

Modelling Catchment Land Use Changes against Water Yield with Satellite Multi-Temporal Data

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Abstract: Land-use changes are the main issue which affects the availability of water resources. Water supply is the leading ecosystem service, directly influence the sustainable development of the social economy and ecological systems. This study model the effects of land-use changes in respect of water yield, using Soil water assessment tools (SWAT) model in Sg. Layang catchment, Johor, Malaysia. Changes in Land-use for the period of 2000-2005, 2005-2010 and 2000-2010 obtained through post-classification comparison of Landsat 7 ETM+ data acquired in 2000, 2005 and 2010 using maximum likelihood classifier. The results indicate a rise in water yield, as a result of forest decline as well as an increase in agricultural activities and urbanization. The changes in the forest are found directly proportional to water yield ($R^2 > 0.85$, $p < 0.001$). It is therefore concluded that the satellite multi-temporal land use changes within the catchment are paramount for monitoring the corresponding water yield in the area. These land use changes to water yield are crucial to assist authorities to create a balance between environmental protection and urban development for sustainable management of water resources.

Keywords: Land use change, water yield, SWAT, data analysis

1. Introduction

Water is a crucial element for life sustenance on the surface of the globe. Increase in a population gives rise to an increase in the demand for water. Accessibility of water in a given study area mainly depends on rainfall distribution, which further distributed into different element like; water yield, surface runoff, evapotranspiration. Also, the land-use change affects the proportion of this component significantly, that lead to a considerable change in ecological systems [1]. Similarly, the change in land use results to modification in flood frequency, base flow and annual means streamflow [2]. The way humans use the land is considered as land use while the physical structure of the land such as; forest area, waterbody, is referred to as a land cover. Therefore, land use changes as a result of anthropogenic activities influence the integrity of the good and services of the ecosystem as well as natural resources.

Furthermore, the influence of land-use changes is regarded as vital to consider for many ecosystems. Though, well, plan and development can lead to a new pattern of land-use land cover that may enhance the wellbeing of human [3, 4]. Land-use change may alter the hydrology of Sg. Layang, in Johor river basin. Also, in a different part of Malaysia fast urbanization and development of socio-economic aspects have led to the land use change to a large degree. Since, it transforms the hydrological process, which

includes water yield, evapotranspiration, infiltration and groundwater recharge [6,7]. Likewise, changes in land use results to the modification; in a flash flood, surface runoff, baseflow, and water yield [8]. Additionally, the usual hydrological cycle of soil infiltration, streamflow, surface runoff, water yield, groundwater quantity and quality alters as the forest is cleared [9].

Moreover, the Soil water assessment tools (SWAT) model, developed by the united states department of agriculture (USDA), applied by many researchers around the globe [10], for the simulation of water quantity and quality and analyse the effects of land-use change for water resources management such as streamflow, surface runoff simulation as well as sediment yield [11 - 13]. As the model is freely available on the internet, user-friendly and straight forward in calibration.

Consequently, the land-use changes of the sub-basin, which is one of crucial area for water resources, need to be considered by the researchers. However, land-use changes influence on water yield has been ignored. This wide gap resulted in studying changes in land-use in respect of water yield remain unaddressed. Therefore, this study will bridge the gap by focusing on the analysis of long term variation of land-use for water yield using the SWAT model. Therefore, this study aimed at analysing changes in land-use in respect of water yield. This will assist the policymakers, in the planning of potential shifts in ecosystem productivity and water resources at the watershed to the national level.

2. Study Area

The Sg. Layang catchment with a total area of 3017.61ha is located in the southern part of Johor river basin Johor state Peninsular Malaysia. Regarded as one of the tributaries of Johor river basin, the study area is located between latitude $1^{\circ} 31' 30''$ N to $1^{\circ} 33' 50''$ N and Longitudes $103^{\circ} 51' 00''$ E to $103^{\circ} 54' 30''$ E (Figure1). The study area also has a reservoir which is for agriculture and drinking water supply.

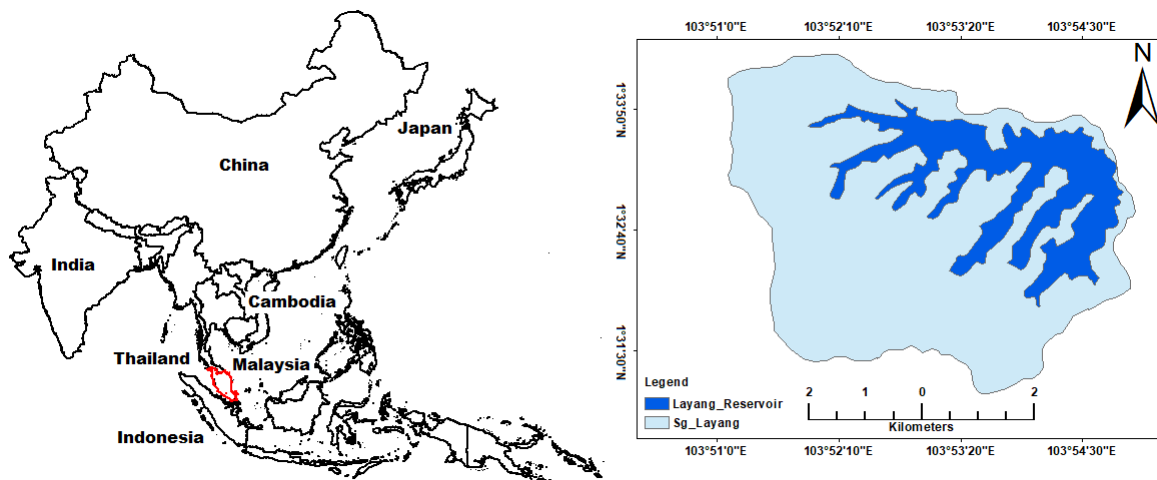


Figure 1. Location of the study area; Layang catchment of JRB, Malaysia, Southeast Asia.

3. Material and Methods

There are three main materials and methods presented in this study, which include; (i) satellite-based data, (ii) ancillary data (iii) soil water assessment tools model.

3.1 Satellite-based data

Landsat 7 enhanced thematic mapper plus (ETM+) of images 2000, 2005 and 2010 as well as digital elevation model (DEM), were obtained from the United States Geological Survey (USGS) with 30m resolution. These data sets were downloaded from (www.usgs.gov/earthexplorer-0); data Landsat 7 collection 1 on demand level 2 of Landsat 7 ETM+.

3.2 Ancillary data

There were three ancillary data used for this study, which involve; (a) soil map, and (b) climate datasets, the Soil map obtained from the ministry of agriculture and agro-based industry Malaysia. The climate

datasets which include; the daily precipitation, minimum and maximum temperature, relative humidity, wind speed and solar radiation, as well as streamflow, were obtained in the Department of Irrigation and Drainage Malaysia (DID) and the Malaysian Meteorological Department (MMD).

3.3 Soil water assessment tools (SWAT) model

The SWAT model developed by the United States department agriculture (USDA) [15] is considered the most reliable tool and accessible model for studying effects of land use land cover changes on agricultural chemical, sediment and water yields around the globe [14]. Therefore, this physical-based, watershed scale, the continuous model can simulate the hydrological cycle, transportation of sediment, agricultural chemical yields and cycle of plants growth on regular time step [15]. The hydrological part of the model is centred on the water balance equation. The soil profile with processes, include surface runoff, infiltration, lateral flow, precipitation, evapotranspiration, groundwater flow and percolation [15 - 18]. Figure 2 indicates the methodological flow chart of the study.

Furthermore, Soil Water Assessment Tools has been used for several watershed issues such as; sediment transport, soil erosion, total maximum daily loads, top management practices at watershed scales as well as land cover and climate change effects [19]. Therefore, the model with the feature of land cover change was selected as a means of modelling, since its available in the internet, flexible, ability to carry out calibration easily, wide range of coverage in water properties in the past, present and future it also considers land use that affects evapotranspiration. The model can be expressed as [13].

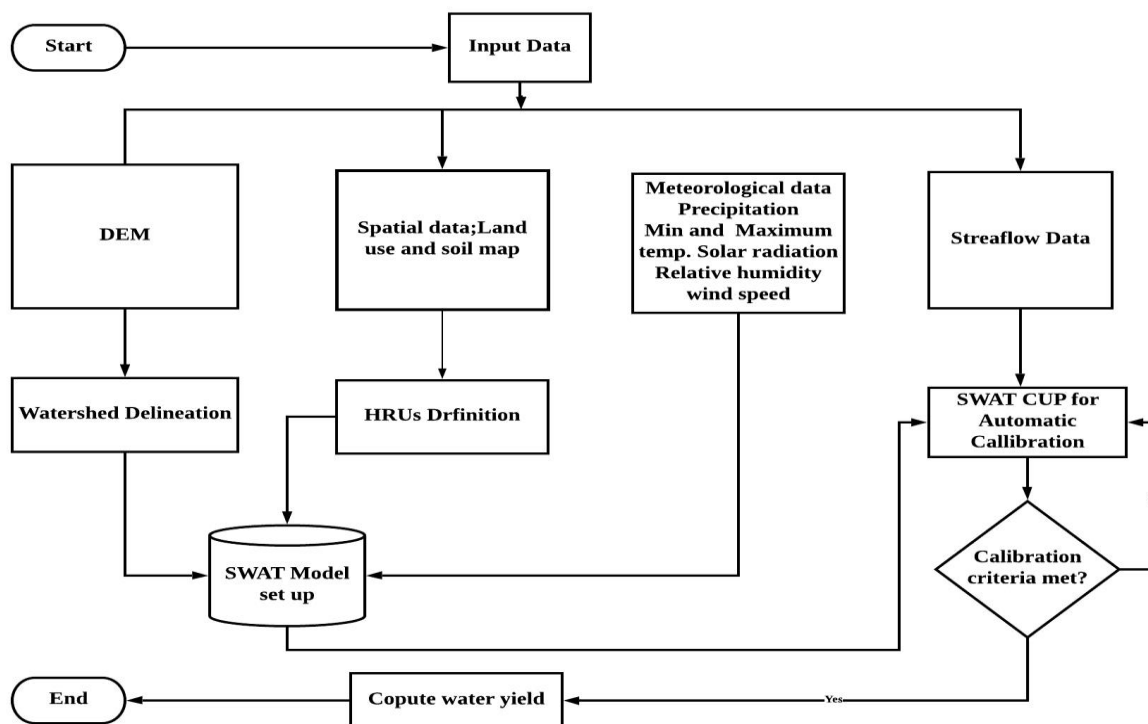


Figure 2. Methodological flowchart.

$$SW_t = SW_o + \sum_{i=1}^t (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}) \quad (1)$$

Where SW_t = Final soil water content (mm), SW_o = Initial soil water content on day i (mm), t = time (days), R_{day} = amount of Precipitation on day i (mm), Q_{surf} = amount of surface runoff on day i (mm), E = amount of evapotranspiration on day i (mmH₂O), W_{seep} = amount of water entering the vadose zone from the soil profile on day i (mm), and Q_{gw} = amount of return flow on day i (mm),

4. Results and Discussion

There are five main results presented in this study, which include; (a) image classification and land-use land cover changes, (b) assessment accuracy of the results (c) water yield assessment (d) correlation variables (e) water yield analysis.

4.1 Image classification and Land-use land cover changes

The enhanced thematic mapper plus (ETM+) of Landsat 7 was considered for generating Land-use land cover classes of the three epochs 2000, 2005 and 2010. The classification of the three sets of images was carried out after generating a training sample by means of maximum likelihood classifier through supervised classification. Six classes of land use land cover were identified such as; agriculture other than oil palm, bare land, forest, urban, Oil palm, and water body

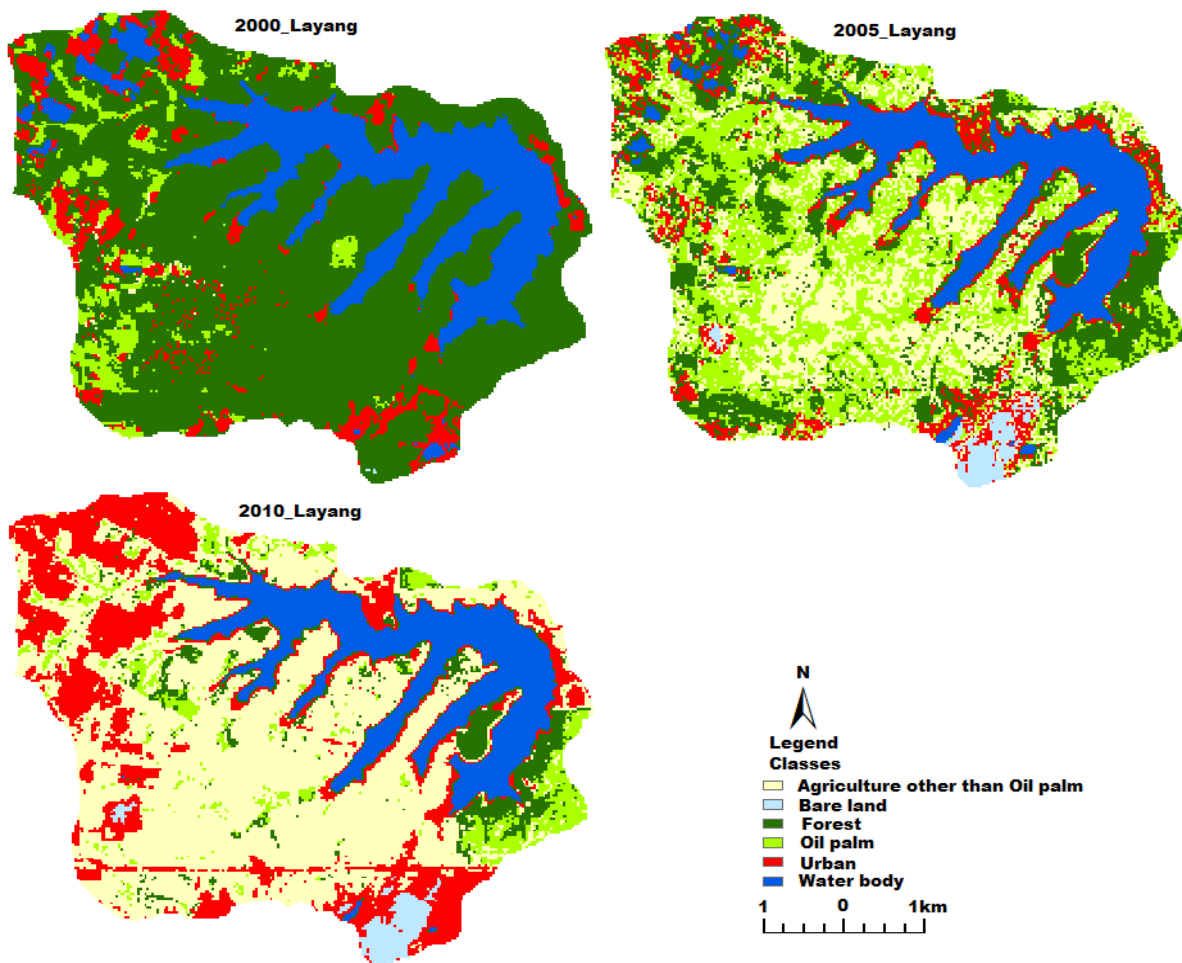


Figure 3. Classes of land use land cover for 2000, 2005 and 2010.

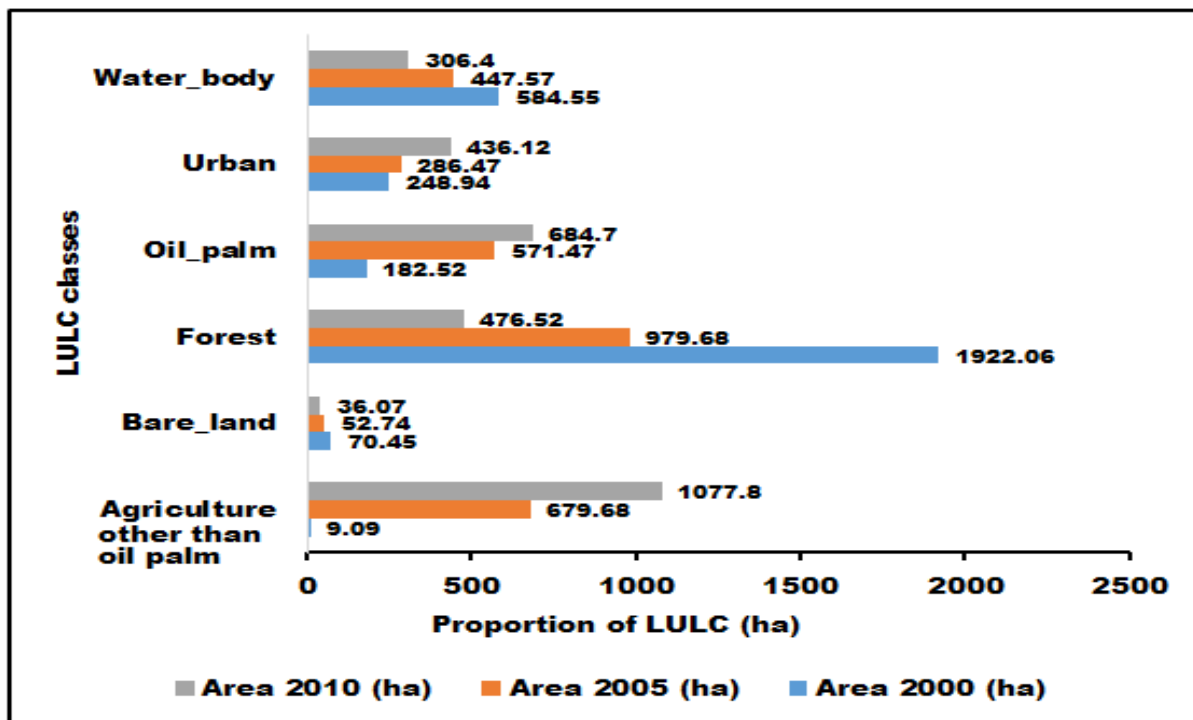


Figure 4. Land-use land cover changes in the study area, 2000, 2005, and 2010.

The area (ha) for the land use land cover change over time in the form of a histogram (Figure 4) indicates that forest has the highest coverage of 1922.06 ha of the subwatershed total area in 2000, in 2005 the total area of the forest has reduced to 979.68 ha, likewise in 2010 the forest has reduced to 476.52 ha consequently, from 2000 to 2010 the forest has reduced by 1445.54 ha (47.90%). However, agriculture other than oil palm and oil palm increased to 1068.71 ha (35.42%) and 502.18 ha (16.64%) respectively from 2000 to 2010. Similarly, urban also increase to 187.18 ha 6.20% from 2000 to 2010. While bare land and waterbody reduced to -34.38 ha (1.14%) and -278.15 ha (9.22%) respectively from 2000 to 2010. The result shows a significant declined in the forest within eleven years, while agriculture increased substantially within the same period. These changes are significant, and it has a high impact on water yield, which is in line with the study, which states that land-use change affects the proportion hydrological component significantly, that lead to a considerable change in ecological systems [20].

4.2. Assessment accuracy of the results

The accuracy of the classification was ascertained using the error matrix, as well as applying the global positioning system (GPS) via filed validation. The images classified with their overall accuracies and Kappa/indexes are presented in table 1 below.

Table 1. Classification accuracy of the study area.

Land cover category	2000		2005		2010	
	Producer's accuracy (%)	User's accuracy (%)	Producer's accuracy (%)	User's accuracy (%)	Producer's accuracy (%)	User's accuracy (%)
Agriculture other than oil palm	86.21	88.52	87.21	85.38	86.12	85.72
Bare land	85.55	86.55	85.00	87.00	87.21	88.80
Forest	89.00	85.36	85.00	85.81	94.00	86.79
Oil palm	90.55	85.76	85.00	86.40	86.21	85.21
Urban	85.00	87.62	86.21	85.71	87.21	88.80
Waterbody	87.21	86.43	88.55	87.55	85.00	88.62
Overall Kappa	86.00		85.55		85.55	
Overall accuracy	86.38		87.60		86.10	

4.3 Water yield assessment

Some of the watersheds /catchment in Peninsular Malaysia being almost similar in hydrological characteristics with Sg Layang shows good relevance with the water yield computed for the watershed in 2010. Table 2 demonstrates the comparison of water yield of some selected watershed in Peninsular Malaysia as there are few numbers of related works published in index publications.

Table 2. Comparison of Johor river basin Water yield and some other watersheds in Peninsular Malaysia.

Watershed/ catchment	Type of watershed/catchment	Size (km ²)	Mean annual precipitation (mm)	Total WY (mmyr ⁻¹)	Reference/ Approach Satellite
Sg. Layang	Semi-urban	33.61	2690	1334	This study/ SWAT
Setiu	Mixed hot	1077.5	2794	1862	Hashim 2010/ Satellite
Langat River	Semi urban	1257.7	2401	1207	Nadzri 2015/ Satellite

The polygon-based water yield assessment was carried out by comparison of the SWAT based water yield and satellite-based water yield as well as streamflow station for validation. The outcome shows that the mean annual precipitation and the total water yield per annum are almost similar to the nearby streamflow and the watersheds.

4.4 Correlation of variables

Linear regression was employed to identified or to predict the relationship between water yield and land use land cover classes which include; agriculture other than oil palm, forest, oil palm and urban. The result indicates that; the correlation between; water yield and agriculture other than oil palm, water yield and oil palm as well as water yield and urban are directly proportional with $R^2 = 0.83$, 0.63 and 0.90 respectively. While water yield and forest inversely proportional with $R^2 = 0.76$ (Table 2). This result is in line with the finding of [20 - 22], which established that land-use land cover changes influence

significantly on water quality and quantity through spatial and statistical analysis as well as hydrological modelling.

Table 3. Correlation between water yield with land use classes: Agriculture, Oil palm, urban and forest.

WY correlation with Land use classes:	Number of variables (n)	R ²	Significance level	Remark / linear regression equation
Agriculture other than oil palm	30	0.83	P= \leq 0.001	Directly proportional/ Y = 2.0256X-48.672
Oil palm	33	0.63	P= \leq 0.001	Directly proportional Y = 0.8689X-13.07
Urban	31	0.90	P= \leq 0.001	Directly proportional Y = 0.4106X-2.9582
Forest	35	0.76	P= \leq 0.001	Inversely proportional Y = -2.6447X+125.47

4.5 Water yield analysis

The changes in water yield from 2000 to 2010 were evaluated. The study reveals that water yield increased by 35.46% from 2000 to 2010. The results from figure 4, indicate a remarkable decrease in forest and increase in agriculture other than oil palm. At the same time, Table 4 shows a substantial increase in water yield. The study is in line with the study of [4, 7], which state that land use changes may likely; influence the availability of water resources and hydrological cycle by changes of infiltration rate and evapotranspiration.

Table 4. water yield changes from 2000 to 2010.

Hydrological component	2000 (mm)	2000 (%)	2005 (mm)	2005 (%)	2010 (mm)	2010 (%)	2000 - 2010 (mm)	2000 - 2010 (%)
Water yield	1207.63	27.37	1333.64	30.22	1871.16	42.41	663.53	35.46

5. Conclusion

The analysis of land use changes for water yield, which employed enhanced thematic mapper plus (ETM+) of Landsat 7 was evaluated. Also, Qualitative and quantitative assessment of the trend of land use changes influence on water yield from 2000 to 2010 was analysed. The results indicate a significant change in forest and agriculture other than oil palm from 2000 to 2010. Consequently, the forest land reduced by 47.9% between 2000 to 2010, while agriculture other than oil palm expands by 35.42% during the same period. The water yield has increased by 35.46% between 2000 and 2010. This finding indicates that changes in land-use as a result of the conversion of the forest to agriculture other than oil palm led to the influence of hydrological changes processes in the area. This results will assist policymakers and managers of water resources in future land use policy and water resources management. Most importantly, it will aid in fast-tracking of target 6.1 and 6.4 of the United Nations sustainable development goal 6th, which stress the need to bring the end of water scarcity by 2030. However, there will be future work improvement by incorporating the land use and climate change, to analyse the changes in water yield.

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