Challenge and opportunities of space-based precipitation radar for spatio-temporal hydrology analysis in tropical maritime influenced catchment: Case study on the hilly tropical watershed of Peninsular Malaysia

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Challenge and opportunities of space-based precipitation radar for spatio-temporal hydrology analysis in tropical maritime influenced catchment: Case study on the hilly tropical watershed of Peninsular Malaysia

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Abstract. This paper highlights two critical issues regarding hilly watershed in Peninsular Malaysia; (1) current status of spatio-temporal condition of rain gauge based measurement, and (2) potential of space-based precipitation radar to study the rainfall dynamics. Two analyses were carried out represent each issue consecutively. First, the spatial distribution and efficiency of rain gauge in hilly watershed Peninsular Malaysia is evaluated with respect to the land use and elevation information using Geographical Information System (GIS) approach. Second, the spatial pattern of rainfall changes is analysed using the Tropical Rainfall Measuring Mission (TRMM) satellite information. The spatial analysis revealed that the rain gauge distribution had sparse coverage on hilly watershed and possessed inadequate efficiency for effective spatial based assessment. Significant monthly rainfall changes identified by TRMM satellite on the upper part of the watershed had occurred occasionally in 1999, 2000, 2001, 2006, and 2009 went undetected by conventional rain gauge. This study informed the potential and opportunities of space-based precipitation radar to fill the gaps of knowledge on spatio-temporal rainfall patterns for hydrology and related fields in tropical region.

1. Introduction

Spatio-temporal rainfall changes at tropics had raising concern among scientists. However, comprehensive studies at catchment scale of Southeast Asia where the combined regional and local factor is a tough task to be carried out due to the inherent limitations of rainfall data sources especially in the remote, upper part and difficult access of the watershed. Often the hydrological analysis and reports informed less spatial information [e.g. 1] regarding those areas which are getting more significant for the regional application. Therefore, an alternative support is strongly recommended to improve the spatio-temporal rainfall analysis and fill the gaps of knowledge in this watershed environmental niche.

The opportunities provides by the space-based precipitation radar is significant to satisfy the raising issues. It provides temporal measurement, higher spatial gridded information, cost effective and convenient data inter-operability. There are increasing open sources options for such information from wide range of satellites such as Tropical Rainfall Measuring Mission (TRMM). Their potential to the local watershed application had been immensely studied by many researchers for the past decades [e.g.,

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2,3]. With the launch of the new Global Precipitation Mission in 2014, there is bright prospect of such rainfall measurement options to become one of the rainfall information sources at global scale. Nevertheless, comprehensive use of this kind of data at local Peninsular Malaysia especially in upper hilly watershed remained less explored.

There are two main issues addressed in this paper. First is the current spatio-temporal condition of rain gauge measurement in hilly catchment of Peninsular Malaysia and second is to explore how the space-based precipitation data could support to anticipate the sparse coverage and data inter-operability issues. In correspondence of both issues, two preliminary analyses were carried out. First, the spatial distribution and efficiency of rain gauge in hilly forested catchment of Peninsular Malaysia is evaluated with respect to the land use and elevation information using Geographical Information System (GIS) approach. Second, the spatial pattern of rainfall changes is analysed using the TRMM satellite information.

2. Materials and Method

2.1 Study Site Description

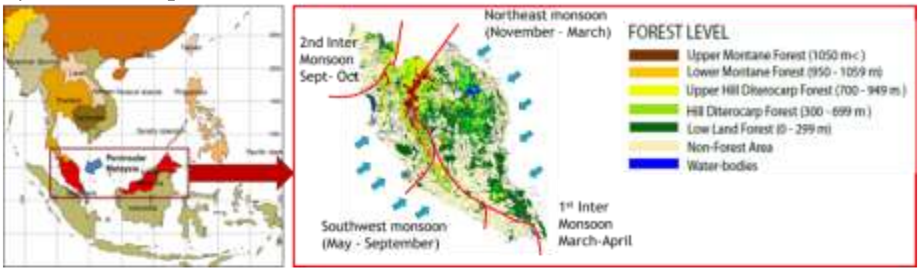

Figure 1. Precipitation zone in Peninsular Malaysia and forest elevation (Source for Precipitation Zone: [20] Dept. of Irrigation and Drainage).

Peninsular Malaysia is located at Southeast Asia and experiencing humid tropics climate through the year. The hilly and mountainous catchment in Peninsular Malaysia is highly dominated by dipterocarp and montane forest. The elevation ranged from 400m up to the highest peak of 2191m of Mount Tahan. The rainfall distribution pattern over Peninsular Malaysia is strongly influenced by the regional seasonal wind flows [4]. Rainfall patterns experienced by Peninsular Malaysia are determined by the two main monsoon seasons, the northeast monsoon (November to March) and southwest monsoon (May to September). From 1977 to 2001, Peninsular Malaysia produced about 580 cubic kilometres of natural renewable water resources where 97.6% were generated from the surface water [5]. Figure1 showed the study area and its hydrological description.

2.2 Using GIS Approach for Rain Gauge Spatial Distribution and Efficiency Analysis in Hilly Catchment

Major hilly and mountainous watershed in four states namely Kelantan, Selangor, Perak, Pahang, and Terengganu were analysed. 85% of hilly watershed is located in these four states. Total of 571 rain gauge information was collected from various sources, mainly Meteorological Department and Department of Irrigation and Drainage. The first step of this analysis is determining the spatial rain gauge distribution over the watershed areas by using land cover types and elevation. Cross tabular overlay analysis between rain gauge against the land use and forest elevation is implemented.

The next step is to analyse the efficiency of the rain gauge which located in the hilly catchment or nearby (~1.5km radius distance). Five indicators were then used to determine the efficiency of those rain gauges. Those indicators are; (i) Telemetry, (ii) Data logger, (iii) Automatic Operation, (iv) Ownership and (v) International Organization of Standardization (ISO) status. The score of each indicator is then plotted using radar chart analysis. A perfect score of 50 indicates 100% efficiency of the rain gauge network system. Figure 2a showed the summary of the methodology flow.

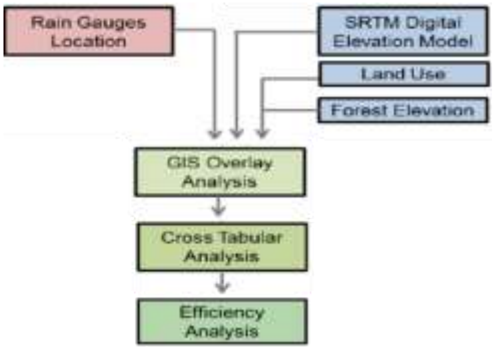

Figure 2a. GIS approach method for rain gauge distribution and efficiency analysis.

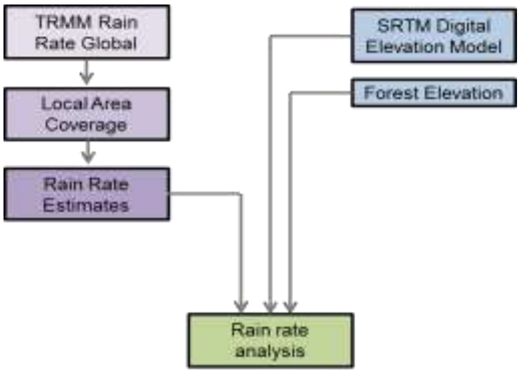

Figure 2b. Rain rate changes analysis using TRMM data.

2.3 Precipitation Change Analysis using Space-based TRMM Precipitation Radar Data
13 years of satellite observation period from 1998 to 2010 were acquired from the TRMM for this analysis. TRMM 3B43 Version 6 global data product is subset to the local area coverage and projected to the local projection and coordinate system. Then, the monthly rain rate is obtained and the annual basis co-efficient of variation (COV) is computed. Long term in-situ rainfall and evaporation records (>25 years) are also included for supporting the satellite analysis. Figure 2b illustrates the processing flow of the methodology.

3. Results

3.1 Rain Gauge Distribution Spatial Analysis against Land Use and Elevation

Table 1. Rain gauge distribution vs. major land cover.

Landuse	Rain Gauges (Count)	Percentage (%)
Forest	67	12
Agriculture	370	65
Built Up	134	23

Table 2. Rain gauge distribution vs. forest elevation

Forest Types	Forest Elevation (m) *a.s.l	Rain Gauges (Count)	Percentage (%)
Upper Montane	>1200	9	13
Lower Montane	950-1200	3	4
Upper Hill Dipterocarp	750-950	4	6
Hill Dipterocarp	300-750	6	9
Lowland	<300	45	68

Table 1 presents the general classification of rain gauge distribution over major land cover in the four states. Based on the GIS spatial analysis, it showed that the proportion rain gauges located in the forested areas of the watershed were only 12% (Table 1). Further analysis indicates that apart from this 12% proportion, rain gauges coverage over higher elevation forest (300 – 1200m) experienced sparse distribution (Table 2). Spatial analysis also revealed that the hilly watershed in the west part of Peninsular Malaysia is more sparsely monitored compared with the east part. This is confirmed with a detailed view on three major hilly catchments in Kuala Kangsar, Hulu Perak and Kinta where most rain gauges were located at non-forested areas (Figure 3).

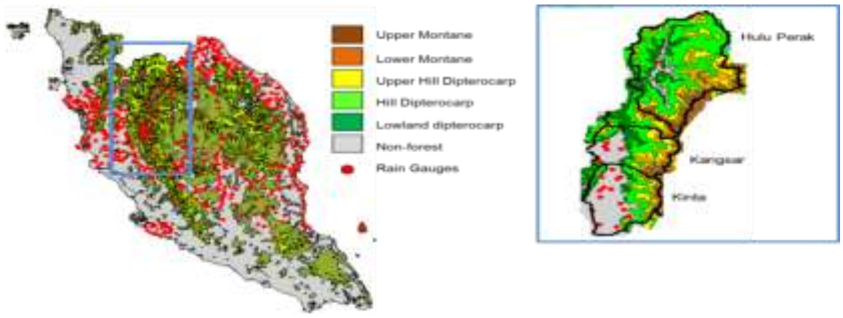

Figure 3. Rain gauges distribution on different forest elevation in Kelantan, Perak, Selangor, Terengganu and Pahang.

3.2 Rain Gauge Efficiency in Hilly Watershed Areas

Figure 4 showed the radar chart analysis on the efficiency of the rain gauge located exactly in the hilly watershed areas and 1.5km from it. The figure illustrates imbalance scores in all indicators especially the ISO standard. The overall performance of the rain gauge was only 40% (Table 3). Considering that one of the most critical criteria is the ability of rain gauge to log and transmits data via telemetry, only 63% from the rain gauge distribution or 14 rain gauges is available to provide rainfall data effectively. This analysis indicates that effective assessment of hilly watershed is a very challenging tasks due to intangible daunting condition to obtain a rainfall information.

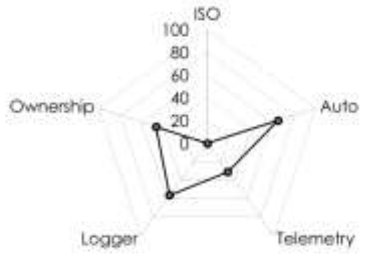

Figure 4. Radar chart analysis on the efficiency of rain gauges located in the hilly watershed and 1.5km radius. The performance of each indicator is scaled from 0 to 100%.

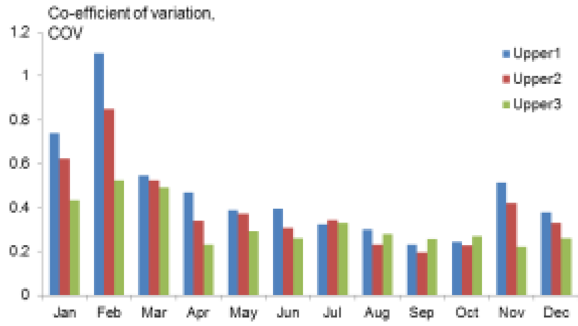

Figure 5. Monthly basis co-efficient of variation (COV) on rain rate derived from TRMM at three different upper area.

From the results, it strongly suggests that there are gaps that must be fulfilled in the rainfall measurement especially on the remote, thick, and upper hilly areas forested watershed. By referring to the recent evidence of the local rainfall spatial variations changes [6,7] it showed that the local hydrological patterns become more unpredictable and intensive studies is strongly needed.

3.2 Hilly Watershed Rain Rate Changes Analysis

From the previous analysis in section 3.1, Hulu Perak watershed is one of the areas which had less rain gauge distribution as well as having low rain gauge efficiency scores. It was one of a critical catchment in West Peninsular Malaysia. TRMM satellite data was used to analyse the rain rate which limited to be portrayed by rain gauge information. Monthly basis *COV* indicated that for the past 13 years significant rainfall pattern changes was identified in the month of January and February (Figure 5). Map had showed that obvious changes occurred at the upper part of the watershed which elevation more than 1000 meter and gradually lower towards the lower elevation (Figure 6). Since January and February are not the typical wet season of this region, there are possibilities that the changes may due to the influence of external continental factors [8] or seasonal local monsoon shifting changes.

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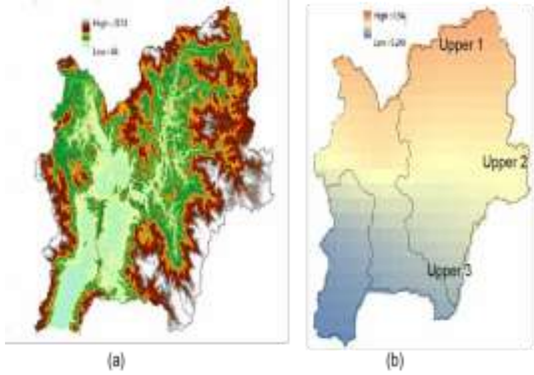

Figure 6. (a) Hulu Perak watershed elevation, (b) TRMM rain rate co-efficient variation COV in the month of February (1998-2010).

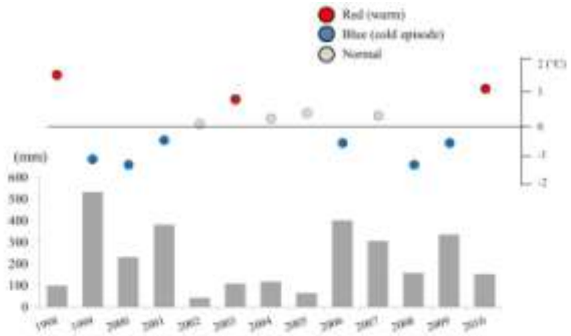

Figure 7. Total satellite derived rainfall in January and *Global Oceanic Nino Index (ONI) from 1998 to 2010. (*Source: [21] NOAA National Weather Service – Climate Prediction Center).

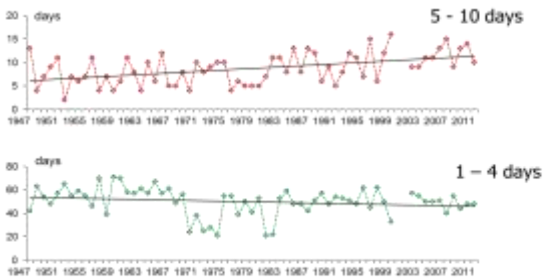

Figure 8. Time series of rainy days pattern from 1947-2011

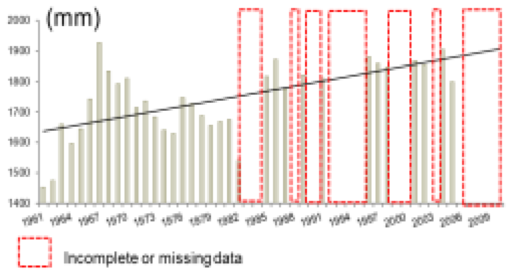

Figure 9. Time-series of the evaporation from 1961 to 2009.

Further analysis with the global Oceanic Nino Index (ONI) record from the Climate Prediction Center of the National Weather Service US had indicates that the increased rainfall amount in the January and February coincide with the high magnitude ocean cold due to La-Nina event in 1999, 2000, 2006 and 2008 (Figure 7). La Nina phenomena did resulted wet condition in Southeast Asia [10] and in 1999 several other areas in the world did severely affected [11]. On the other hand, significant evidence of local climate change also had been detected through the individual rain gauge analysis term of increased of longer rainy days (Figure 8) and increased evaporation (Figure 9).

4. Discussion

The spatial rain gauge analysis obtained in this study suggest that appropriate utilization of various spatial data and satellite precipitation information in GIS environment can be effective supports in the hilly watershed productivity assessment. The rain gauge spatial distribution and efficiency reports can be utilized by local responsible authority. The output of hilly watershed rainfall changes in this study also confirmed that the extent impact of climate change at local scale has increased their variability varies at spatial location and time. For records, there are growing trend of frequent water induced disaster reported for the past 15 years [e.g. 12,13]. Most two recent disasters were flood due to extreme heavy rainfall events in hilly watershed of Cameron Highlands [14] and second are the lowland high urban settlement areas of Ipoh [15].

Successful utilization of space-based precipitation radar which set for global scale basis measurement at local scale environment requires intensive validation and calibration efforts. Even though the preliminary assessment of TRMM rain rate data in Peninsular Malaysia suggests positive correlation with discrete rain gauge [16], however its actual accuracy when converted into rainfall estimates are less defined. Moreover, the rainfall intensity, pattern, and seasonality in this region are highly dynamics [6,7]. A direct use of space-based precipitation radar data into hydrology models revealed that uncertainties can be varies within geographically condition and latitude [9,17,18,19].

5. Conclusion

The current status of rain gauge distribution spatial analysis in major hilly watershed in Peninsular Malaysia and the potential of space-based precipitation radar are presented in this study. The spatial analysis revealed that the rain gauge distribution had sparse coverage on hilly watershed and possessed inadequate efficiency for effective spatial based monitoring. Significant monthly rainfall changes on the upper part of the hilly watershed occurred occasionally. The phenomenon can be associated with the cold temperature La-Nina events. The study informed the potential and opportunities of space-based precipitation radar to fill the gaps of knowledge on spatio-temporal rainfall behavior for hydrology and related fields.

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