HARNESSING EARTH OBSERVATION SYSTEM FOR FAST-REALIZING SUSTAINABLE DEVELOPMENT GOAL (SDG) ON CLEAN WATER AND SANITATION

Mazlan Hashim, Mohd Rizaludin Mahmud, Mohd Nadzri Reba, and Nurul Nadia Yahya

Universiti Teknologi Malaysia (UTM), Geoscience & Digital Earth Centre (INSTeG),
81310 UTM Johor Bahru, Malaysia
Email: mazlanhashim@utm.my

KEY WORDS: Sustainable Development Goal; Clean Water and Sanitation, Earth Observation System, Water Yield, SDG targets

ABSTRACT: This paper demonstrates on study undertaken for development on application of using fully satellite-based water yield indicator for mapping, and monitoring status of availability of sources of resource of large area watersheds to sub-basin level for SDG 6, themed for clean water and sanitation. Employing the water-balance model with 3 major fully satellite inputs, namely: (i) satellite precipitation radar from Tropical Rainfall Measurement Mission (TRMM); (ii) Evapotranspiration rate from MODIS satellite; and (ii) Landcover types from Landsat Thematic Mapper (TM) data. Assessments of these satellite derived products systematically analysed before further computation of water yield. Results of this study shown good agreements all the satellite derivatives to the corresponding gauged rainfall, selected in-situ evapotranspiration and stream-flow, respectively. Hence, it is therefore concluded this satellite-based initiative is best approach for fast-tracking in realisation of specific targets of the SDG as exemplified in goal # 6 in this paper.

1. INTRODUCTION

The Sustainable Development Goals (SDGs), is a widely known global policy for guiding the method countries together transform and manage their economic, social, and environment. SDG addresses also the pattern of people as well as the planet for the next 15 years (2030 agenda). Attaining these goals presents the entire nations and the world-wide policy community through a set of essential development challenges, which are almost generally geographic. Several of these issues impacting on sustainable development could be examined, modelled, and mapped in a geographic context using Earth Observations (EO) as a prospect to SDGs. Employing the EO technology offers the integrative framework essential for consensus, global collaboration, and evidence-based decision-making. In fact, the current EO landscape are fast changing and focused to: (1) customer need and technical performance – these include the performance on the advancement on data acquisition, processing and delivery as effective business packages; (2) market and competition – continuous and global growth including shifting of the value chain of data supply to specific services and applications; and (3) regulation of very fine resolution EO data remains highly sensitive information and legislation could continue to evolve impacting the new business models.

Despite the existence of the inevitable space gaps within the EO data users, the applications of EO have widely used and operational even in non-space fearing nations without any direct facilities of space-infrastructure. The key advances in these EO applications have been attained through sharing and partnerships which have amongst other include: capacity building that support and train user communities; Technological competency that have improve data access and increase data utilization; and the political stability and the wills of the sharing and partnership countries in addressing specific issue.

This paper demonstrates on study undertaken in UTM for development on application of using fully satellite-based water yield indicator for mapping, and monitoring status of availability of sources of resource of large area watersheds to sub-basin level for SDG 6, themed for clean water and sanitation. Employing the water-balance model with 3 major fully satellite inputs, namely: (i) satellite precipitation radar from Tropical Rainfall Measurement Mission (TRMM); (ii) Evapotranspiration rate from MODIS satellite; and (ii) Landcover types from Landsat Thematic Mapper (TM) data. Assessments of these satellite derived products systematically analysed before further computation of water yield. Results of this study shown good agreements all the satellite derivatives to the corresponding gauged rainfall, selected in-situ evapotranspiration and stream-flow, respectively. Full reports of these results are given in Hashim et al. (2016); Mahmud et al. (2017); and Mahmud et al. (2018). Hence, it is therefore concluded this satellite-based initiative is best approach for fast-tracking in realisation of specific targets of the SDG 6.

2. MATERIALS & METHOD

2.1 Study Area

The Setiu watershed, located in the northeast Peninsular Malaysia, experiences the highest record of mean monthly rainfall of 2700 mm/year; computed from 1973 to 2011 rainfall data. The site experiences humid tropical climate with a distinct wet season (NEM; northeast monsoon) from November to March, a dry season from May to September (SWM; southwest monsoon) and inter-monsoon seasons (hereafter IM) in April and October (Figure 1). The main river networks are Sg. Setiu, Sg. Caluk, Sg. Bari, Sg. Merang and Sg. Marang, with catchment areas of about 1076 km^2. All river networks flow and discharge into the South China Sea.

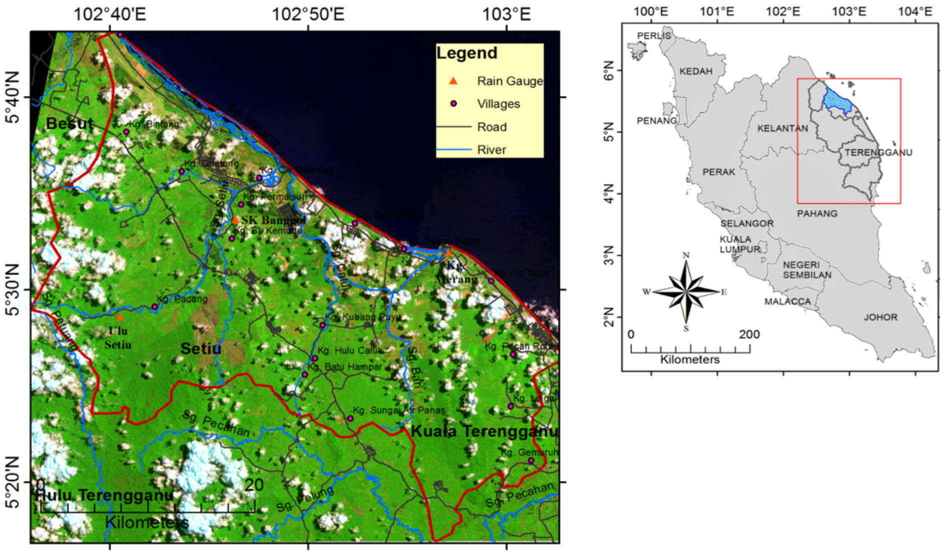

Figure 1. Setiu watershed, Terengganu, Malaysia.

2.2 Satellite Data & Ancillary Information

Three sources of satellite data were used in this study: satellite precipitation radar data from the Tropical Rainfall Measuring Mission (TRMM) and ET data from the Moderate Resolution Imaging Spectroradiometer (MODIS). The Landsat ETM+ data were used for land use mapping of Setiu for 2010.

The rainfall data were extracted from TRMM using geospatial tool based on the same position of the rain gauge on the ground. Table 1 shows specifications of TRMM data. The MODIS data level of 16A2 (MODIS16A2) is a payload scientific instrument, launched by NASA on board the Terra and the Aqua satellites are useful to study global dynamics and processes occurring on the land, in the oceans, and in the lower atmosphere. MODIS16A2 has been used in this study because it provides the quality ET for solving the water balance equation (Mu et al., 2007). MODIS16A2 were then been validated using ground technique, the Penman-Monteith equation. The MODIS 16A2 acquired for 2010 (Jan-Dec) of Setiu area was in HDF format, containing information on, latent energy, potential ET, potential latent energy, ET quality check. The monthly MODIS data were acquired due to the limitations of compatibility of the on-the-ground rainfall data (Table 1).

Two main ancillary information used are :

(a) Corresponding Topographic map of Setiu (1:25,000) and Digital Elevation Model (DEM) products of 30m resolution were generated using the Shuttle Radar Topography Mission (SRTM v4.1). DEM data enabled to understand the high and low terrain relief which provided a comprehensive understanding of the water flow and its potential for reservoir,

(b) Rainfall and stream flow information. There are two rainfall data sources: the on-the-ground measurement of rainfall using rain gauge from Malaysian meteorological department (MMD) and Department of Irrigation and Drainage (DID). Data obtained the MMD rainfall stations were used for calibrating the TRMM rainfall data, while data obtained from the DID were used for an independent validation check of our proposed method. Note, there were only three rain gauge measuring stations that were functional and were regularly maintained in Setiu watershed.

Table 1. Specifications of satellite data products.

Satellite Data	Spatial resolution	Temporal resolution	Coverage	Period
Landsat ETM+	20 m	18 days	Path/ row: 127/56	2010
TRMM (3B43V7)	0.25^{o}	Daily	Global (50^{o} N-S)	Jan-Dec 2010
MODIS16A2	1 km	Daily	Global (0° to 0° S)	Jan-Dec 2010

2.3 Satellite Data Processing

All the satellite data processing pertaining to this study were carried out using ENVI Digital Image Processing System and ArcGis System software, and facilitated by Geoscience and Digital Earth Centre (INSTeG), Universiti Teknologi Malaysia.

2.3.1 Data pre-processing

Data pre-processing stage comprised of image sub-setting, geometric correction, atmospheric correction and image masking, sun glint removal and conversion of DN to radiance. To ease analysis, the subset image was created for TRMM, MODIS and Landsat ETM+ using the Region-of-interest (ROI) function available in ENVI 5.0 software. The geometric correction was performed using an image-to- map registration. The corresponding topographic map was digitised from 1:25,000 map (source: Dept of Survey & Mapping Malaysia). In the image-to-map registration process involved relating coordinates of ground control points (GCP) on the image to the corresponding map (ground) coordinates (Jensen, 1996). The transformation using second order polynomial. The accuracy of the image-to-map is measured by the root mean square errors (RMSE) and found acceptable as it was < 0.05 m. Next, the resampling process were performed where every pixel after the registration process was interpolated from the original raw satellite images. All the images were resampled on a pixel-by-pixel basis using nearest neighbour scheme with final pixel size of 30 m.

The atmospheric correction for all the spectral bands of all images was performed using Fast Line-of-sight Atmospheric Analysis of Hypercubes (FLAASH) program in the ENVI 5 software. The FLAASH atmospheric correction was chosen to minimize the atmospheric perturbations of nadir-viewing images inclusive of correcting the adjacency effects. This is crucial for minimizing of scattering effects of neighbouring pixels of sea surface to final retrieval of substrate-leaving radiances.

2.3.2 Data Processing for Water Yield Estimation

The overall method for WY estimation from satellite TRMM and MODIS ET data is illustrated by the flowchart in the Figure 2. The process followed the following steps: (i) acquisition of rainfall from TRMM and ET from MODIS, and (ii) calibartion and validation of satellite-based rainfall and ET with corresponding ground data. The calibrated TRMM-rainfall and MODIS-ET data were then used in determining the WY. Detailed process has been described in the subsequent sections. Full descriptions of the calibrations is given Hashim et al. 2016.

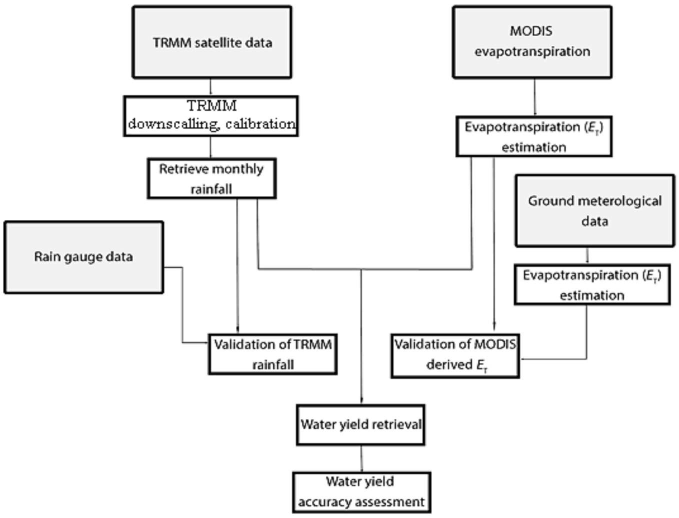

Figure 2. Methodological Flowchart of satellite-based water yield mapping in Setiu catchment. (Source: Hashim et al., 2016)

The conventional water balance equation was used in developing the satellite-based WY model is described in Thornthwaite's water balance model for WY estimation given is:

$$WY = P - ET \pm S_m \qquad (1)$$

where WY is WY, P and ET are satellite precipitation and ET, respectively, and S_m is soil moisture. The available water capacity was considered constant at 250 mm, based on two main assumptions: (i) the mean rooting depth of the vegetation is about 1.5 m (Kleidon et al., 1998); and (ii) the soils in Setiu and Peninsular Malaysia is about the same but at different portions where silt loams (58%), clay loams (30%) and clays (12%) (Department of Irrigation and Drainage, 2016). The soil moisture, S_m and the accumulated potential water loss, A_{PWL} have the following exponential expression:

$$S_m = a.e^{b.A}{}_{PWL} \qquad (2)$$

where both a and b are constants. The values for a and b are 249.5 and -0.0040, respectively for available fixed water capacity at 250 mm.

3 RESULTS & DISCUSSION

The main outputs are the mean annual and monthly WY spatial distributions for Setiu watershed in 2010. The mean monthly and annual WY of Setiu watershed in 2010 are shown in Figure 3. Th monthly WY in the monsoon season is tabulated in Table 2. North east monsoon months (NEM) (November, December and January) showed the highest total amount of WY compared to other month including the south-west monsoon (SWM) and intermediate monsoon (IM) period.

Table 2. Monthly WY in Setiu watershed within the monsoon seasons.
Notes: NEM= north-east monsoon, IM=inter-monsoon, SWM= south-west monsoon.

Parameter	Year 2010											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Water yield (mm)	193.6	185.7	136.2	177.2	130.4	117.9	153.5	98.1	96.5	177.5	200.4	207.4
Season	NEM		IM	SWM						IM	NEM	

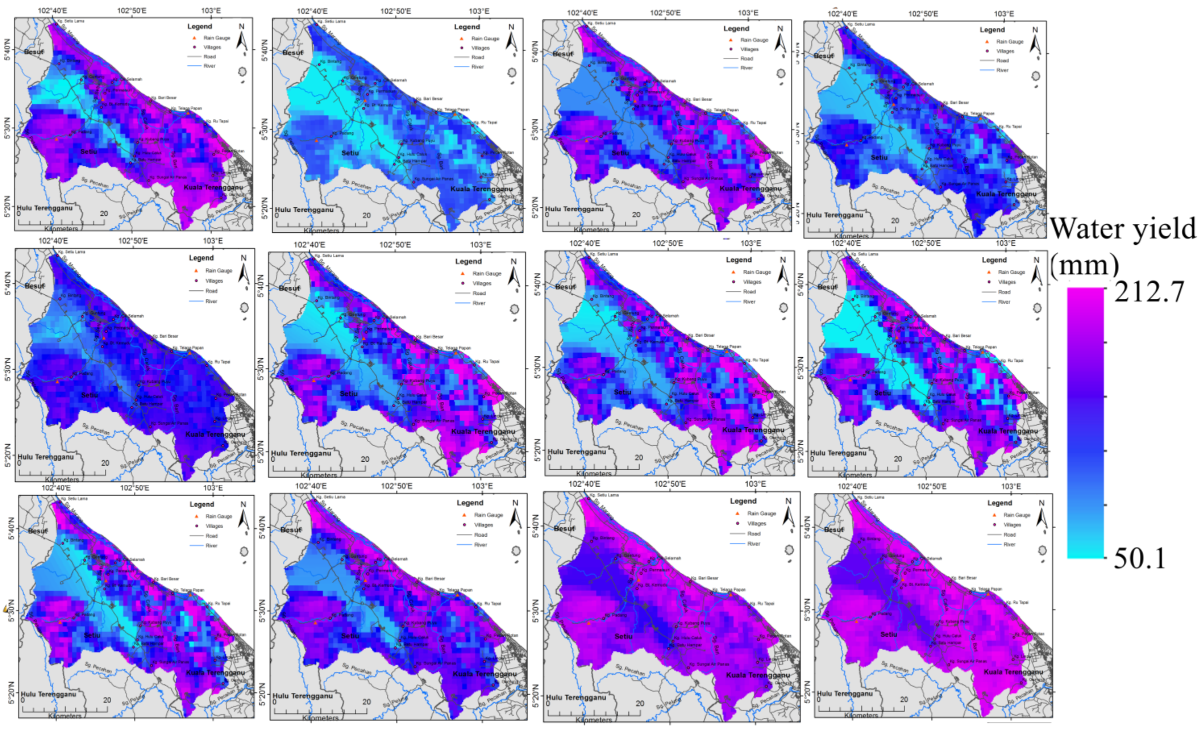

Figure 3: Spatio-temporal water yield distributions Setiu watershed in 2010

3.1 Assessment of results

Amount of water yield computed in Setiu watershed in 2010 shows good relevancy with water yield at other watersheds/catchment in Peninsular Malaysia that experienced almost similar hydrological and meteorological characteristics. Table 3 shows the comparison of water yield of selected watersheds in Malaysia as there is a limited number of published related works in indexed publications. Figure 4 shows the agreement of satellite-based WY obtained against the only available stream flow at Sg. Calok station. Conversion of WY and river flow to either unit show good agreement for all the temporal period.

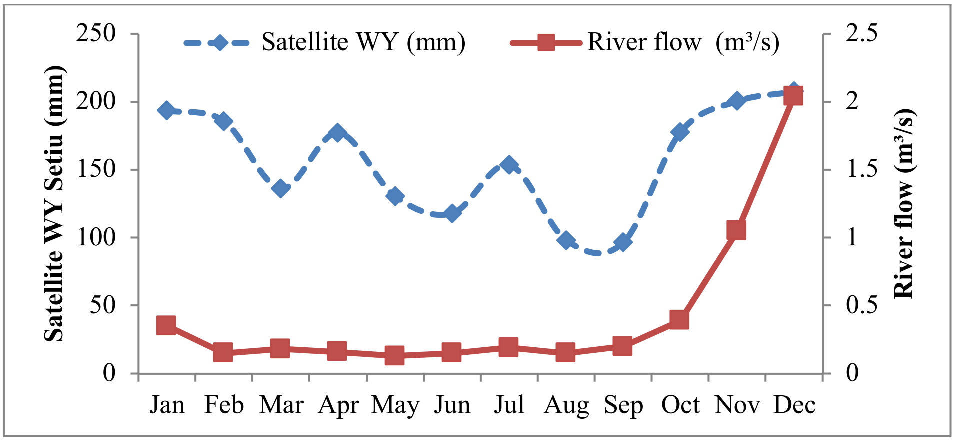

Figure 4. Comparison of satellite WY and stream flow at Sg. Chalok station.

Table 3. Comparison of WY in Setiu watershed and other watersheds in PM

Watershed /catchment	Type of watershed /catchment	Size (km^2)	*M.A.P (mm)	Total WY ($mm.yr^{-1}$)	Reference / approach
Setiu	Mixed hort.	1077.5	2794	1862	This study / satellite
Padang Terap	Forest	1032.3	2406	868	Hashim and Nadzri, 2013/ satellite
Sg. Tekam	Forest	96.9	579	110	Nik, 1998 / conventional
Sg. Tekam	Cocoa+oil palm	56.3	748	155	Nik, 1998 / conventional
Sg. Tekam	Cocoa	37.7	2552	706	Nik, 1998 / conventional
Hulu Perak	forest	857.3	2641	687	Hashim et al. 2016 / satellite
Bernam	Rubber + oil palm	1123.0	2745	1275	Ngah, 2007 / conventional
Linggi	Rubber + oil palm	528.1	2251	1146	Ngah, 2007 / conventional
Kenyir Lake	forest	1260.0	2606	1473	Hashim and Nadzri, 2013/ satellite
Johor River	Semi urban	2636.5	na	788	Hashim and Nadzri, 2013/ satellite
Langat River	Semi urban	1257.7	2401	1207	Hashim and Nadzri, 2013/ satellite

*mean annual precipitations

4. CONCLUSION

This work has successfully demonstrated satellite-based water yield mapping in Setiu watershed. The satellite precipitation radar TRMM data and MODIS ET are the two parameters derived for estimation of WY. Good accuracy obtained in the TRMM precipitation and MODIS ET with RMSE of ± 20.04mm, and ± 43mm, while the satellite WY showed good trend agreement with conventional approaches. Satellite-based WY approach offers a comprehensive spatio-temporal distribution of WY over any sizes of watershed to large areal coverage, and the technique could be replicated for other watersheds elsewhere provided there are availability of related satellite data. In addition, the approach is the only cost-effective alternative for water yield mapping for places that have no evapotranspiration measuring stations or country that has small number and sparsely distributed ground-based rainfall and evapotranspiration measurements stations.

Acknowledgments

Acknowledgments of research facilities used at Universiti Teknologi Malaysia and grant on Satellite-based Spatio-Temporal LULC Analysis to Water Yeilds (Ref: PY/2018/02721).

REFERENCES

Hashim, M.; Reba, N.M.; Nadzri, M.I.; Pour, A.B.; Mahmud, M.R.; Mohd Yusoff, A.R.; Ali, M.I.; Jaw, S.W.; Hossain, M.S. Satellite-Based Run-Off Model for Monitoring Drought in Peninsular Malaysia. *Remote Sens.*2016, *8*, 633.

Mahmud, M.R., Hashim M. , Reba, M.N.M, ((2017), How effective is the new generation of GPM satellite precipitation in characterizing the rainfall variability over Malaysia?; Asia-Pacific Journal of Atmospheric Sciences; Vo;l. 53, Issue3; pg 375-384; DOI 10.1007/s13143-017-0042-3

Mahmud, M.R., Hashim, M, Matsuyama, H., Numata, S., Hosaka, T..(2018),; Spatial downscaling of satellite precipitation data in humid tropics using a site-specific seasonal coefficient; Water; Volume 10, Issue 4, 31 March 2018, Article number 409; DOI: 10.3390/w10040409

Mahmud, Mohd Rizaludin; Numata, Shinya; Matsuyama, Hiroshi; Hosaka, Tetsuro; Hashim, Mazlan (2015); *Remote Sensing*; Assessment of effective seasonal downscaling of TRMM precipitation data in peninsular Malaysia; Vol. 7; No. 4; pg 4092-4111; DOI 10.3390/rs70404092

Nik, A. R. (1998). Water yield changes after forest conversion to agricultural landuse in Peninsular Malaysia, Journal of Tropical Forest Science 1(1), 67 - 84.

Hashim,M. and Nadzri, M. I. (2013). Validation of MODIS data for localized spatio-temporal evapotranspiration mapping, *8th International Symposium of the Digital Earth (ISDE)*, 26-29 August 2013, Sarawak, Malaysia