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REMOTE SENSING-BASED WATER YIELD ESTIMATION OF THE KELANTAN RIVER BASIN, MALAYSIA

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ABSTRACT

The management of water resources in this study refers to the control of catchment water in the state of Kelantan. The quantity of water yield at a given time is important to identify the amount of water in a catchment area. The objective of this study is to obtain the quantities of water in the watershed of Kelantan. This study focuses on identifying 21 new water catchments based on Soil and Water Assessment Tool (SWAT) model and GIS location of Water Treatment Plant intake. The catchment area features the data relating to each catchment area such as the main river, land lot and area. Subsequently, a simple water balance model was used to obtain the total amount of water in each catchment area in June 2010. This model uses the rainfall and actual evapotranspiration derived from the Tropical Rain Measuring Mission (TRMM 2A25) satellite and the Landsat-5 TM satellite, respectively. The actual evapotranspiration was extracted using the False Color-Composite Model (FCC). This study shows the remote sensing-based water yield model is able to measure the amount of water in June 2010 for 20 catchment areas.

Keywords: water yield, Kelantan, landsat-5 TM, TRMM, remote sensing.

INTRODUCTION

Sustainable water resource management is defined as “water resource systems designed and managed to fully contribute to the objectives of society, now and in the future, while maintaining their ecological, environmental, and hydrological integrity” (Loucks, 2000). Rapidly increasing of populations combined with un-controllable deforestation, agricultural land expansion, urbanization and industrialization could lead to critical water shortage issues in the future (Sun *et al*., 2016). Therefore, sustainable water resource management should be implemented to secure sufficient water resource for future generations. Water yield is among the major water elements that essential for developing a reliable sustainable water resources management.

In the Tenth Malaysia Plan (10MP), Malaysia government is dedicated to provide an efficient water supply system for ensuring a high quality lifestyle. Kelantan, a state in the north-eastern region of Peninsular Malaysia, receives abundant rainfall yearly. However, water-related disasters such as drought and flood are frequently occurs in this region due to high variability of rainfall. For instance, one major drought event has occurred in 2014, causing the paddy yield losses of about USD $22 million (Tan *et al*., 2017a). On the other hand, a violent flood in 2004 has caused losses of about USD $370 million and evacuation of more than 10,000 people (Tan *et al*., 2017b). Therefore, a more comprehensive and systematic water resources management should be developed to reduce the water crisis issues in the future.

The main objective of this study is to estimate water yield of the Kelantan River Basin (KRB), Malaysia. Firstly, basin delineation was conducted using the topography information extracted from the local topography maps. Then, water yield from each basin were estimated by using Geographical Information System (GIS) and remote sensing technologies. Water yield information is important to the local authorities such as Jabatan Air Negeri Kelantan (JANK), Air Kelantan Sdn Bhd (AKSB), Department of Drainage and Irrigation Malaysia (DID) and Lembaga Kemajuan Pertanian Kemubu (KADA) for water resources management. Besides that, it is also vital for controlling human activities development within the lack water resources basin areas.

STUDY AREA

Kelantan lies between 4°~6°N and 101°~103°E, with an area of about 14,922 km^2 (Figure-1). It is comprises eleven districts, such as Kota Bharu, Pasir Mas, Bachok, Tumpat, Kuala Krai, Tanah Merah, Machang, Jeli, Gua Musang and Lojing. The Kelantan River flows from south to north into the South China Sea. The average annual precipitation of Kelantan is more than 2500 mm/year (Tan *et al*., 2016c). The basin is mainly influence by the southwest monsoon (SWM) and northeast monsoon (NEM) seasons, where the latter brings heavy precipitation from October to January. Average annual evapotranspiration rate of the Kelantan state is ranging from 1000 to 1600 mm/year.

LAND USE DATA

Three Landsat-5 Thematic Mapper (TM) images were obtained from the United States Geological Survey (USGS) webpage at https://landsat.usgs.gov/landsat-data-access. These images were collected on 2 February 2010 and 1 June 2010. Geometric and atmospheric corrections were conducted as pre-processing of the satellite images. Then, evapotranspiration information was extracted from the Landsat images by using the False Color Composite (FSS) algorithm. Besides that, Landsat imagery also used to produce the land use map of the Kelantan state.

RAINFALL DATA

Tropical Rainfall Measuring Mission (TRMM) is a joint mission between National Aeronautics and Space Administration (NASA) and the Japan Aerospace

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Exploration Agency (JAXA). The TRMM satellite carried five main instruments including Precipitation Radar (PR), TRMM Microwave Imager (TMI), Visible Infrared Scanner (VIRS), Lightning Imaging Sensor (LIS) and Cloud and Earth's Radiant Energy System (CERES). The TRMM 2A25 product provides rainfall data in daily scale. As rainfall is the main input of a hydrological cycle, so the TRMM 2A25 is used to provide rainfall information of the study area.

METHODOLOGY

SWAT model

Basin delineation function in the Soil and Water Assessment Tool (SWAT) model is used to delineate the sub-basin areas of the Kelantan River Basin. The SWAT model is a public domain hydrological modl developed to quantify the impact of land management practices in a large basin. Gassman *et al*. (2007) stated that there are more than 250 peer-reviewed SWAT-related articles has been published, showing the capability of the model in hydrology studies. There is no doubt the model is reliable to be used for basin delineation. There are two approaches for basin delineation in SWAT model: (1) Digital Elevation Model (DEM) approach and (2) pre-defined approach where users can define the basin and sub-basins manually. We used the DEM-based approach that widely applied in many SWAT studies (e.g. Tan *et al*., 2014).

The Shuttle Radar Topography Mission (SRTM) with an accuracy of ±16m and spatial resolution of 90m is used in this study. It is freely available at http://srtm.csi.cgiar.org/. The use of spatial elements in the formation of catchment areas has yet to be fully tested but will increase the boundary accuracy of the catchment area as the hydrological modelling process will be connected to each other in each sub-basin. The basin delineation is mainly based on the location of the water treatment plant (WTP) in the basin. The intake location at each WTP provides water resources at key plants in the study area and is the main vase for catchment catching. There are 21 intake locations used as the bases for the basin delineation (Table-1).

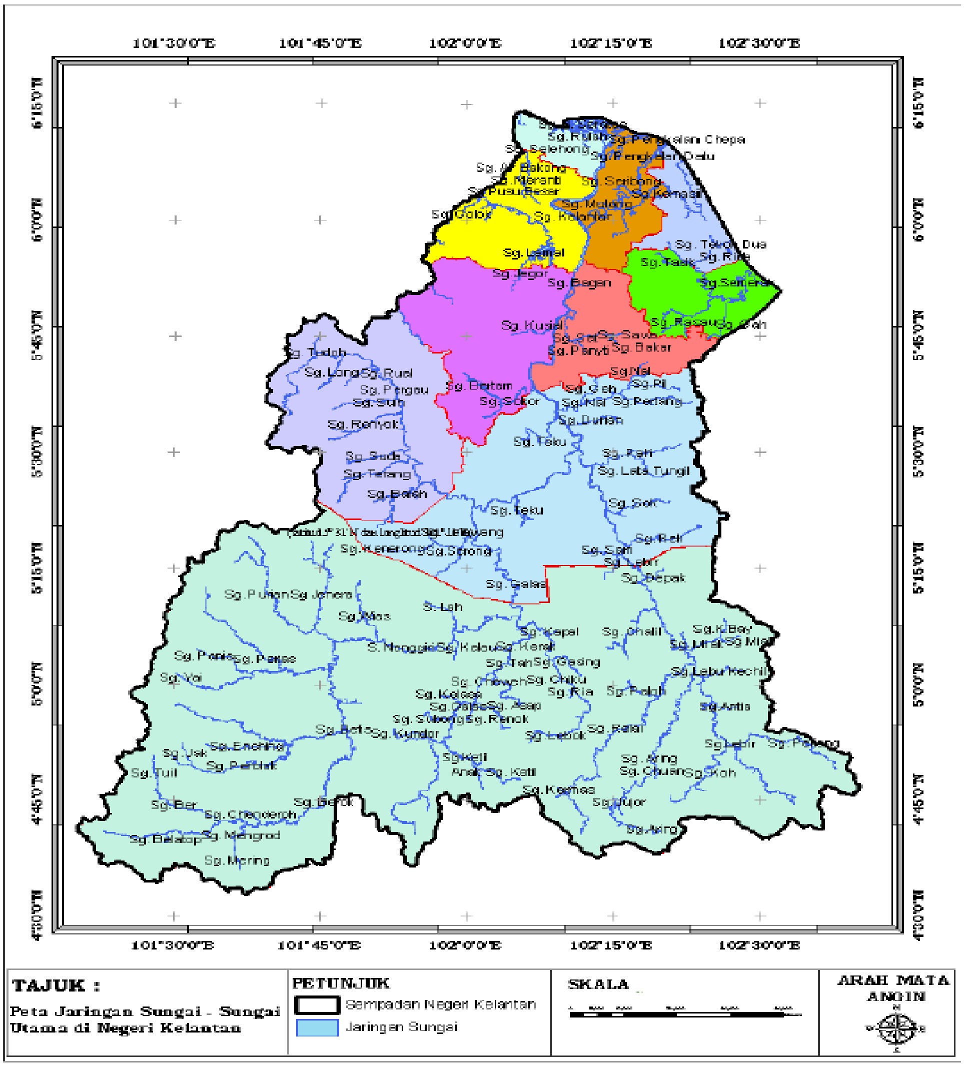

Figure-1. Kelantan.

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Table-1. Water treatment plants in the study area.

No	WTP name	District	Sources	Volume of capacity
1	Merbau Chondong WTP	Machang	Kelantan River	40 MLD
2	Kelar WTP	Pasir Mas	Kelantan River	64 MLD
3	Wakaf Bunut WTP	Pasir Puteh	Rasau River	9 MLD
4	Bukit Remah WTP	Tanah Merah	Kelantan River	28 MLD
5	Kuala Tiga WTP	Tanah Merah	Kelantan River	1.13 MLD
6	Bendang Nyior WTP	Tanah Merah	Jegor River	1.70 MLD
7	Batu Gajah WTP	Tanah Merah	Jedok River	2.30 MLD
8	Jeli WTP	Jeli	Pergau River	4 MLD
9	Kuala Balah WTP	Jeli	Terang River	2.3 MLD
10	Ayer Lanas WTP	Jeli	Lanas River	2.6 MLD
11	Pahi WTP	Kuala Krai	Lebir River	16 MLD
12	Manik Urai WTP	Kuala Krai	Lebir River	7 MLD
13	Tualang WTP	Kuala Krai	Kelantan River	8.69 MLD
14	Stong WTP	Kuala Krai	Stong River	3.77 MLD
15	Bertam WTP	Gua Musang	Galas River	0.50 MLD
16	Limau Kasturi WTP	Gua Musang	Galas River	1.2 MLD
17	Aring WTP	Gua Musang	Aring River	1.8 MLD
18	Chiku WTP	Gua Musang	Chiku River	6 MLD
19	Sg Ketil WTP	Gua Musang	Ketil River	13 MLD
20	Lojing WTP	Gua Musang	Pelaur River	5 MLD
21	Panggung Lalat WTP	Gua Musang	Betis River	0.70 MLD

Water balance

A simple water balance equation is popularly used in the field of remote sensing in producing the value of water yield. This equation was pioneered by Thornthwaite and Mather (1955) through the concept of calculating the balance of water based on climate. They states that when the rain falls over the water demand then the moisture content of the soil will increase and the effect will cause an area experiencing excess water when the amount of water continues to be excessive. This is supported by Ab. Latif Ibrahim (1994) argues that water shortage will occur when the value of evaporate exceeds the value of the rain. The main parameters used in this study are precipitation (P) and the actual evapotranspiration (λEt). The simple water balance equation used in this study is:

$$\text{Water Yield} = P - \lambda Et$$

Precipitation

The use of TRMM 2A25 data for producing precipitation is data that is ready to be processed and displayed via data algorithm at the second level. This level refers to the assessment of rain, no rain and rainfall. An important process in this algorithm is an atmospheric correction that refers to surface features. The algorithm processes the data through the radar atmospheric correction with method Hitschfeld -Bordan and in turn affects the accuracy of the assessment of the precipitation. This method is used in the TRMM 2A25 data algorithm aimed at obtaining rainfall from atmospheric correction. After that, precipitation data from TRMM 2A25 were compared to rainfall data from 38 of stations of Department of Irrigation and Drainage Kelantan throughout Kelantan.

Actual Evapotranspiration

Actual evapotranspiration data is generated from the Landsat-5 TM using the False Color Composite approach. This method is one of the tools in ArcGIS 10.1 software that combines the main bands in the Landsat-5 TM to produce the Normalized Difference Vegetation Index (NDVI) and subsequently produced actual evapotranspiration value. The main advantage of this method can evaluate the actual evapotranspiration for each surface through pixel to pixel (Parikshit Renade and Ayse Irmak, 2009). The actual evapotranspiration value of this model is obtained by the equation:

$$\lambda Et = n{*}xEt_0$$

Where;
λEt = daily actual evapotranspiration,
Et_0 = raster data of potential evapotranspiration from Landsat-5 TM data, and
n* = portion of plant cover

The plant cover portion of each pixel is determined by relation $n^* = (n^*)^2$. This equation has been suggested by Brunsell and Gillies (2002) to obtain parts of the plant cover and also the scale of the emission division between the vacant land and the plant area. The value of the plant cover portion is derived from:

$$n^* = (NDVI - NDVI_0) / (NDVI_{max} - NDVI_0)$$

Where;

n* = portion of plant cover,
NDVI = NDVI value,
$NDVI_0$ = NDVI value for vacant land, and
$NDVI_{max}$ = maximum of NDVI value for plant cover.

The main purpose of NDVI is used to minimize the effects of atmospheric and topographic diversity on the image. Near infra rows (NIRs) and red lines are used in obtaining NDVI values. This path is used as it reduces space spatial space with multiple dimensions to one dimension to detect changes in biomass, plant parts index or plant cover. By merging into these two paths, the plant index reacts to the high absorption of red light. This is because the presence of chlorophyll in the plant part absorbs red light. Whereas for NIR strips, there is a significant reversal due to absorption in the internal structure of leaves (Jensen, 2000). The formula for obtaining NDVI values for Landsat-5 TM data is;

$$NDVI = (Band\ 4 - Band\ 3) / (Band\ 4 + Band\ 3)$$

A formula developed by Tasumi *et al.* (2000) has earned the evapotranspiration value through daily evaporation. This value refers to the whole of June 2010. The formula is measured as follows:

$$\lambda Et_S = \sum_{i=1}^{n} (ET_0)_i \times (Km)_i$$

where λEts is a monthly actual evapotranspiration it's referring to June 2010. Km is the cumulative value which is derived from the ratio of monthly actual evapotranspiration value and daily evaporation value.

RESULTS AND DISCUSSIONS

Basin delineation

The study area has divided into 21 sub-basin areas based on the SWAT model delineation and WTP locations. The total area of the new basin area is 1,213,620.93 hectares, which is 81.33% of the total study area. This sub-basin area covers 7 major districts in Kelantan, where a sub-basin in Machang, Pasir Mas and Pasir Puteh, three sub-basins in Jeli, and four sub-basins in Kuala Krai and Tanah Merah. While, Gua Musang district has the highest number of sub-basins, where seven sub-bains are located. Three districts, named Bachok, Kota Bharu and Tumpat located in the north and near the coast of Kelantan do not have any sub-basins.

The total area of the new established sub-basins area is 321,891.38 hectares, with the 110,487 land lots located om these sub-basins. There are 5 main watershed areas involved, namely Kelar (Pasir Mas district), Merbau Chondong (Machang district), Bukit Remah (Tanah Merah district), Kuala Tiga (Tanah Merah district) and Tualang (Kuala Krai district). The Tualang catchment area is the most widespread in the Kelantan River basin of 167, 990.81 hectares or covers 52.18% of the total catchment area in the Kelantan River Basin.

The main river basins in the Gua Musang district that have watershed areas are the Galas River, Aring River, Chiku River, Betis River, Pelaur River and Ketil River. The total area of the watershed area is 488,273.34 hectares. Although this area is larger than the watershed area of the Kelantan River Basin, the total land lots involved only 11,645 lots of land. For example, the Panggung Lalat at Betis River is 5,341.3 hectares but has only 1 lot of land. This shows that the watershed area in Gua Musang is composed of for forest land use because it does not have lot of land.

The watershed area in the western part of Kelantan which covers Jeli district is 89,668.09 hectares. In particular, watershed areas are Jeli (31,765.70 hectares), Kuala Balah (50,176.50 hectares) and Ayer Lanas (7,725.89 hectares). The total number of land lots involved is 12,722 lot land. The watershed area formed from the Pergau River, Terang River and Ayer Lanas Rivers. The river is caused by the Titiwangsa Range lying between Kelantan and Perak.

The smallest catchment area is located in the Gua Musang district which is Lojing area. The area is only 419.9 hectares of land and only has 2 lots of land involved. This catchment area is threatened with forest exploration for the development of a cold-based agricultural area in Lojing. This exploration has affected the quality of water resources in the Perlaur River. The river has a small extent and is so easily affected if there is a threat of unobstructed forest exploration. This Lojing watershed area supplies water to major agricultural areas around the small of Lojing district.

In addition, Wakaf Bunut watershed area is so important for the Pasir Puteh district. The main river in this watershed area is the Rasau River which is due to Bukit Yong which borders the State of Terengganu. This watershed area covers an area of 8,542.79 hectares which supplies major water resources to residents in the city of Pasir Puteh and its surrounding areas to the Tok Bali shipping center. The total number of land lots involved in this catchment area is 7,488 lot land. These land lots are mostly made up of agricultural land lots. Agricultural activities as well as logging in this catchment area have caused the Rasau River profile to change frequently when it comes to rainy season and drought.

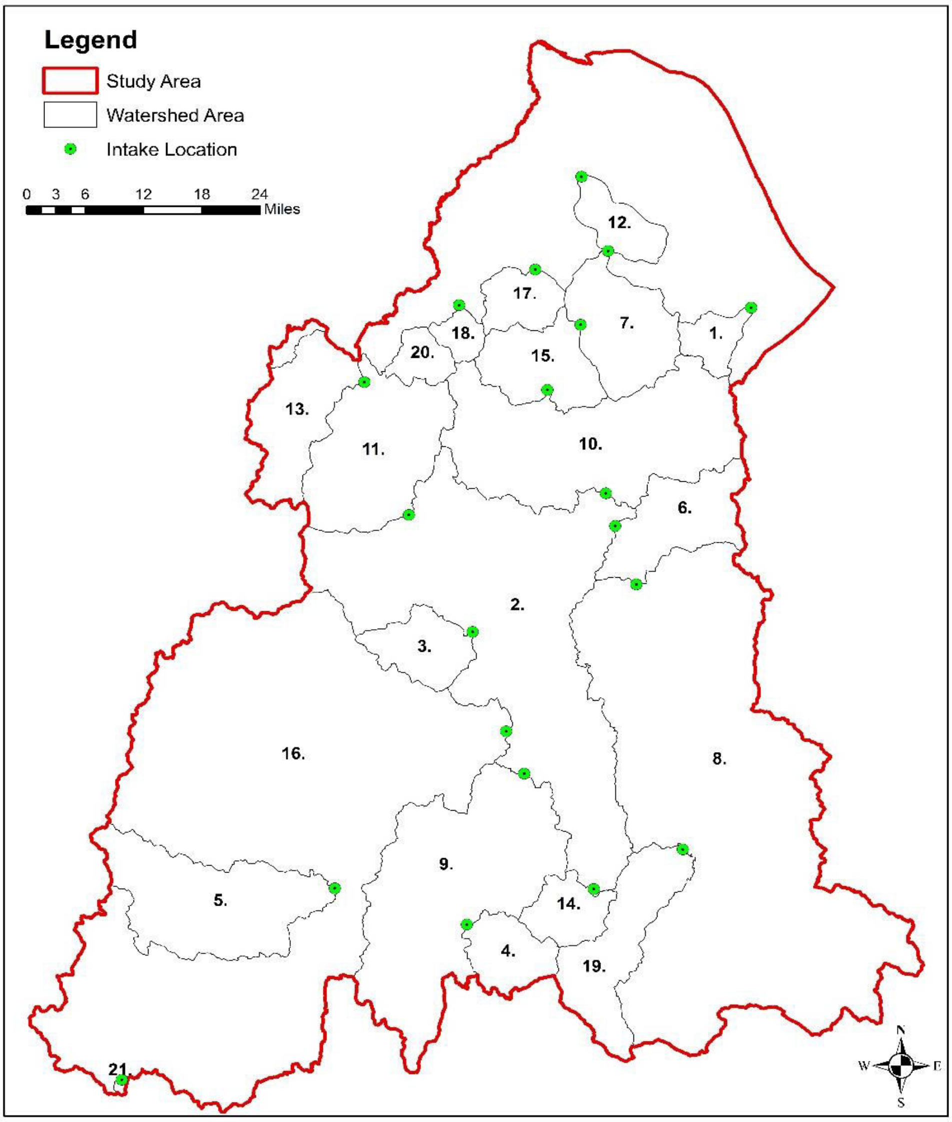

Figure-2. New sub-basins delineation with integration of the DEM-based and water treatment plants.

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Table-2. Result of watershed area.

No	Watershed area	District	River	Area(hectares)	Lands lot
1	Wakaf Bunut	Pasir Puteh	Rasau River	8,542.79	7,488
2	Tualang	Kuala Krai	Kelantan River	167,990.81	13,329
3	Dabong / Stong	Kuala Krai	Stong River	16,921.12	158
4	Sg Ketil	Gua Musang	Ketil River	1,574.93	681
5	Panggung Lalat	Gua Musang	Betis River	5,341.3	1
6	Pahi	Kuala Krai	Lebir River	2,848.16	5,233
7	Merbau Chondong	Machang	Kelantan River	30,668.92	48,070
8	Manik Urai	Kuala Krai	Lebir River	267,638.419	4,801
9	Limau Kasturi	Gua Musang	Galas River	95,498.50	8,983
10	Kuala Tiga	Tanah Merah	Kelantan River	86,608.95	429
11	Kuala Balah	Jeli	Terang River	50,176.50	6,415
12	Kelar	Pasir Mas	Kelantan River	12,564.17	30,080
13	Jeli	Jeli	Pergau River	31,765.70	3,426
14	Chiku	Gua Musang	Chiku River	13,294.87	513
15	Bukit Remah	Tanah Merah	Kelantan River	24,058.53	18,579
16	Bertam	Gua Musang	Galas River	337,776.56	1,246
17	Bendang Nyior	Tanah Merah	Jegor River	12,336.39	13,204
18	Batu Gajah	Tanah Merah	Jedok River	5,501.244	2,251
19	Aring	Gua Musang	Aring River	34,367.28	219
20	Ayer Lanas	Jeli	Lanas River	7,725.89	2,881
21	Lojing	Gua Musang	Pelaur River	419.90	2
Total				1,213,620.93	167,989

Precipitation

The results of rainfall parameters in the study area are based on rainfall data obtained from the TRMM 2A25 data. The results show the pattern of rainfall to total in June 2010 between 0.482 mm to 317.31 mm. In comparison, rainfall is the lowest in the northern and coastal areas of the study area. However, the distribution dropped considerably in the interior of the state of Kelantan, especially around Lojing, Panggong Lalat and Bertam in the Gua Musang district. In addition, the findings show that the lowest rainfall in June 2010 was observed daily at Kennet Farm Station 0.14 mm only while the highest was at Ulu Sekor Station 0.72 mm. In short, rain falls this month is slightly compared to other months, especially at the end of the year. This is because the month of June is outside the season of the Northeast Monsoon season which starts in October until March each year.

Actual Evapotranspiration

The actual evapotranspiration value from Landsat-5 TM data refers to only 20 catchment areas excluding Lojing. This is because the Landsat-5 TM data used does not cover the Lojing area due to cloud problems. The table shows the actual evapotranspiration value and the parameters used in 20 catchment areas in June 2010. Results show that the entire watershed area has a maximum value of over 20.0 mm with the highest recorded at Bertam of 26.186 mm. However, the lowest maximum value is recorded at Kelar which is 0.277 mm. There are 16 watershed areas with average value of refuse ranging from 13.0 mm to 21.0 mm while 4 watershed areas have an average value of less than 2.0mm. Furthermore, 10 catchment areas which recorded 0.0 mm for the minimum value of the year 2010 were Tualang, Merbau Chondong, Manik Urai, Kuala Tiga, Kelar, Jeli, Bukit Remah, Kuala Balah, Bertam dan Bendang Nyior.

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Table-3. Actual Evapotranspiration of the sub-basins extracted from Landsat data.

No	Basin area	NDVI value	Temperature value	Actual evapotranspiration value
1	Wakaf Bunut	Max:0.859 Mean:0.712 Min: 0.085	Max:30.0 Mean:24.9 Min: 19.0	Max: 22.3 Mean: 15.1 Min: 1.6
2	Tualang	Max:0.883 Mean:0.722 Min: -0.473	Max:30.05 Mean:24.0 Min: 18.1	Max:24.734 Mean:17.461 Min: 0.0
3	Stong	Max:0.882 Mean:0.656 Min: 0.024	Max:31.1 Mean:22.5 Min: 18.1	Max:23.971 Mean:15.177 Min: 1.847
4	Sg Ketil	Max:0.869 Mean:0.672 Min: 0.026	Max:28.9 Mean:22.7 Min: 15.3	Max: 21.930 Mean:16.444 Min: 0.470
5	Panggong Lalat	Max:0.872 Mean:0.597 Min: -0.043	Max:27.8 Mean:22.6 Min: 15.3	Max: 21.930 Mean: 16.444 Min: 0.470
6	Pahi	Max:0.877 Mean:0.729 Min: -0.397	Max:29.6 Mean:24.1 Min: 18.1	Max: 22.973 Mean: 18.280 Min: 1.409
7	Merbau Chondong	Max:0.857 Mean:0.403 Min: 0.016	Max:27.4 Mean:22.3 Min: 18.1	Max: 20.361 Mean: 1.945 Min: 0.0
8	Manik Urai	Max:1.0 Mean:0.703 Min: -0.368	Max:29.8 Mean:22.9 Min: 15.3	Max:24.355 Mean: 16.569 Min: 0.0
9	Limau Kasturi	Max:0.887 Mean:0.709 Min: -0.397	Max:34.6 Mean:23.9 Min: 15.3	Max:24.374 Mean: 17.424 Min: 0.316
10	Kuala Tiga	Max:0.887 Mean:0.709 Min: -0.397	Max:31.6 Mean:23.1 Min: 18.1	Max: 23.272 Mean: 13.096 Min: 0.0
11	Kuala Balah	Max:0.887 Mean:0.753 Min: -0.421	Max:30.4 Mean:23.4 Min: 18.1	Max: 25.600 Mean: 19.592 Min: 0.0
12	Kelar	Max:0.752 Mean:0.200 Min: 0.067	Max:19.6 Mean:18.9 Min: 18.1	Max: 0.277 Mean: 0.0 Min: 0.0
13	Jeli	Max:0.889 Mean:0.680 Min: -0.363	Max:29.2 Mean:22.3 Min: 18.1	Max: 25.387 Mean: 17.586 Min: 0.0
14	Chiku	Max:0.868 Mean:0.680 Min: 0.065	Max:27.7 Mean:23.0 Min: 16.4	Max:22.539 Mean:16.279 Min: 3.363
15	Bukit Remah	Max:0.840 Mean:0.392 Min: -0.196	Max:22.0 Mean:19.7 Min: 18.1	Max:17.689 Mean: 1.562 Min: 0.0
16	Bertam	Max:0.887 Mean:0.652 Min: -0.448	Max:34.2 Mean:22.9 Min: 15.3	Max:26.186 Mean:16.502 Min: 0.0
17	Bendang Nyior	Max:0.823 Mean:0.386 Min: 0.153	Max:21.6 Mean:19.8 Min: 18.1	Max:7.039 Mean:0.906 Min: 0.0
18	Batu Gajah	Max:0.878 Mean:0.681 Min: 0.125	Max:28.4 Mean:23.1 Min: 18.1	Max:21.618 Mean:16.260 Min: 4.716
19	Aring	Max:0.873 Mean:0.710	Max:26.3 Mean:22.9	Max:22.301 Mean:17.231

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		Min: 0.028	Min: 15.3	Min: 2.306
20	Air Lanas	Max:0.887 Mean:0.790 Min: 0.129	Max:28.4 Mean:24.5 Min: 18.1	Max:22.944 Mean:20.746 Min: 17.721

Water yield

Overall, in June 2010 it was found that there was a water surplus in all catchment areas as a result of the amount of rainfall exceeding the sum of the total. This resulted in a total water count of 607.22 mm for the entire catchment area. On average, the total water yield for 20 catchment areas is 30.36 mm with a total water yield exceeding 35mm recorded at Stong (35.39 mm), Chiku (37.16 mm), Sg. Ketapak (49.97 mm), Panggong Lalat (94.54 mm), Limau Kasturi (50.41 mm) and Bertam (72.61 mm). The Panggong Lalat area has the highest water yield value with the recorded amount of precipitation (110.49 mm) and actual evapotranspiration (16.09 mm). The watershed area which records more than 35 mm of water is located in the south of the study area, concentrated in the Gua Musang district.

Wakaf Bunut recorded the lowest water yield of 11.34 mm with a total rainfall of 29.1mm and a total actual evapotranspiration of 17.81 mm. In addition, between the watershed areas with the lowest water yields below 16 mm are Merbau Chondong (15.95 mm), Kuala Tiga (15.18 mm), Bukit Remah(15.92 mm), Bendang Nyior (14.43 mm) and Air Lanas (15.9 mm). The location of this watershed area is concentrated in the center of the study area between Machang district and Tanah Merah district. All these areas recorded rainfall values ranging from 29.1 mm to 39.56 mm only affecting the low water value.

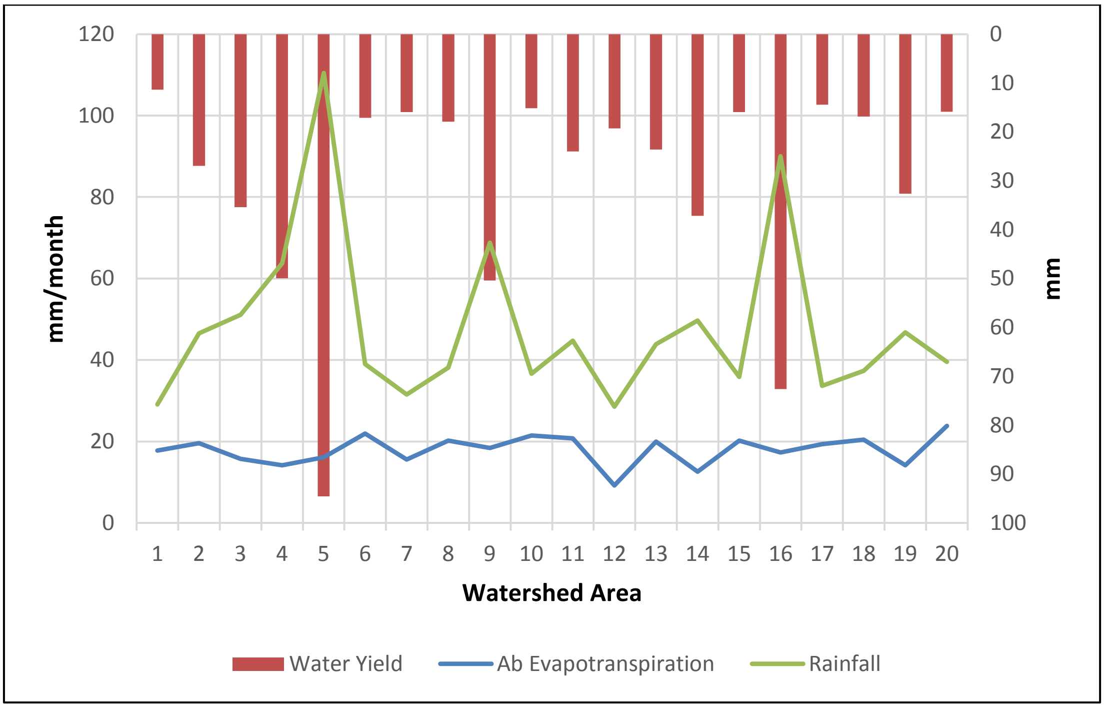

Figure-3. Water yield of the Kelantan river Basin in June 2010.

CONCLUSIONS

This study is to identify new catchment areas and water yield in Kelantan using remote sensing, GIS and hydrological modeling techniques. Watershed area uses SWAT Model and combined with GIS technique analysis. The novelty of this study is the integration of the location intake of water treatment plant and the SWAT Model in the delineation of the watershed area. Rainfall and actual evapotranspiration were used to calculate the water yield of the basin. Rainfall values were obtained from the TRMM 2A25 data, while the actual evapotrasnpiration from the Landsat 5 TM data.

Evaporation value is measured for each watershed area, except Lojing that covered by cloud covers. This indicates that this data can produce actual evapotranspiraiton content in every unselected pixel cloud. So, the actual evapotranspiration can be determined in every 30 m x 30 meters (pixel area). Besides that, integration of the SWAT Model and the water treatment plant information gives a better basin delineation result. Remote sensing techniques can only be used when it comes to obtaining the value of water only for a minimum of a day or a month. This is because the water yield is only dependent on the time the data is taken. However, this technique is so popular for obtaining the value of water yield for a wide area of study. In addition, this water-based analysis is compared with the planned increase in clean water production in every district in Kelantan.

There are several suggestions to improve the research results in the study area. The use of Landsat-5 TM data needs to be classification for a land use. Supervised land use can be made throughout the state of Kelantan. The map of this published land use of each watershed identified in this study. The use of this land is then used for the analysis of classification watershed of forests and towns. Something new in this study is to determine the catchment of forests and cities. Additionally, almost 60% of the people in Kelantan use groundwater as the main water source. The study of water resources should take into volume the value of groundwater in the state of Kelantan.

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