

Assessing water availability over peninsular Malaysia using public domain satellite data products

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Abstract. Water availability monitoring is an essential task for water resource sustainability and security. In this paper, the assessment of satellite remote sensing technique for determining water availability is reported. The water-balance analysis is used to compute the spatio-temporal water availability with main inputs; the precipitation and actual evapotranspiration rate (AET), both fully derived from public-domain satellite products of Tropical Rainfall Measurement Mission (TRMM) and MODIS, respectively. Both these satellite products were first subjected to calibration to suit corresponding selected local precipitation and AET samples. Multi-temporal data sets acquired 2000-2010 were used in this study. The results of study, indicated strong agreement of monthly water availability with the basin flow rate ($r^2 = 0.5$, $p < 0.001$). Similar agreements were also noted between the estimated annual average water availability with the in-situ measurement. It is therefore concluded that the method devised in this study provide a new alternative for water availability mapping over large area, hence offers the only timely and cost-effective method apart from providing comprehensive spatio-temporal patterns, crucial in water resource planning to ensure water security.

1. Introduction

Remote sensing satellite missions over the past decade has seen great success in generating and sharing high level products, particularly for applications related to environmental management and natural resources. Among them are the TRMM (Tropical Rainfall Measurement Mission) and MODIS (Moderate Resolution Imaging Spectro-radiometer) satellite data products. Numerous studies related water resources using both TRMM and MODIS data data sets as the main input for precipitation and actual-evapotranspiration, respectively [1, 2, 3, 4]. TRMM data were used to estimate recharge potential of fresh water shallow aquifers for their sustainable management of water resources in arid ecosystem. Water balance analyses for planning for water resources have also successfully in studies using TRMM and MODIS along with Gravity Recovery And Climate Experiment (GRACE) satellite data sets [2].

Data processing involved in retrieving precipitation rate from radar data of the TRMM is quite elaborate involving data pre-processing of level 0 data, up to the validation and calibration of the outputs to the corresponding in-situ measurement. Such studies [5, 6, 7, 8] are now considered

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matured. Similarly for deriving AET from MODIS data having same data processing trends [9]. In fact in Malaysia such studies have also noted in [10, 11].

Higher level satellite data products are now created using specific algorithms for specific biophysical parameters such rainfall-related information from TRMM and AET from MODIS data products. Usability of such higher level products still require one to address the local validation and calibration for operational applications but avoid the most bulk of data pre-processing where bulk of the uncertainties due to systematic and random errors persist. However, there are less studies addressing the local validation of these satellite biophysical products, apart from devising a local calibration method. This paper highlights the assessment of TRMM and MODIS higher level products for determining water availability. The focus is emphasized on absolute accuracy of water yield over large watershed from multi-temporal data sets, and finally this paper concluded how this study could contribute the digital earth environment.

2. Materials and methods

2.1. Test site

The study area comprised all watersheds in peninsular Malaysia. The climate is governed by the yearly alternation of the northeast, southwest monsoons and inter monsoon. The Northeast Monsoon occurs from November till March, and the Southwest Monsoon between May and September. The Northeast Monsoon brings heavy rains and extensive flooding to the east coast of Malaysia Peninsular. The rainfall is dominantly govern by wet and dry climate, and also renewable of water resource that area. The amount of rainfall is much influenced by monsoon system at meso-scale level and orographic convective system and land-sea interactions at local level.

2.2. Satellite precipitation data –TRMM products

The TRMM 3B42.v6 three-hourly data were used to generate precipitation information; downloaded from <http://disc.sci.gsfc.nasa.gov/site> for study period June-2000 to July 2010. The TRMM rain rate data are available at a temporal resolution of three-hourly with spatial resolution of $0.25^\circ \times 0.25^\circ$ latitude–longitude grid [12]. The corresponding rainfall data for representative rain gauge stations within the research area were obtained from the Malaysia Meteorological Service (MMS) - Set 1: Jul 2000 – Jun 2005; and the Department Irrigation and Drainage Department (DID) - Set 2: Jul 2005 – Jun 2010.

2.3. Satellite AET - MODIS products

The AET for entire study area for June 2000 to July 2010, were derived using derived using MODIS satellite product NDVI (normalised difference vegetation index). The AET derivation method is based on [13], monthly composite NDVI data used, where the data sources are obtainable from <http://neo.sci.gsfc.nasa.gov/>.

2.4. Data processing for water availability

The downloaded TRMM product sets were transformed into ASCII format files containing both the geographical location coordinates and the rainfall intensity for each location. Subsequently, exported to the *.tiff data format ready for further processing within a GIS platform. We used ArcGIS 9.2 to define coordinate system for TRMM data sets to WGS84 and sub-set to study area (1° - 7° N and 99.5° - 104.5° E). Then, monthly and yearly rainfall also derived from TRMM data sets over the study area for the period Jul 2000 –Jun 2010.

The TRMM monthly rainfall (Jul 2000-Jun 2005) was linearly regressed against in-situ observation obtained from MMS Set 1, yielding the slope coefficient and constant used for calibrating the entire TRMM data set. To validate the calibrated data, in-situ DID Set 2 (Jul 2005 – Jun 2010) data were

used to determine the accuracy by root mean square error (RMSE). The calibrated TRMM data sets and the derived AET were then input into the water-balance analysis, where this computation is carried in ArcGIS system.

3. Results and discussions

3.1 Calibration and validation

Figure 1 illustrates the regression output of the in-situ (set 1) against the corresponding TRMM data set, best shown with $y = 0.9x + c$, ($R^2 = 0.71$, $P < 0.0001$, $n = 1337$), where y is calibrated TRMM data set, $x =$ bias coefficient, and c is an offset value $= 7.9094$. An independent test to further validated the calibrated TRMM output yield $RMSE + 83\text{mm}$ ($n = 2308$).

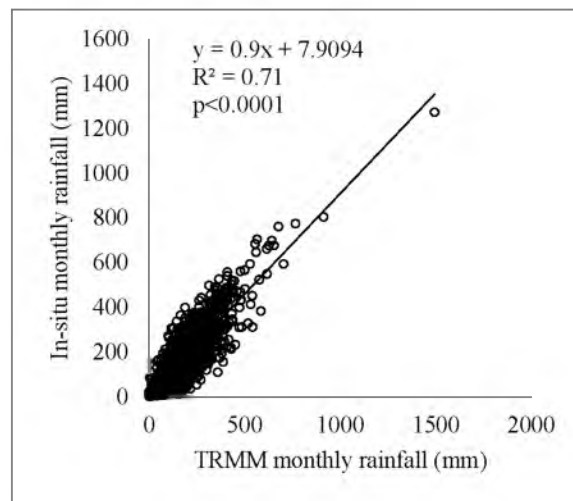


Figure 1: TRMM monthly rainfall against corresponding gauges, used as basis data calibration.

3.2 Spatial distribution of rainfall mapping

TRMM data provided quantitatively rainfall value over every point on earth surface without interpolation process. This gives an advantage. During the study period from Jul 2005 to Jun 2010, the annual average rainfall over the study area was 2439 mm, compared the country's average value for 1961–1990 is 2490 mm [14]. TRMM recorded -2% lower average rainfall year. The annual rainfall for period Jul 2005-Jun 2006, Jul 2006-Jun 2007, Jul 2007-Jun 2008, Jul 2008-Jun 2009 and Jul 2009-Jun 2010 were 2420mm, 2353mm, 2430mm, 2470mm and 2520mm, respectively (Figure 2). Hence, they were -5.5% to 1.2% from yearly average. *El Nino* phenomena expected causes for low rainfall for period Jul 2006-Jun 2007.

3.3 Distribution of water yield

At national level, during the study period from July 2005 to June 2010, the annual average water yield over the study was 1294 mm, whereas the country average value for were 1210mm [14] and 1185mm. It was only 7 and 9% above-average annual water yield. The annual water yield for period July 2005-June 2006, July 2006-June 2007, July 2007-June 2008, July 2008-June 2009 and July 2009-June 2010 were 1278mm, 1205mm, 1279mm, 1328mm and 1380mm, respectively. These are -0.4% to 14% and

1.7% to 16%, against annual yield, respectively. El Nino phenomena expected causes for low water availability for period July 2006-June 2007 (see Figure 2).

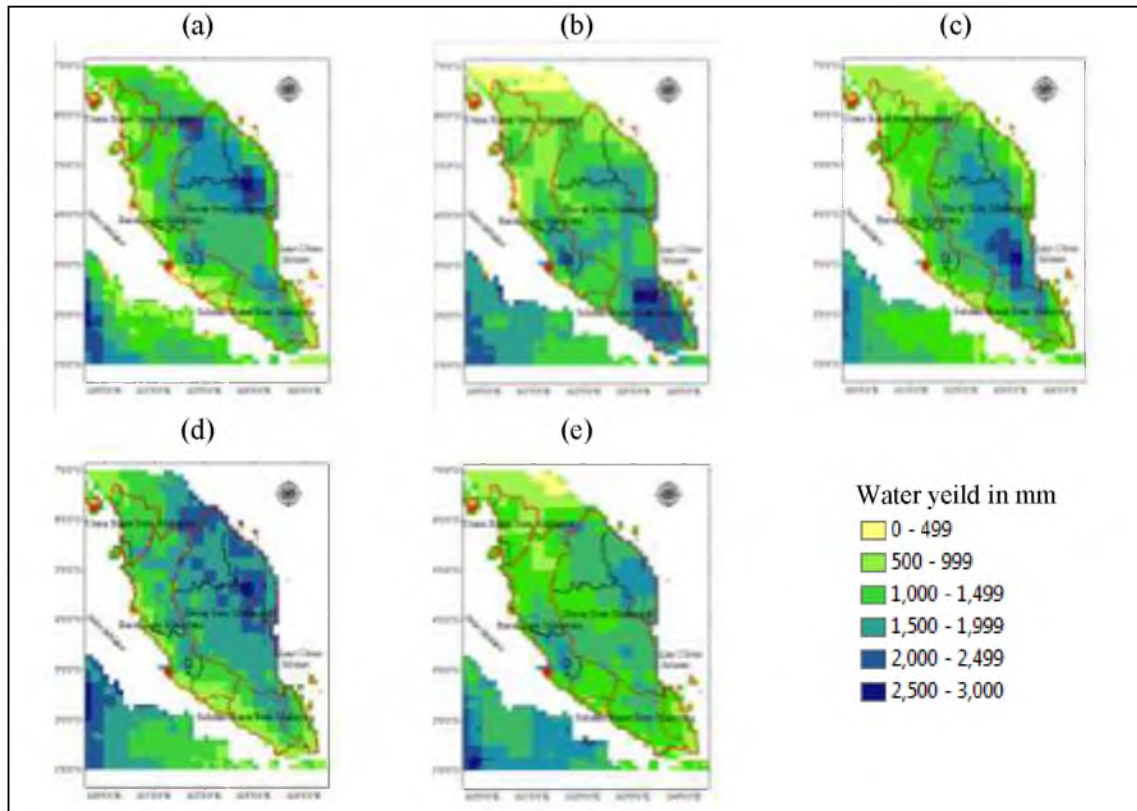


Figure 2. Estimated annual water yield derived fully from satellite data products: a) 2005-2006; b) 2006-2007; c) 2007- 2008; d) 2008-2009; and e) 2009-2010.

Monthly water availability during the study period were also independently compared against selected area of Cameron Highlands District (East Malaysia Region - Central Zone), Mukim Hulu Kuantan (East Malaysia Region), Gua Musang District (East region of Malaysia Peninsular) and Gombak (Western Region Malaysia Peninsular). The TRMM-derived estimation again reported a good agreement with selected basin flow rate ($R^2 = 0.50$, $p < 0.001$).

4. Conclusion

The devised methodology has provided an undeniably best alternative method, that relies fully on satellite higher-level products. It was also a cost-effective method as these data are from public-domain satellite sources. In term of the reliability of outputs, it was noted the good agreement between satellite-based and the gauge-based water yield. This allows best analysis of spatio-temporal water availability for water resource planning, in tandem with sustainable development within the watershed. In the larger context of this research, it provides a platform the devised method to the

digital earth environment to contribute for sustainable management of watershed to ensure long-term water security

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