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AN ASSESSMENT OF LAND USE SURROUNDING HYDROPOWER RESERVOIRS USING REMOTE SENSING IN SARAWAK, MALAYSIA

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Abstract: The existence of a complex river system in Sarawak has contributed to the abundance of its water resources. The State is drained by 22 major river basins and has a combined installed capacity of hydropower potentials of approximately 20,000 MW of sustainable energy. However, little has been documented on land use around these hydropower dams. The current study is aimed at understanding the general land use composition surrounding the existing and planned hydropower reservoirs in Sarawak. The land uses surrounding these dams are expected to influence the livelihood, water discharge and water quality of the dams. A total of ten sites were selected and land use surrounding these study sites identified using Remote Sensing and Geographic Information System tools. Temporal assessment on land-use changes was only conducted for Batang Ai. The study found that a total of six sites have higher forest cover (> 50%) compared to built-up and agricultural lands and showed that 85% variation in built-up land is explained by reservoir area. Agricultural land has increased at the mean rate of 2.25% within 500 metres distance from Batang Ai reservoir shoreline. The findings of this study will hopefully contribute to the knowledge of hydropower reservoir planning and management.

Keywords: Reservoir shoreline, forest cover, hydroelectric planning, sustainable energy, green economy, Borneo.

Introduction

Dams are typically designed to store water and have played an integral role in the early history of many civilisations (Luis *et al.*, 2013). The International Hydropower Association's (IHA) Hydropower Sustainability Assessment Protocol (HSAP or the "Protocol") defines 'reservoir' as "any artificial pond or lake used by the project for storage and regulation of water", and reservoir area as "the area that is inundated when the reservoir is at its maximum expected level and the dry buffer zone above this level" (IHA, 2018). In Malaysia, there are at least 73 man-made lakes that have been created for purposes such as water supply, irrigation, hydropower generation, and flood mitigation (Luis *et al.*, 2013).

The hydropower potential in Malaysia is identified at 29,000 MW (Hosseini & Wahid, 2014). Eighty-five per cent (85%) of the country's hydropower potentials are found in East Malaysia (Ali *et al.*, 2012). Bakun Dam (2,400 MW), which was built on Balui River of the Upper Rajang River Basin in Sarawak, has the largest hydropower installed capacity in Malaysia. The state of Sarawak, located on the island of Borneo, has a total land area of 124,450 km^2 and is drained by 22 major river basins. Its three largest river basins are Batang Rajang (approximately 50,000 km^2), Batang Baram (approx. 22,000 km^2), and Batang Lupar (approx. 6,500 km^2) (Department of Irrigation and Drainage Sarawak, n.d.). In the year 1981, the Master Plan for Power System Development for Sarawak was completed. Known as the SAMA study (1981), the document identifies the potential combined installed capacity and energy production for hydropower in Sarawak as 20,000 MW and 87,000 GWh, respectively. Currently, 17.3% (3,452 MW) of Sarawak's hydropower potentials have been developed at Batang Lupar (or, the Batang Ai Hydroelectric Plant (HEP) (108 MW)) and Batang Rajang at Bakun HEP (2,400 MW) and Murum HEP (944 MW). The selection of suitable hydropower projects and the optimum long-term power expansion programme in Sarawak depends on the energy demand scenarios (SAMA Consortium, 1981). A site that is deemed as unsuitable at present may become attractive in the future and this shall depend on various conditions and factors (e.g., power tariffs, social, and environmental characteristics) surrounding the development of the potential hydropower site (International Finance Corporation, 2015). In the past decade, energy development in the State was driven by the Sarawak Corridor of Renewable Energy (SCORE). SCORE was identified by the past Federal Government of Malaysia as one of five economic development corridors in the country and this development agenda targets 10 high-impact priority industries – aluminium, oil-based, steel, glass, and the trigger industries (i.e., marine engineering, palm oil, livestock, timber-based, aquaculture, and tourism) (RECODA, 2015). The energy-intensive industries such as aluminium smelting, iron ore and steel plants are mostly concentrated in the Bintulu region. At the current capacity, the Bakun and Murum hydropower plants are capable of electrifying at least two aluminium smelter plants (Faizal *et al.*, 2017). The hydropower capacity in Sarawak is projected to increase to 3,500 MW and 7,723 MW by the years 2015 and 2020, respectively (Ong *et al.*, 2011). The upcoming Baleh Hydroelectric Project (Baleh HEP), which is to be constructed on the Baleh River, is expected to produce approximately 1,200 MW power. By the year 2030, the State is expected to develop a total of 9,379 MW hydroelectricity power (Faizal *et al.*, 2017).

Similar to other lakes around the world, the hydropower reservoirs in Malaysia exhibit a variety of physical characteristics. The two most challenging aspects of hydropower lake management are to manage the issue of reservoir sedimentation and the risk of storage loss resulting from unsustainable land-use practices within the catchment area of the hydropower reservoir (Luis *et al.*, 2013). Land-use change within the draining river basin poses threats that may lead to lake degradation in Malaysia (Sharip & Zakaria, 2008). In Cameron Highlands, rapid developments due to intensive agricultural activities, urbanisation, infrastructure expansion, and deforestation are among the factors that have contributed to soil erosion in the upper river reaches (Gasim *et al.*, 2009). The Ringlet Reservoir in Cameron Highlands was designed with a total storage capacity of 6.5 million m^3 with an estimated lifespan of 85 years, but over 50% of its storage capacity has been taken up by sediments within just 35 years of operation (Luis *et al.*, 2012). Vegetated buffer strips around the reservoir shoreline can play a critical role to serve various management objectives. Zainuddin *et al.* (2013) stated that the main difference between “riparian buffer” and “buffer zone” is the latter is simply a strip of land along the riverbank and may not necessarily have flora and fauna. Based on the Department of Irrigation and Drainage (DID) Manual on River Management (2009), there is no “one-size-fits-all” riparian buffer zone that will serve ecological functions and therefore must be based on the objectives of the buffer zone. Riparian buffer improves water quality by trapping and removing various non-point source pollutants and provides habitat for plant and animal species (Fischer & Fischenich, 2000). The size of the riparian buffer zone may differ from one lake to another, depending on the functions of the buffer zone as well as the management objectives. DID (2009) recommended the size of buffer zone, among others: to protect water quality (5–30 m); to reduce bank erosion (10–20 m); to provide food input/aquatic habitat and to maintain light/temperature level (5–10 m); to provide terrestrial habitat (30–500 m); to enable agricultural production (10–30 m); and to attenuate downstream flood (20–150 m).

This study is the first in Sarawak to have utilised the Remote Sensing (RS) and Geographic Information System (GIS) to identify the general land use composition within 500 metres distance from the reservoir shoreline of the existing and planned hydropower reservoirs in Sarawak.

There is virtually no information on the types of land use adjacent to the hydropower reservoirs in Sarawak. The identification of land use and land cover is made possible by using remote sensing because different land cover features (e.g., water, soil, vegetation, and cloud) reflect visible and infrared lights in different ways (Navalgund *et al.*, 2007). The spatial, temporal, and spectral resolution on a satellite image can help in determining the suitability to detect different land cover types (Aspinall & Pearson, 2000).

The rationale of this study is to describe the general land use composition along the shoreline of the existing and planned hydropower reservoirs in the state of Sarawak. The fact that buffer zones surrounding reservoir are crucial in ensuring the sustainability of the hydropower operations and management, there are no known legal requirement, standards or guidelines for the protection of hydropower lakes in Sarawak. Any land uses adjacent to the hydropower reservoir rim if developed in an unsustainable manner, may affect the 'health' of the reservoir, structural integrity, and the operations of the hydropower dam. The findings of this study may be utilised by hydropower planners and operators as well as the policy-makers on the hydropower reservoir planning and management.

The study was conducted within the following scopes: (i) General assessment on the land-use composition surrounding the reservoir at 500 metres distance from the reservoir shoreline of the existing and planned hydropower reservoirs; and (ii) Detailed assessment on the temporal land-use change for every 100 metres, within the 500 metres distance from the Batang Ai reservoir shoreline.

Materials and Methods

Study Area

The study area is located "strictly within the 500 metres distance from the reservoir shoreline of existing (n = 2) and planned (n = 8)" hydropower reservoirs in Sarawak. Ten sites were selected, namely, 'Batang Ai', 'Murum', 'Baleh, Belaga', 'Pelagus', 'Baram',' Limbang 1', 'Limbang 2', 'Lawas', and 'Trusan 2'. Because of security, the coordinates of the study sites are not provided. The approximate locations of the study areas are shown in Figure 1. Two of 10 sites namely, Batang Ai and Murum are currently under operations. The remaining eight sites are potential hydropower sites.

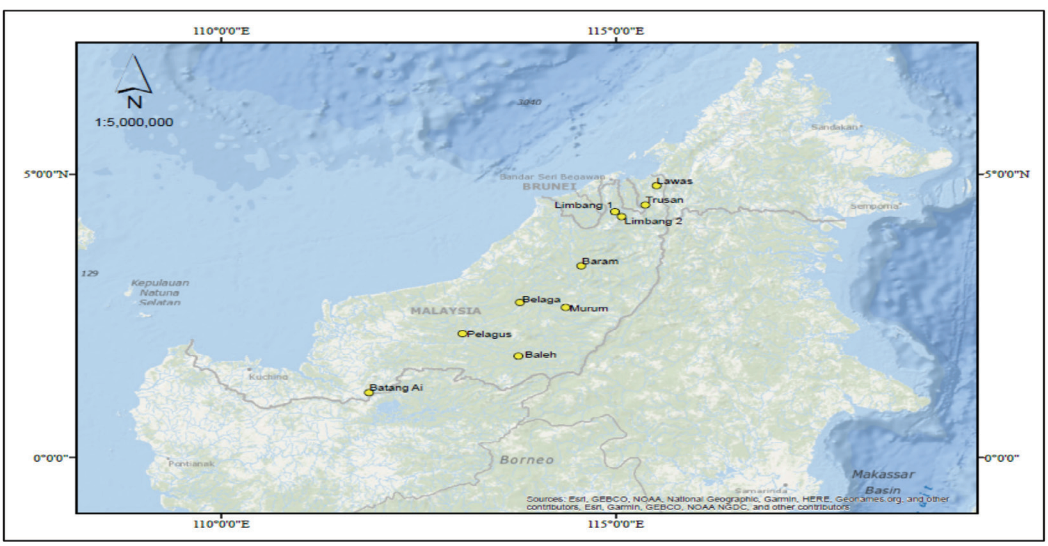

Figure 1: The study sites showing two currently operational dams (Batang Ai and Murum) and other eight potential hydropower sites in Sarawak

Data collection

The primary source of data was obtained from the United States Geological Survey (USGS)'s Earth Explorer website at https://earthexplorer.usgs.gov/. The Landsat imageries were collected from Landsat Thematic Mapper (TM) carried by Landsat 4 and Landsat 5, and Landsat Enhanced Thematic Mapper Plus (ETM+) carried by Landsat 7. The Landsat imageries collected are listed in Table 1. The Global Positioning System (GPS) data and more than 200 digital photos collected during field surveys on 11 September 2015 and 26 February 2016 were compiled for the Batang Ai Reservoir.

Satellite Image Analysis

The satellite image pre-processing and classification are guided by the analysis technique described by Navalgund *et al*. (2007). The four basic steps involved were: (i) Image correction or restoration, (ii) image enhancement, (iii) image transformation, and (iv) image classification. The remote sensing data were pre-processed by using ERDAS Imagine 2014 and were analysed by using ArcGIS 10.3 (ESRI, 2014). The satellite images were classified by using both unsupervised and supervised classification tools. Unsupervised classification utilised the K-means method to the selected image, in which the number of classes tested was in the range of 10 to 36 classes. The classes that defined cloud cover, reservoir and water bodies were identified and subsequently, were masked from the selected image. Masking was necessary to eliminate these features from the land use analysis. Upon unsupervised classification and masking of relevant features, maximum likelihood supervised classification was performed. Training sites were created and defined by using the Signature Editor tool. For this study, the land use and land cover were identified at Level I based on Anderson *et al*. (1976), namely the Built-up Land (Code 1), Agricultural Land (Code 2), and Forest Land (Code 4). The summary of signature editor files used for supervised classification is in Table 2.

Accuracy Assessment

Accuracy assessment was performed on the classified image to determine the quality of the information provided from the data (Navalgund *et al*., 2007). The method utilised is the Kappa test, in which the pre-defined producer and user-assigned ratings were calculated. The minimum level of accuracy to be achieved for this study is 75%.

Table 1: Landsat imageries based on site

Site	Image Source	Path/Row	Year
Batang Ai Reservoir	Landsat ETM+ 7 Landsat TM 5	120/059 120/059	2015 1995
Murum Reservoir	Landsat ETM+ 7	118/058 119/058	2016 2016
Baleh	Landsat ETM+ 7	119/059	2016
Belaga	Landsat ETM+ 7	119/058	2016
Pelagus	Landsat ETM+ 7	119/058	2016
Baram	Landsat ETM+ 7	118/058	2016
Limbang 1	Landsat ETM+ 7	118/058	2016
Limbang 2	Landsat ETM+ 7	118/058	2016
Lawas	Landsat ETM+ 7	118/058	2016
Trusan 2	Landsat ETM+ 7	118/058	2016

Table 2: Signature Editor Files for supervised classification.

Code	Land Use	Colour	Description
1	Built-up Land		Residential areas, longhouses, facilities, access roads, logging road, mixed development or other built-up lands
2	Agricultural Land		Cropland, orchards, shifting cultivation, monocrop cover
4	Forest Land		Undisturbed forests, secondary forest

Statistical Analysis

The two statistical analyses conducted were the regression analysis and analysis of variance (ANOVA). The following hypotheses were tested for linear regression analysis:

H_0: There will be no linear relationship between the reservoir area and the built-up land, agricultural land, or the forest land.

H_1: There is at least one linear relationship between the reservoir area and the built-up land, agricultural land, or the forest land.

The relationship between the reservoir and land use were tested independently based on the category of supervised classified land uses. The significance level was set at 0.05. If the significance F is valued ≤ 0.05, the null hypothesis would be rejected.

The following hypothesis was tested for ANOVA:

H_0: The mean values of land use changes for built-up land, agricultural land, and forest land are equal.

H_1: Not all mean values of land-use changes are equal.

Temporal Land Use Changes in the Surrounding of Batang Ai Reservoir

Batang Ai Reservoir is a man-made lake that covers an area of approximately 90 km^2 and the Batang Ai hydroelectric power station has been operating since the year 1985. Before the creation of the reservoir, 25 Iban longhouse communities, with a population of approximately 3,600 people were resettled (Ngidang, 1995). Those who were not resettled are still residing in the upper reaches of the two main tributaries of the reservoir, namely, Engkari and Delok River. The presence of scattered human settlements in the upper reaches of the reservoir may contribute to the land use pattern of patches of agricultural land. Batang Ai site was selected for further assessment on the land-use change within 500 metres distance from the reservoir shoreline. The land-use changes were described based on the following zones: Zone 1 (upper section of the reservoir including Engkari and Delok rivers); Zone 2 (mid-section of the reservoir); and Zone 3 (lower section of the reservoir). The test statistic used is the F statistic for ANOVA. At df1 = 2, df2 =12, and probability level = 0.05, the critical F-value = 3.885. If the F-value > critical F-value, the null hypothesis would be rejected.

Results

Land Use Composition

The land-use classification for this study is defined only at Level 1 of classifications for three (3) types of land use, namely, the built-up land, the agricultural land, and the forest land. The overall land use classification results for all study sites are as depicted in Figure 2.

The top three (3) sites with largest built-up land (i.e., residential areas, longhouses, facilities, access roads, logging roads, mixed development or other types of built-up land) are Baleh (28.7%), Baram (25.9%), and Pelagus (21.6%). For agricultural land (cropland, orchards, shifting cultivation, monocrop cover), the three (3) sites with largest areas are Pelagus

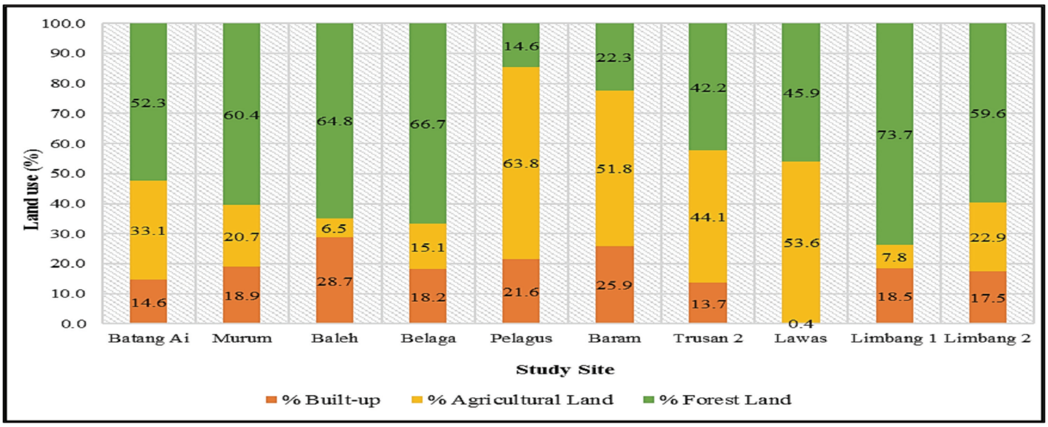

Figure 2: Land use composition within 500 metres distance from reservoir shoreline for all sites

(63.8%), Lawas (53.6%), and Baram (51.8%). Pelagus also recorded the lowest composition of forest land (14.6%). Cross-reference with the topographic maps found out that both Baram and Pelagus sites are found to be inhabited by humans as evidenced by the presence of settlements along the river. This corresponds to the supervised images for Pelagus and Baram sites, in which the agricultural land composition is at 63.8% and 51.8%, respectively, and the built-up land is at 21.6% and 25.9%, respectively. The relationship between the reservoir size and the built-up land areas within 500 metres from the reservoir shoreline is shown by the linear regression model is illustrated in Figure 3.

The R-Square value (R^2 = 0.85) indicated that 85% of the variation in Y-variable (built-up land) is explained by the X-variable (reservoir area). Several outliers are observed, particularly for reservoir size within the range of 5,000 to 45,000 ha. Majority of the study sites (7 sites) are consisting of reservoir size less than 5,000 ha and had shown a built-up land size pattern of less than 10,000 ha within 500 metres from the reservoir shoreline. For reservoir size 5,000–45,000 ha, the built-up land sizes are scattered in between 20,000 and 60,000 ha. The three (3) largest reservoirs are Baleh (approximately 53,000 ha), Baram (ca. 45,700 ha), and Murum (ca. 27,000 ha). Therefore, the outliers represented by these three largest reservoirs could simply indicate the distinctiveness and complexity of built-up land areas surrounding these reservoirs. The output of this model is summarised in Table 3.

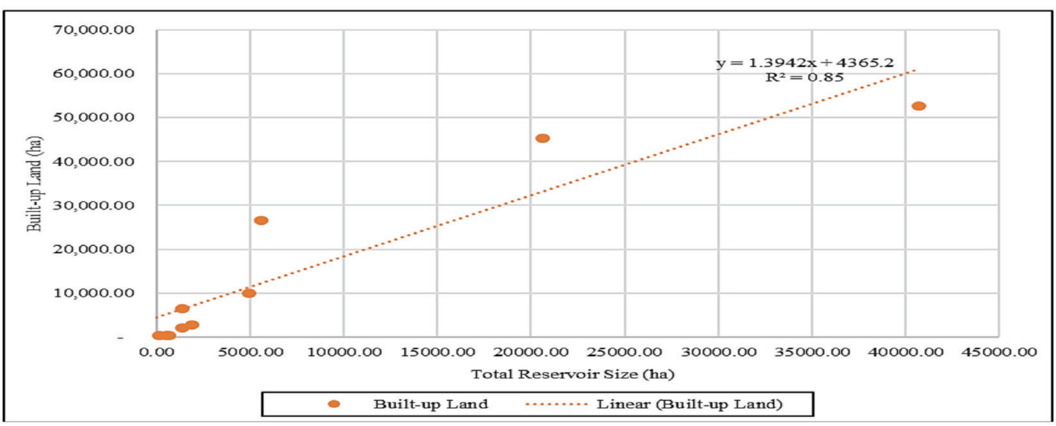

Figure 3: Linear regression model for reservoir and built-up Land

Table 3: Summary output for regression analysis between reservoir size and built-up land areas

Regression Statistics								
Multiple R	0.9220							
R Square	0.8500							
Adjusted R Square	0.8313							
Standard Error	5375.6936							
Observations	10							
ANOVA								
	df	**SS**	**MS**	**F**	**Sig. F**			
Regression	1	1310095669	1310095669	45.33503896	0.000147587			
Residual	8	231184655.2	28898081.9					
Total	9	1541280324						
	Coefficients	**Standard Error**	**t Stat**	**P-value**	**Lower 95%**	**Upper 95%**	**Lower 95.0%**	**Upper 95.0%**
Intercept	-1513.999	2177.614	-0.695	0.50658	-6535.59	3507.59	-6535.59	3507.59
X Variable	0.610	0.091	6.733	0.00015	0.40	0.82	0.40	0.82

Referring to the ANOVA table, the F value is 45.34 and the significance F (also the P-value) is 0.0001. Since the significance F-value (0.0001) is < than the significance level (0.05), the null hypothesis is rejected. There is at least one linear relationship between the reservoir area and the land uses (i.e. built-up land, agricultural land, or the forest land). The Multiple R (0.92) indicates the strong relationship between the two variables. Six study sites (i.e., Limbang 1 (73.7%), Belaga (66.7%), Baleh (64.8%), Murum (60.4%), Limbang 2 (59.6%), and Batang Ai (52.3%)) have land-use composition of higher forest cover (>50%) than the built-up and agricultural land. However, for Batang Ai site, the "ideal" concept of the riparian buffer is absence due to the discontinuity of forest cover surrounding the reservoir due to fragmented forest land (Figure 4).

Temporal Land Use Changes Surrounding of Batang Ai Reservoir

The results of the ANOVA test for land use changes within the 500 metres distance at every

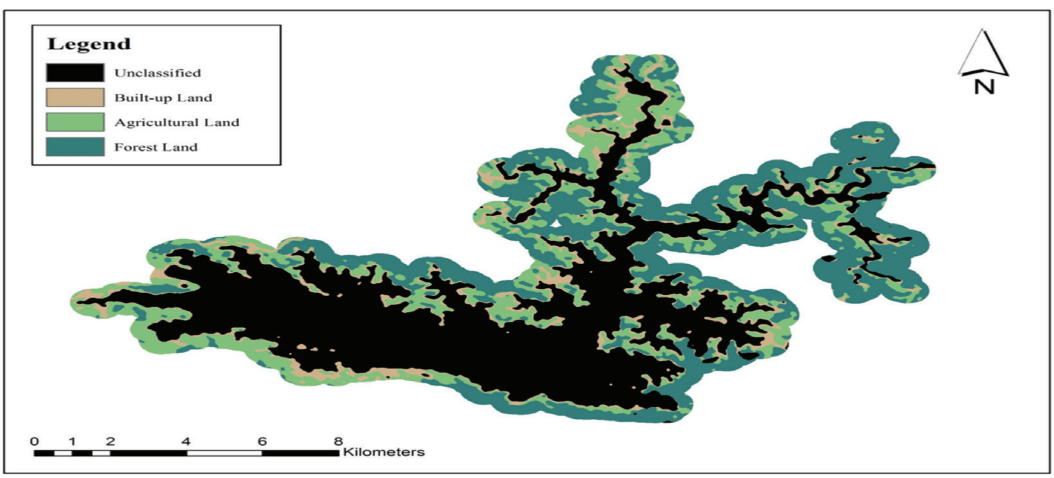

Figure 4: Overview of land use classification for the year 2015 within 500 metres distance from Batang Ai reservoir shoreline

100 metres for Batang Ai site in between the year 1995 and year 2015 are as tabulated in Table 4. The F-value (15.60) is more than the critical F-value (3.8853). The null hypothesis is rejected. Not all mean values of land-use changes are equal, and their differences are statistically significant. This also denotes that the land-use changes within 500 metres distance from the reservoir shoreline, at 100 metres intervals are statistically significant for the period in-between year 1995 and 2015. The mean value of land use changes at 100 metres intervals for agricultural land (2.25%) is higher than built-up land (0.34%) and forest land (0.15%). Agricultural land is ranked as the top land-use type that contributes to the land-use changes within 500 metres from the reservoir shoreline, at 100 metres intervals over 20 years along the shoreline of the Batang Ai reservoir. The supervised classification images illustrating the land use within 500 metres distance from the Batang Ai reservoir shoreline in the year 1995 and year 2015 are shown in Figure 5.

The supervised classification images illustrate the increase of agricultural land at Zone 1 and western rim of Zone 3; the decrease of built-up land within the vicinity of Zone 1 (i.e., tributaries of Engkari River) and western rim of Zone 3; and the decrease of forest land in the Zone 1, Zone 2 (i.e., near the confluence of Engkari and Delok rivers), and western rim of Zone 3. The land-use change at Zone 1 and Zone 3 appears predominantly due to clearing of forest and the conversions of built-up land into agricultural land.

Discussion

Land-use changes in Sarawak are mainly due to the logging activities, land conversion into oil palm and shifting agriculture practises (Hon & Shibata, 2013). Chin (cited in Drummond & Taylor, 1997) stated that at least 50% of Sarawak's population may be dependent on the forest for their livelihood. Cash cropping such as planting rubber, cocoa, and pepper is one of the livelihood strategies of the rural population to buffer their subsistence rice farming (Sim, 2011). The land use within 500 metres from the reservoir shoreline of the existing and planned reservoir in Sarawak is highly likely to be consisting of built-up land areas. This land use may comprise of residential areas, longhouses, facilities, access roads, logging road, mixed development or other forms of built-up land. Dale *et al*. (2000) stated that the growth in the human population can be considered as the main factor that leads to land-use changes. While the presence of human settlements in and within the vicinity of the planned reservoir may have contributed to the land use classified as built-up land (i.e., residential areas, longhouses, facilities, access roads) and agricultural land (i.e., to support livelihood), this may not be the direct factor for Baleh site (6.5% agricultural land and 28.7% built-up land). Apart from Long Singut, the upper reaches of the planned Baleh reservoir are no other known settlements or large human population inhabiting the area. Cross-reference with the topographic maps found the presence of logging camps adjacent and within the planned Baleh reservoir catchment area. The

Table 4: ANOVA test for land-use change every 100 metres interval for Batang Ai Site.

Summary						
Groups	**Count**	**Sum**	**Average**	**Variance**		
Built-up Land	5	1.700363	0.340073	0.002091		
Agricultural Land	5	11.25275	2.250549	1.295107		
Forest Land	5	0.727928	0.145586	0.004001		
Groups	Count	Sum	Average	Variance		
ANOVA						
Source of Variation	**SS**	**df**	**MS**	**F**	**P-value**	**F critical**
Between Groups	13.53103	2	6.765515	15.5984	0.00046	3.8853

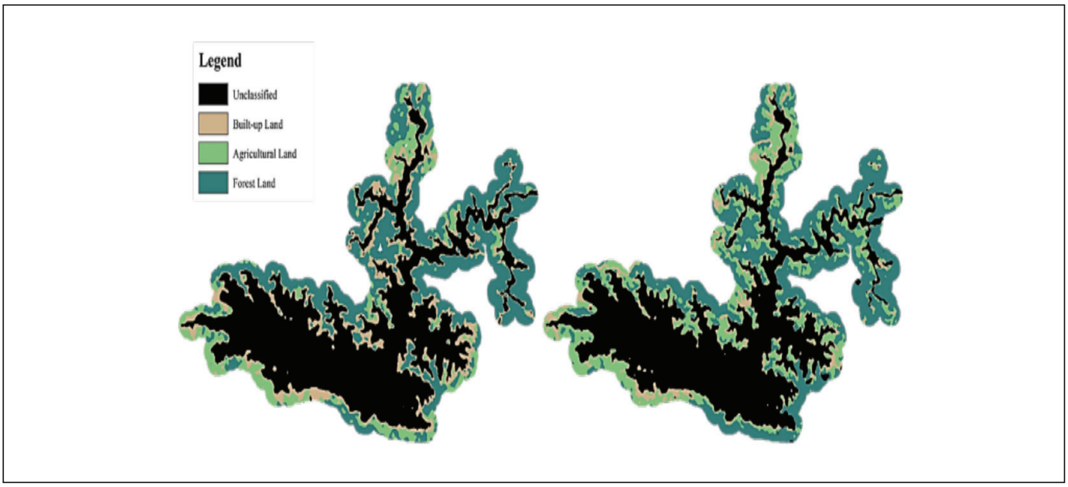

Figure 5: Land Use within 500 metres distance from the Batang Ai reservoir shoreline for the year 1995 (Left) and 2015 (Right)

classified image illustrates networks of built-up land, suggesting the presence of logging road network and logging activities. This finding corresponds with the study by Ling *et al*. (2016), whereby logging activities are impacting the water and sediment quality in the upper reaches of the Baleh River.

The future Baleh reservoir, particularly at the western rim of the reservoir, will be surrounded by extensive networks of built-up land.

The changes in land cover due to land use may not necessarily indicate degradation, but land-use changes that are driven by social causes may impact the surrounding environment (Rawat & Kumar, 2015). A study by Riduan *et al*. (2006) on the Ringlet's Lake in Cameron Highland found that soil erosion within the catchment impacts the water quality of the lake. Luis *et al*. (2016) reported that the Jor Reservoir has lost 50% of its storage capacity due to sedimentation. From reservoir management, lakes are facing degradation threats due to excess sediment and non-point sources of pollution resulting from rapid development and land-use changes with the draining basin (Sharip & Zakaria, 2008). By having a comprehensive inventory on the land-use composition, patterns, and change rate within a hydropower reservoir catchment, the impacts of land use on reservoir health can be better understood.

Land use also plays a role in promoting forest fragmentation (Abdullah & Nakagoshi, 2007). Despite the high composition of forested area in six (6) study sites, the forest land is subjected to fragmentation due to other land uses. The forest land cover in Sarawak can be broadly categorised into three types, namely mangrove, peat swamp, and mixed dipterocarp forest (MDF) (Taylor *et al*., 1994). Forest land in this study, mostly consists of undisturbed forest or secondary forests. Forest land could play an important role in the reservoir shoreline management by taking advantage of the vegetation to serve various ecological functions such as trapping and removing the non-point source pollutants and provide habitat for animals and plant species (Fischer & Fischenich, 2000).

The land-use change observed in Batang Ai is driven by the construction of the dam itself. Reference made to the land use map found that the area was historically predominated by hill paddy (i.e. bush fallow and shifting cultivation) before the dam was built. Ichikawa (2007) observed that the land use pattern in "Iban territory" was opened in a dispersed manner because of shifting cultivation. Shifting cultivation is an agricultural system that typically involves a short-term cropping and long-term fallowing of land practised by the native groups (Padoch, 1988). This corresponds to the uneven, dispersed distribution of the agricultural land at upper reaches of the Engkari and Delok river.

A study by Ichikawa (2007) on the native land use by Ibans in the north-eastern part of Sarawak reported that the land-use changes in the "Iban territory" is progressing at slower rate than the changes in "State Land". The estimated annual rate of land-use conversion under shifting cultivation areas is at 0.2% in 100 years (Cramb, 2009). This rate is relatively slower than the rate of agricultural land expansion (+2.25%) at Batang Ai site in between the year 1995 and year 2015, which suggests a larger scale, non-traditional agricultural system being practised. Furthermore, the conversion of land and development activities associated with traditional uses usually cause minimal impacts to the river basin hydrological regime (Salleh & Ghaffar, 2010). According to Wong (cited in Abdullah & Nakagoshi, 2007), from the 1950s to 1970s, most of the natural forests in Malaysia were converted into agricultural land particularly into monocrop such as rubber and oil palm before other types of land uses were developed to cater for housing, new urban areas, and residential estates in the 1980s. For Sarawak, significant land use and land cover changes began in the 1960s due to modern economic transformation (Hansen, 2005). Cross-reference with topographic map does not indicate any logging activities within 500 metres distance from the Batang Ai reservoir shoreline. Nevertheless, the mapping of monocrop (oil palm) with patches of secondary forest adjacent to each other were observed. Two possibilities for this pattern are the planting of cash crop as one of the rural livelihood strategies to buffer their subsistence rice farming (Sim, 2011) and the expansion of oil palm plantation into customary lands via several modes of development (Cramb, 2009).

Conclusion

This study illustrates the intensity of anthropogenic activities and land-use changes near hydropower reservoir shorelines in Sarawak. This study reveals the importance of establishing riparian buffer zones that could ameliorate various ecological functions and achieve reservoir management objectives. The design of the riparian buffer zone for future hydropower reservoirs shall take into considerations the size, function, management objectives, and the adjacent land uses surrounding reservoirs. However, the study sites have unique characteristics which comprise of different land-use composition, therefore the conclusion from this study need to be carefully interpreted. The strong correlation between the built-up land and reservoir areas indicating that the future planned reservoirs in Sarawak may be surrounded by fragmented forest. Developing an integrated lake management system is critical in ensuring the sustainable management of lakes in the state. This is the first study in Sarawak identified the general land usage surrounding hydropower reservoir and may present the opportunity for further investigations and detailed assessment on the land use activities adjacent to the hydropower reservoir. As there are no known legal requirements, standards and/or guidelines for the protection of hydropower lakes in Sarawak, understanding the land use activities and it impacts to the reservoir water quality and hydropower plant operation will be critical to support for the management of the existing reservoir.

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