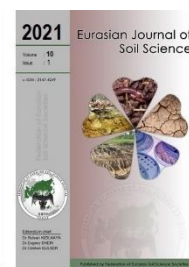




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## Soil data definition for hydrologic response unit analysis in SWAT model of Langkawi Island, Malaysia

Mohd Rosli Nur Suhaila, Ahmad Zuhairi \*, Azman Nur Syahira Azlyn, Mustapa Mohd Zaini

Kulliyah of Science, International Islamic University Malaysia, Jalan Istana, Bandar Indera Mahkota, 25200, Kuantan, Pahang, Malaysia

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### Author(s)

M.R.N.Suhaila  
A. Zuhairi \*  
A.N.S. Azlyn  
M.M. Zaini



\* Corresponding author

### Abstract

Soil and water assessment tool (SWAT) have been assessed to examine environmental conditions and watershed scale, particularly for water quality and natural resource management. In this study, SWAT model has been applied to the main river basins in Langkawi Island. Soil data, one of the spatially distributed data needed for SWAT model interface. Currently, no soil interpretation record (s5id) data code available in readable format for user soil SWAT database for Langkawi Island. The purpose of soil data definition is to create a soil input data setup for hydrologic response unit (HRU) analysis in SWAT model which includes soil map, soil type, soil texture, and soil s5id code. Study by Leman et al. (2007) showed that geological formation of soil in Langkawi consists of alluvium, granite, Machincang, Setul, Chuping and Singa formation. The dominant soil group was Acrisols (soil unit name: Orthic Acrisols, Ao) and the dominant soil texture classification was sandy clay loam. MY4284 and MY4464 defined as the code for soil interpretation record number (s5id). Percentage of coverage for MY4464 was (62.21%; 10,865.87 ha [26,850.15 ac]) and the percentage of coverage for MY4284 was (37.79%; 6,599.8 ha [16,308.46 ac]) within the selected watershed boundary of Langkawi Island. This data setup has been successfully tested and fully functional for usersoil database of Langkawi SWAT model analysis.

**Keywords:** Hydrologic response unit (HRU) analysis, Langkawi Island, soil input data setup, soil S5id code, soil and water assessment tool.

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### Introduction

Soil water assessment tool (SWAT) is a hydrological model which currently been used widely and has been tested to examine environmental conditions and watershed scale particularly for water quality and natural resource management (Wang et al., 2019). The flexibility and capability of the SWAT model allow it to simulate the hydrological response of catchments from small watershed to large river basins. Furthermore, the model is widely utilized as it is flexible for new data adaptations and continued model development (Gassman et al., 2007).

Common application of SWAT model includes the delineation of watershed into subbasin using elevation and stream data. After watershed delineation, it is further divided into hydrologic response unit (HRU). HRU is defined as integrating land use, soil, and slope characteristics within subbasin. Integration of HRU in SWAT model has provided flexibility for simulating multiple range of condition for watershed (Kalcic et al., 2015).

The broad application of SWAT model has been simulated by software tools such as user documentation and numerous linked databases for soils, crops, pesticides, tillage, and fertilizers (Santhi et al., 2005). Soil

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properties are crucial for the simulation processes including soil water balance, sediment transport, evapotranspiration, and nutrient dynamics (Neitsch et al., 2011). Nevertheless, the existing built-in database is only valid for SWAT application in the United States (US), such as state soil geographic database (STATSGO) and the soil survey geographic database (SSURGO). This limitation urges for the development of a new soil's dataset for application outside the US. This process is time consuming because the properties of the dataset has to be stored in a single row in the usersoil table and it has to be in spatially defined format for it to be readable by SWAT and data requirement by the model not completely available for non-US countries (Cordeiro et al., 2018).

Previously, a large scale soil dataset standardized by Food and Agriculture Organization (FAO) has been prepared. Nonetheless, this dataset was not optimized for SWAT (Batjes, 1997). Soil terrain (SOTER) database was created as another initiative for global soil dataset with global coverage but SOTER is not optimized by SWAT (Dobos et al., 2005). Another database at continental scale such as hydraulic properties of European soils (HYPRES) database only covers soil hydrologic properties (Wösten et al., 1999). Few countries such as Brazil, China, and Australia have soil electronic database however it is not accessible in most countries (Shi et al., 2004; Cooper et al., 2005).

In Malaysia, the application of SWAT model mostly focus on the basin water resources and hydrologic behavior at the major river basin. In Langkawi Island particularly, there is no consistent and applicable of soil information for SWAT model. These limitations highlight the significance of the soil definition dataset presented in this paper. Due to the importance of the water resources and hydrological study, SWAT model has been used for integrated environmental modelling in Langkawi Island. The objective of this paper was to create a soil information dataset with the properties that is in readable format for SWAT model simulations. Soil data definition derived provided information for different soil types and attributed to a grid and polygon based soil map compatible for ArcSWAT version of the model.

## Material and Methods

### Study Area

Langkawi Island (6°19'47"N; 99°43'43"E) is one of the most popular tourist attractions in Malaysia, consists of six sub-districts; Kuah, Padang Mat Sirat, Ayer Hangat, Kedawang, Ulu Melaka, and Bohor. The total area of the main island including the surrounding islands is approximately 478.48 km<sup>2</sup>. Study area covers approximately 174.66 km<sup>2</sup>. The temperature is mainly uniform throughout the year with an annual average of 27.6°C (81.68°F). Average precipitation is 2,360 mm with a mild dry period from December to March. Long rainy season fall in March to November and September is the wettest month (Malaysian Meteorological Service, 2000-2003).

### Soil and Water Assessment Tool (SWAT) Model

This continuous time, physical-based hydrologic model developed to predict the impact of land management practices on surface water, sediment, and agricultural chemical yields in simple watershed to a complex river basin with various characteristics land use condition, soil, and slope condition over long period of time (Arnold et al. 1998). The main driving forces behind SWAT model are divided into two hydrologic components; land phase and water routing phase. Land phase controls the water, sediment, and nutrient quantity flow into water body. Water routing phase simulates flow of water through the network channel. SWAT model deliberate both natural input such as mineralization of organic matter and N-fixation, as well as anthropogenic nutrient input such as fertilizers and manures (Somura et al., 2009). ArcSWAT, ArcView SWAT (AVSWAT), or MapWindow SWAT (MWSWAT) is the available model interfaces used by the model to configure input data in order to define subbasins and HRU (Kalcic et al., 2015). In this study, the model used ArcSWAT extension in the ArcGIS software (Figure 1). SWAT model configuration is expected to be able to provide useful information across various range of time scale such as hourly, daily, monthly, and yearly (Olivera et al., 2006).

### Input Data for Model Setup

SWAT model requires spatial data such as selected basin of study area, land use map, soil map, and digital elevation model (DEM) map (Figure 2a,b,c,d). DEM was extracted from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) satellite image. Land use map and soil geological map of Langkawi Island was retrieved from Special Area Plan 2020 (*Rancangan Kawasan Khas 2020*) by Langkawi Development Authority (LADA, 2019). Besides, daily meteorological data including temperature, rainfall, and precipitation of Langkawi Island from period 2005 to 2018 were obtained from Meteorological Terminal Aviation Routine Weather Report (METAR) by Malaysia Automated Surface Observing Systems (ASOS).

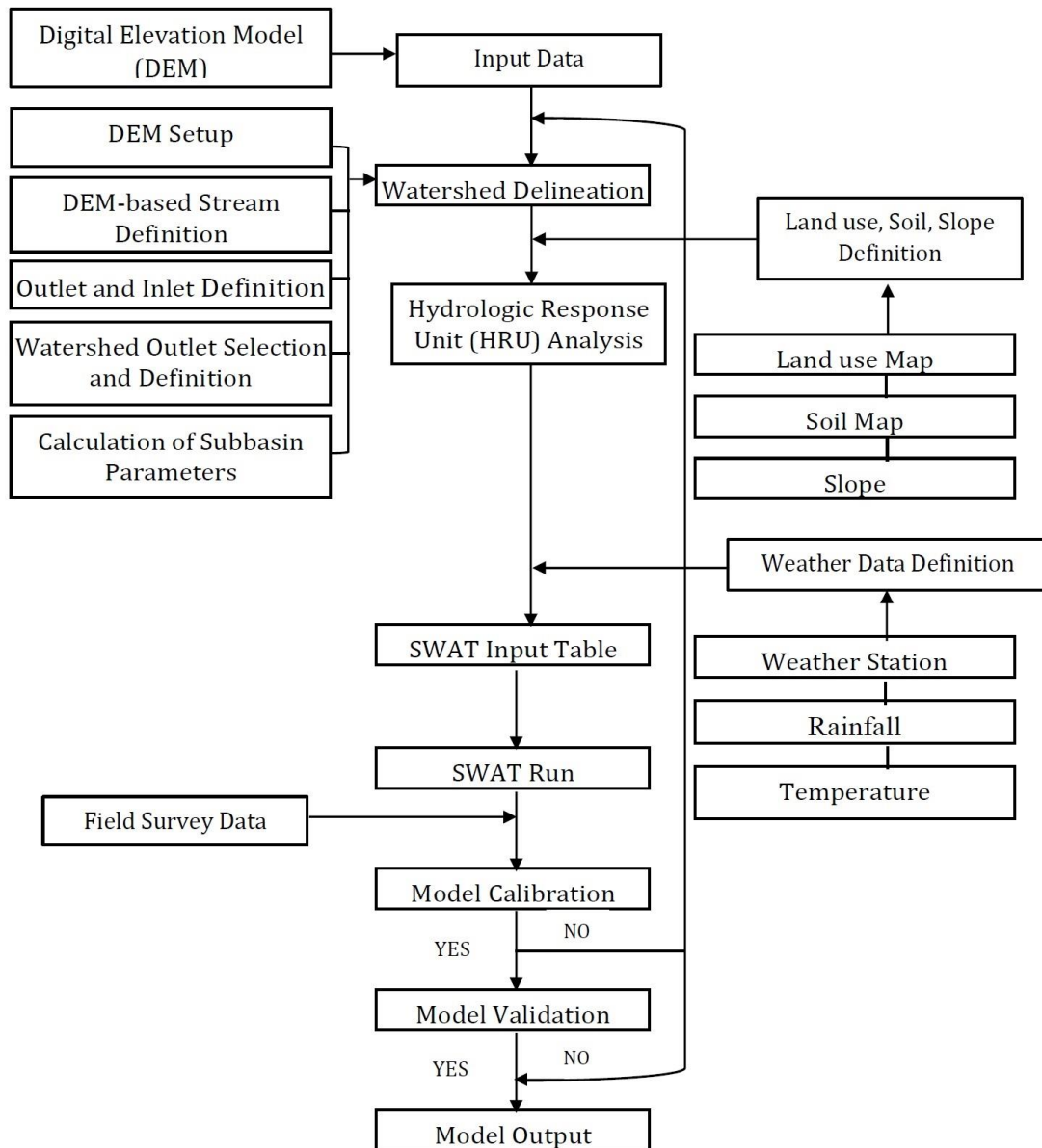


Figure 1. Application of soil and water assessment tool model on selected basin of Langkawi Island.

### Land Use and Soil Definition Input Data for Hydrologic Response Unit Analysis

The land use map of Langkawi Island was used as land use layer map which was overlaid as land use grid data. User-identified land use lookup table was used as land use input for land cover classes (Table 1). Land use was categorized into seven classes; (1) urban (URBN) (included all type of housing, infrastructure, and recreation), (2) institution (UINS) (included school, mosque, hospital, shelter, cemetery, and church), (3) transportation (UTRN) (included the roads, terminal/station, and airplane runway), (4) agriculture (AGRL) (included any type of crop such as paddy, rubber plant, and palm oil), (5) commercial (UCOM) (included all type of businesses and services involved in that area), (6) industrial (UIDU) (included all type of industrial services involved in that area), and (7) forest (FRSE) (included all type of forest).

Table 1. User-identified land use lookup table.

Id	Land cover class	Abbreviation
1	Urban	URBN
2	Institution	UINS
3	Transportation	UTRN
4	Agriculture	AGRL
5	Commercial	UCOM
6	Industrial	UIDU
7	Forest	FRSE

HRU analysis required two types of data; land use and soil map. Both land use and soil map were overlaid with the watershed boundary and linked with the lookup table. Then, land use data and soil data were reclassified and defined before proceeded to HRU analysis (Figure 3).

Soil map of Langkawi Island was used as soil layer data to be overlaid as soil grid data. User-identified soil lookup table was used as soil input data for soil attributes (Table 2). Geological of Langkawi Island can be divided into five types of formation. Granite formation known as Gunung Raya granite mainly consist of coarse-grained granite with some porphyritic granite. Singa formation is known as Early Permian Singa consist of predominantly siltstone and mudstone with alternating sandy facies; the black mudstone contains clasts, blocks originated from glacial; and the basal part has redbed with dropstone formation with several limestone lenses on the upper part. Late Permian Chuping is recognized as Chuping formation consists of thin to thickly bedded limestone and dolomite which often light in color. Cambrian Machinchang or Machinchang formation is mostly cross-bedded sandstone with subordinate shale, mudstone, and conglomerate. Lastly, Ordovician to Middle Devonian Setul or recognized as Setul formation consists of predominantly thin to thickly bedded limestone often dolomitic with intervals of clastic rocks (Leman et al., 2007).

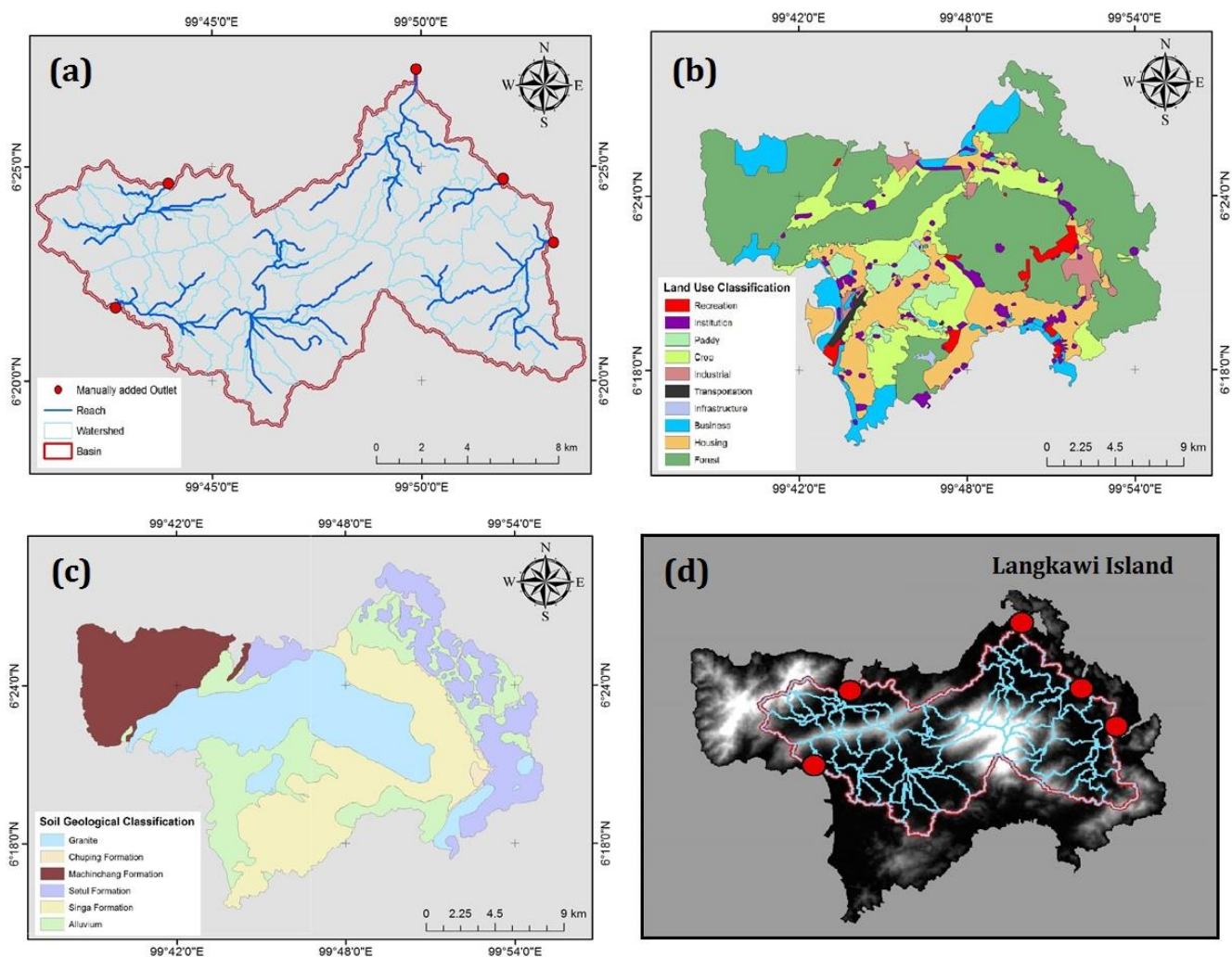


Figure 2. (a) Selected basin of study area, (b) Land use classification of study area, (c) Soil geological classification of study area, (d) Digital Elevation Model (DEM) of study area in Langkawi Island

Table 2. User-identified soil lookup table.

Id/Value	Type	S5id
1	Granite	MY4464
2	Singa	MY4284
3	Chuping	MY4284
4	Machinchang	MY4464
5	Alluvium	MY4464
6	Setul	MY4284

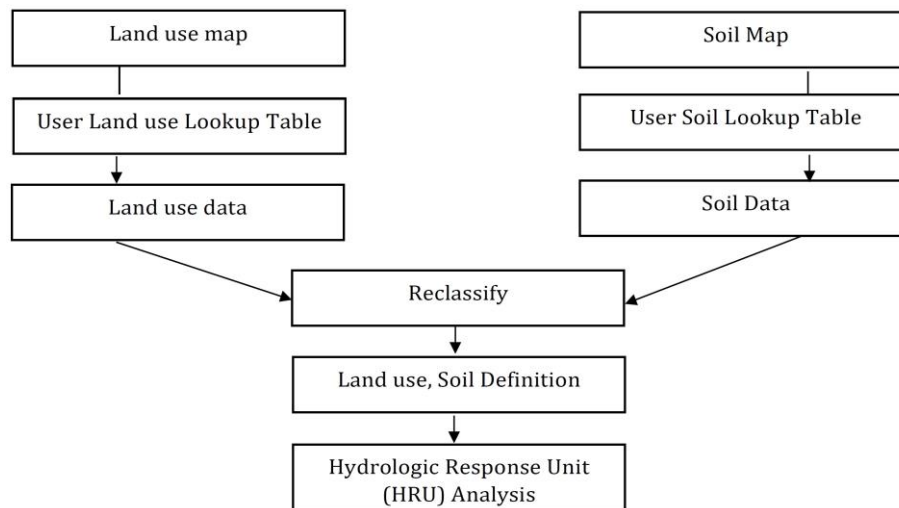


Figure 3. Hydrologic response unit analysis on selected basin of Langkawi Island

## Results and Discussion

### Reclassification of Hydrologic Response Unit Analysis

Land use, soil, and slope are the main component that consist of land use and soil grid data, user-identified land use and soil lookup table in the HRU analysis for definition or reclassification process.

### Land Use and Soil Grid Data

The percentage of overlap between land use grid map and soil map within the watershed boundary was 100% (Figure 4a,b). According to the SWAT model simulation, the percentage of overlap less than 100% may result in some subbasins without any land use data or soil data overlap and lead to the failure of the overlapping process.

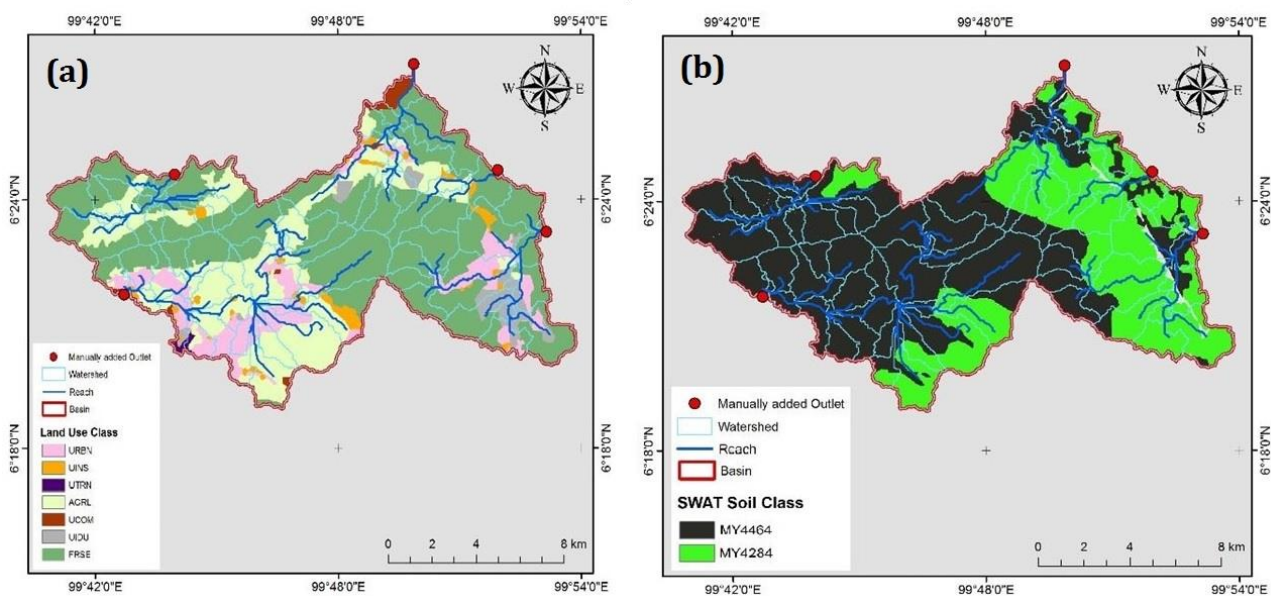


Figure 4. (a) Land use grid map overlapped with watershed boundary, (b) Soil grid map overlapped with watershed boundary of study area in Langkawi Island

### User-identified Land Use and Soil Lookup Table

All the information and variables such as soil formation, soil group, soil texture and soil5ID in the input table prepared according to the properties of the dataset that is in readable format in the SWAT database to run the SWAT model simulation successfully (Table 3).

This study had produced the new soil interpretation record number (S5id) for soil in Langkawi Island which are MY4464 and MY4284. S5id (Soils5 ID number for USDA soil series data) is soil interpretation record number used to represent the map unit. MY is the prefix for the country which stand for Malaysia. The remaining number afterword (4464 and 4284) is the soil map unit which can be retrieved from Harmonized World Soil Database (HWSD).

Table 3. Soil classification for soil water assessment tool model soil input table.

Soil Formation	Soil Group					Topsoil USDA Texture Classification	Subsoil USDA Texture Classification	Soil Texture Code	Soil5 ID No. (S5id)
	Dominant Soil Group	Soil Unit Name	Topsoil Texture	Soil Unit Symbol	Drainage class (0-0.5% slope)				
Granite, Machincang and Alluvium	Acrisols	Orthic Acrisols	Medium	Ao	Moderately Well	Sandy clay loam	Clay loam	SCL	MY4464
Singa, Setul and Chuping	Acrisols	Orthic Acrisols	Medium	Ao	Imperfectly	Sandy clay loam	Clay loam	SCL	MY4284

This study classified the soil formation for S5id MY4464 are Granite, Machincang, and Alluvium where S5id MY4284 had the soil formation of Singa, Setul, and Chuping. Soil formation for both S5id corresponds to dominant soil group Acrisols with the formation of these soils is mostly on residual of sedimentary, igneous, or metamorphic rock (FAO, 1979). According to FAO (1979), Acrisols with the unit symbol (Ao) is the most extensive soils spread around the Southeast Asia region. It can be subdivided into several types (1) Plinthic Acrisols, (2) Gleyic Acrisols, (3) Humic Acrisols, (4) Ferric Acrisols, and (5) Orthic Acrisols. The estimated soil cover is 197,000,000 ha [486,797,601.49 ac] (51%) of the region. Acrisols occur mostly in the region with annual precipitation exceeds 1,500 mm which is corresponds to the annual precipitation of Langkawi Island was 2497.1 mm (Malaysian Meteorological Service, 2000-2003). Soil unit name for MY4464 and MY4284 is Orthic Acrisols or known as other Acrisols that take place over massive tracts of steeply dissected terrain of the main mountain systems. The development of this soil type is predominantly on residuals of integrated elastic sediments, metamorphic, and acid intrusive rocks.

Both soil S5id had medium topsoil texture. Topsoil is the surface layer which usually darker than the subsurface layers based on the topsoil texture and topsoil USDA texture classification (Koenig and Isaman, 2010). Medium topsoil texture is referring to loamy soils that corresponds with sandy clay loam (SCL) soil textural class for both soil S5id with soil texture code SCL (García-Gaines and Frankenstein, 2015). The composition of sandy clay loam is 20% to 35% clay, less than 28% silt, and more than 45% sand (Soil Survey Staff, 1993). This study categorized the subsoil USDA texture classification for both MY4464 and MY4284 as clay loam. Subsoil is the layer immediately below the topsoil that consists of mainly minerals and leached materials. USDA classified subsoil texture as clay loam that composed of 27% to 40% clay, and more than 20% to 46% sand (García-Gaines and Frankenstein, 2015).

Considering the soil formation of MY4464 are Granite, Machincang, and alluvium, the drainage class was moderately well drainage class where the water removal is slightly slow and profiles are wet for short but significant periods where the drainage class for MY4284 with soil formation of Singa, Setul and Chuping was imperfectly drained where the water leaves soil slowly enough to keep it wet for significant periods but not all of the time (FAO, 2006).

### Hydrologic Response Unit Analysis

The HRU analysis output was extracted after a successful run of model simulation in SWAT model. Forest (FRSE) was the highest land use area within Langkawi Island watershed; 13,202 ha [32,622.85 ac] with percentage of 75.59% (Figure 5a,b). The lowest land use area recorded was industrial (UIDU); 105.44 ha [260.55 ac] (0.60%). MY4464 showed the coverage percentage of 10,865.87 ha [26,850.15 ac](62.21 %) and MY4284 showed the coverage percentage of 6,599.8 ha [16,308.46 ac](37.79 %) within the selected watershed boundary of Langkawi Island (Figure 5c,d).

### Conclusion

Soil data for HRU analysis were defined from soil geological map of Langkawi Island consisted of six (6) different type of formation; granite, Singa, Chuping, Machinchang, alluvium, and Setul with two (2) different soil interpretation record number (s5id) code; MY4464 and MY4284. These two codes were successfully tested and fully functional for usersoil SWAT database of Langkawi Island SWAT model analysis. This information may increase the usability of SWAT model to a wider range of applications in other regional and not only restricted to island only.

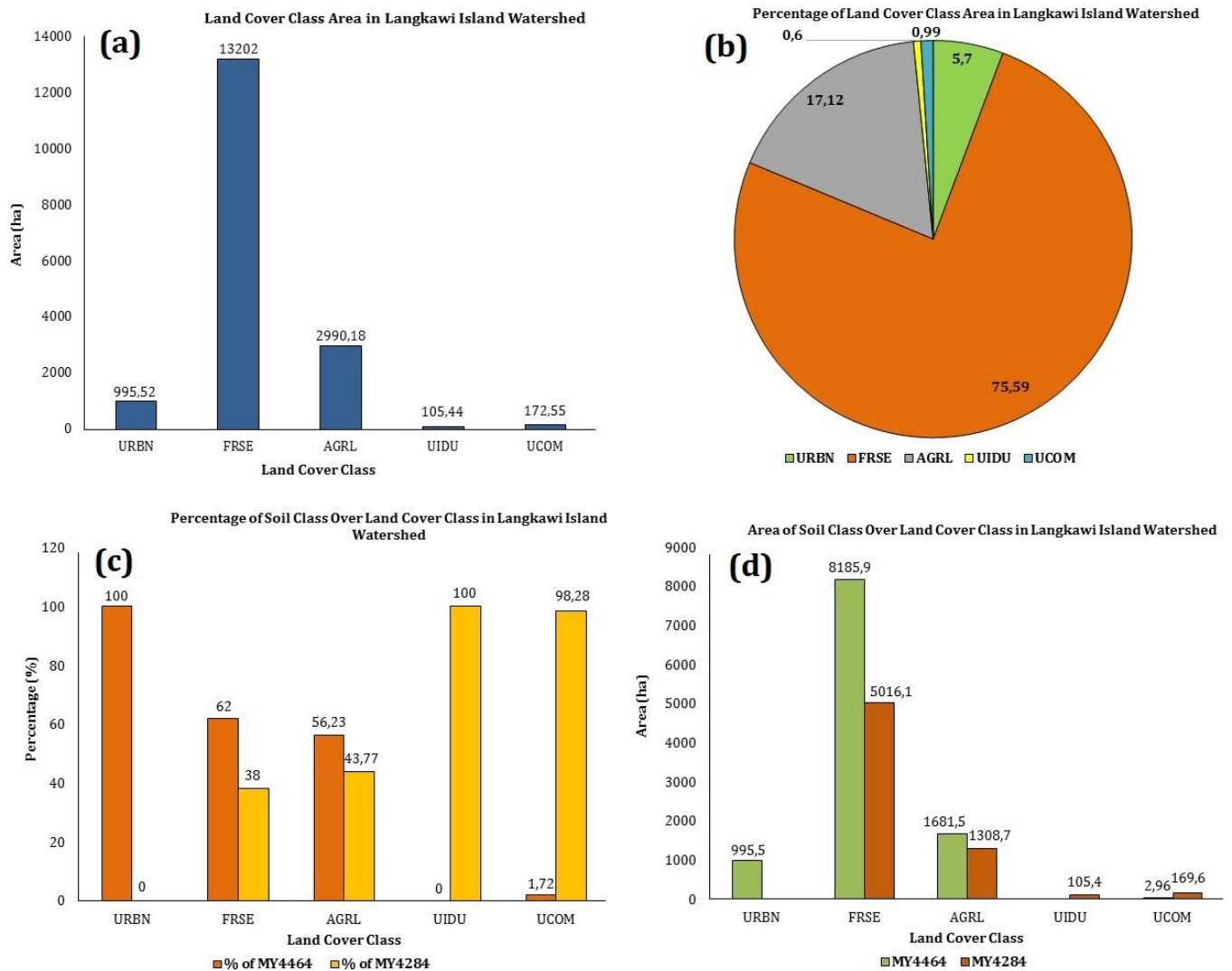


Figure 5. (a) Area of land cover class within the watershed boundary, (b) Percentage of area for land cover class within the watershed boundary of study area in Langkawi Island, (c) Percentage of soil class over land covers class within the watershed boundary, (d) Area of soil class over land cover classes within the watershed boundary

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