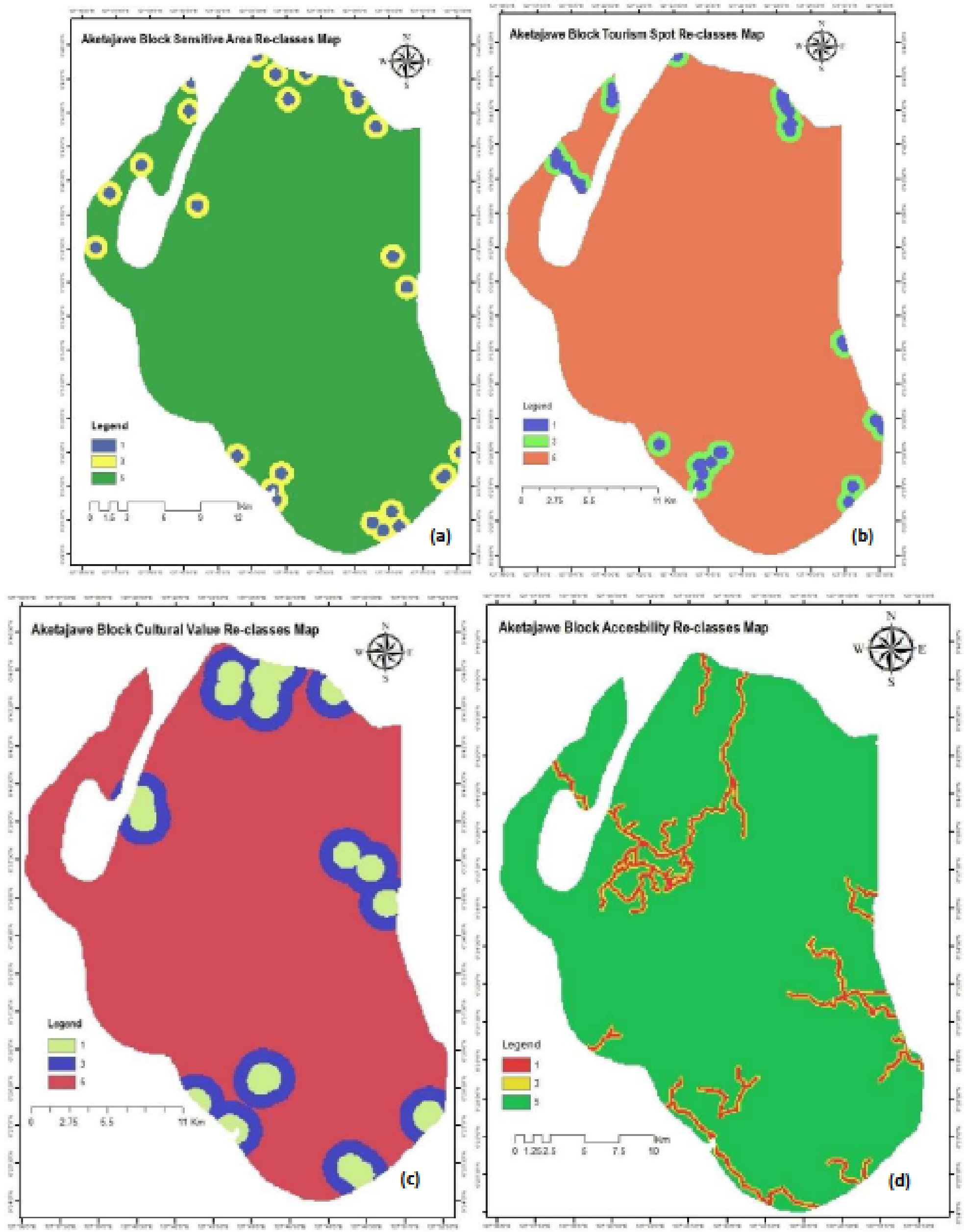
(a) Environmental services reclassification layer, (b) Cultural value reclassification layer, (c) Accessibility reclassification layer, and (d) Sensitivity area value reclassification layer (Socio-economic parameter)

B.4 Wilderness zone



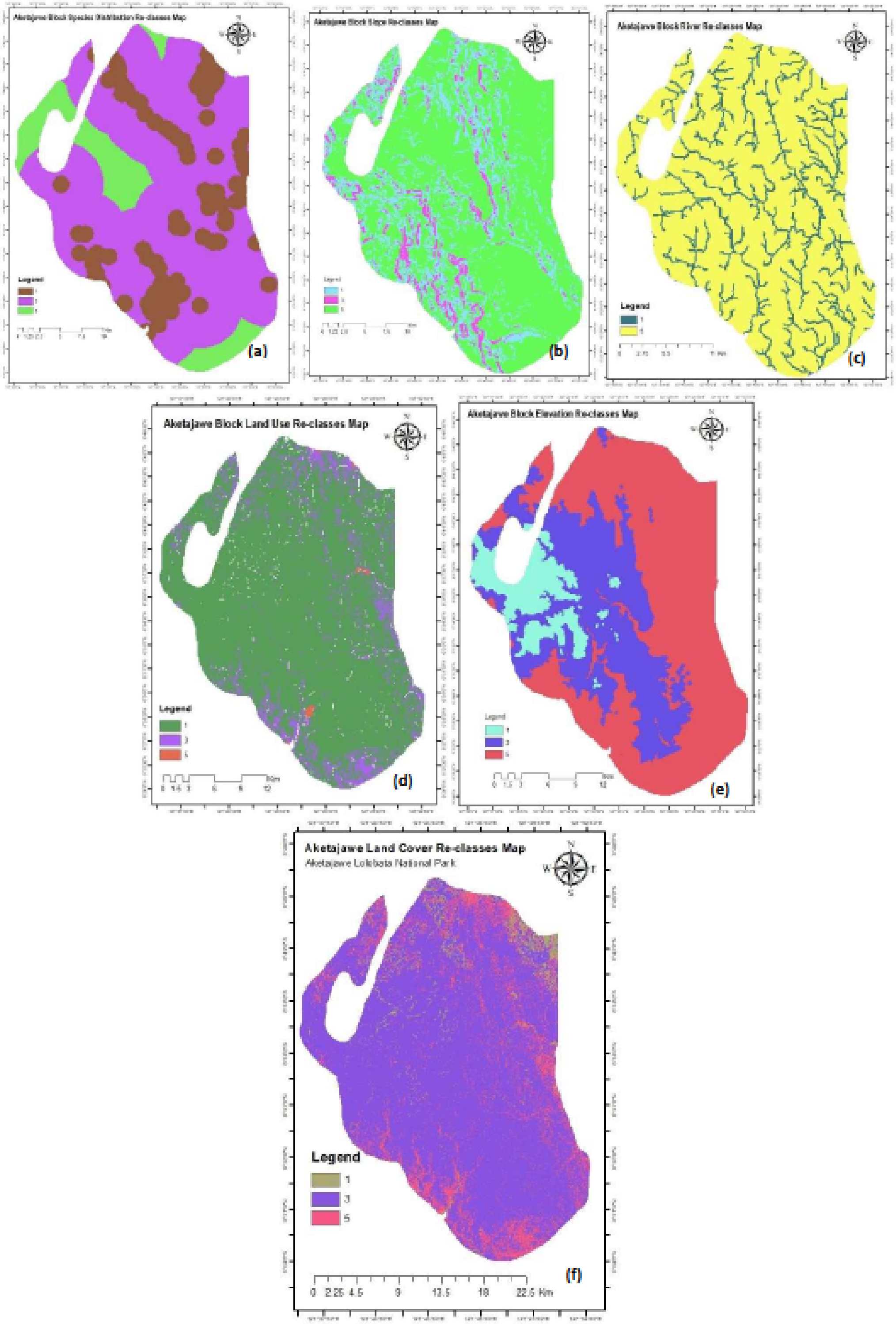
(a) Wildlife distribution reclassification layer, (b) Slope reclassification layer, (c) River reclassification layer, (d) Land use reclassification layer, (e) Elevation reclassification layer (f) Land cover reclassification layer

Ecology Parameter



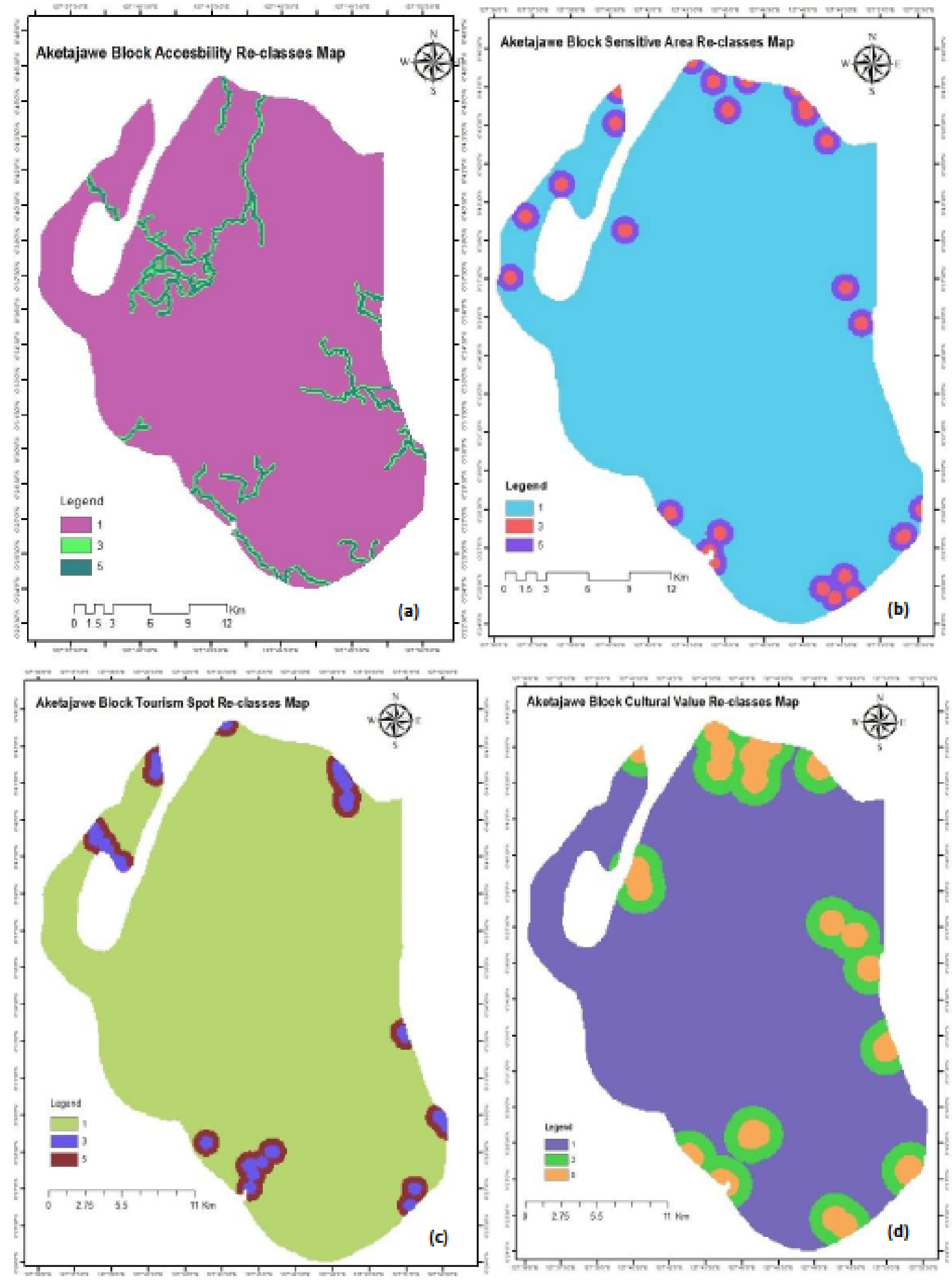
(a) Environmental services reclassification layer, (b) Cultural value reclassification layer, (c) Accessibility reclassification layer, and (d) Sensitivity area value reclassification layer (Socio-economic parameter)

B.5 Traditional zone



(a) Wildlife distribution reclassification layer, (b) Slope reclassification layer, (c) River reclassification layer, (d) Land use reclassification layer, (e) Elevation reclassification layer (f) Land cover reclassification layer

Ecology Parameter



(a) Environmental services reclassification layer, (b) Cultural value reclassification layer, (c) Accessibility reclassification layer, and (d) Sensitivity area value reclassification layer (Socio-economic parameter)

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