Remote sensing entropy to assess the sustainability of rainfall in tropical catchment

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Abstract. This study demonstrated the utility of entropy computation using the satellite precipitation remote sensing data to assess the sustainability of rainfall in tropical catchments. There were two major issues need to be anticipated in monitoring the tropical catchments; first is the frequent monitoring of the rainfall and second is the appropriate indicator that sensitive to rainfall pattern changes or disorder. For the first issue, the use of satellite remote sensing precipitation data is suggested. Meanwhile for the second issue, the utilization of entropy concept in interpreting the disorder of temporal rainfall can be used to assess the sustain ability had been successfully adopted in some studies. Therefore, we hypothesized that the use of satellite precipitation as main data to compute entropy can be a novel tool in anticipating the above-mentioned conflict earlier. The remote sensing entropy results and in-situ river level showed good agreement indicating its reliability. 72% of the catchment has moderate to good rainfall supply during normal or non-drought condition. However, our result showed that the catchments were highly sensitive to drought especially in the west coast and southern part of the Peninsular Malaysia. High resiliency was identified in the east coast. We summarized that the proposed entropy-quantity scheme was a useful tool for cost-effective, quick, and operational sustainability assessment. This study demonstrated the utility of entropy computation using the satellite precipitation remote sensing data to assess the sustainability of rainfall in tropical catchments.

1. Introduction

Tropical catchments are facing serious threat from changing climate especially drought and spatio-temporal rainfall pattern disorder (Van Loon & Laaha, 2015; Yuhaslin, 2012). There were two major issues need to be anticipated; first is the frequent monitoring of the rainfall and second is the appropriate indicator that sensitive to rainfall pattern changes or disorder. Depending on the rain gauge to perform frequent and operational monitoring is sufficing, however, that was not the option for region that experienced data-conflict situation (DCS). Data-conflict situation can be defined as region that facing either one or more of this problems which includes sparse ground measurement, undefined quality of ground data, limited data sharing, and limited data inter-operability. DCS were commonly found in developing countries or rural areas or remote areas (Mustake, 2003). To
resolve this conflict, an alternative measurement is necessary. We suggest the use of satellite precipitation as substitute.

Unlike precipitation radar, satellite remote sensing that carried precipitation radar provides cost-effective, consistent, and fine resolution measurement. Satellite precipitation has evolved significantly where the latest Global Precipitation Mission (GPM) satellite provide half an hour temporal resolution and 0.1 degrees resolution measurement (Hou et al. 2014). The most operational satellite precipitation, Tropical Rainfall Measuring Mission (TRMM) has been widely used to support from global to microscale hydrology studies (e.g., Mahmud et al., 2015, Collischonn et al., 2008). Moreover, their status as public domain data which enabled user to retrieve and utilized it for non-commercial purpose meet the status quo of our first issue of DCS.

Regarding our second issue, most of the drought based indices or techniques to monitor rainfall surplus or deficit, were centralized only to quantity. Another drawbacks for the established index such as Standard Precipitation Index (Gutman, 1999) or Palmer Index (Gutman, 1991) is their reliance to the historical data to obtain good prediction results. This is another disadvantage condition for areas with DCS. To resolve this, a decent approach introduced by Kawachi et al. (2001) can be helpful. They had successfully used the entropy concept in interpreting the disorder of temporal rainfall and later integrate it with the actual rainfall quantity to create sustainability matrix. We hypothesized that if this approach can be repeated using the precipitation data acquired from remote sensing satellite, it can anticipate the two main issues that we are facing earlier.

Therefore, we conducted a study to test the hypothesis. The main objective is to investigate the utility of entropy computation using the satellite precipitation remote sensing data to assess the sustainability of rainfall in tropical catchments. This study consists of three major phases, first is the computation of both rainfall and entropy. After that, the sustainability matrix will be constructed. The third phase consist of verification with the in-situ data. We will consider two case condition in this study, one is normal (non-drought) and second is drought. This is to ensure that our technique is sensitive to represent the extreme variation of rainfall disorder. Peninsular Malaysia is selected as our experimental site. This study would be useful as support tool to measure the productivity of tropical catchments.

2. Material and method

2.1 Data

2.1.1 Satellite precipitation data. We used satellite precipitation from Tropical Rainfall Measuring Mission as primary data. This data was selected due to its high operational condition; fine spatial resolution and high temporal coverage. The monthly rain rate product namely TRMM 3B43 will be used. It will then have converted into total monthly rainfall by multiplying with the corresponding number of days in each day. Two datasets were created, one is during non-drought condition (year 2001) and another is during intense drought (year 1998). This year was selected based on the global anomalies given by National Observation Ocean Administration (NOAA).

2.1.2 Geo-location of reservoir and catchments. The location of the reservoirs and catchments were obtained from the hydro-spatial database of Geoscience and Digital Earth Centre, Universiti Teknologi Malaysia. Those data were in geospatial layers of ArcGIS shapefile format. The reservoir layer consists of the shape of reservoir and its attributes including area, perimeter and size. Meanwhile, the boundary lines of each reservoir’s catchment areas were obtained from separate layer.

2.2 Water catchment and reservoir in Peninsular Malaysia

Peninsular Malaysia is situated at the center of Southeast Asia, neighboring Thailand at north, Singapore at the southern and facing the Sumatera Island of Indonesia on its west. It has humid tropical climate with annual rainfall average is 2200mm and temperature ranging from 26-33 degree Celcius. Peninsular Malaysia humid tropical climate was heavily influenced by Asian monsoon.
Relatively, the period from February to April is the driest (~150mm/month) where convective rainfall dominates. It is followed then by the wet period starting roughly in June until September (~220mm/month) resulted by the southwest monsoon. November to January is the wettest months (~320mm/month) due to the moist air masses from the northeast monsoon. The freshwater resources were entirely depending on surface reservoir (95%), primarily lakes (Fig.1). There are about 91 reservoirs in Peninsular Malaysia. The largest reservoir is Kenyir (36844 hectares) and their catchment reached 500 square kilometer. The growing demand and frequent drought has led to critical water supply conflict. An effective monitoring of the catchment productivity is crucial to support sustainable development.

2.3 Calculating the entropy value from the satellite precipitation

The monthly rainfall estimates were used as the primary input to compute the entropy value. Because the tapping behavior of the reservoir was highly characterized by monsoon season that occupied specific months, therefore it is significant that the monthly rainfall was used. The entropy computation to rainfall developed by Kawachi et al. (2001) was adopted. The following equation is described in equation below.

\[ E = \sum_{i=1}^{n} \left[ \frac{r}{R} \log_2 \frac{r}{R} \right] \]  

Equation 1

where \( R \) is the annual rainfall from satellite estimates, \( r \) is the monthly rainfall from satellite.

In interpreting the entropy, the higher value would indicated consistent order of the temporal variation of heavier rainfall. The low entropy value then suggest that the temporal variation is highly disorder with depleting quantity.

2.4 Validation of the remote sensing entropy and rainfall

To verify the remote sensing derived entropy value, we observed the in-situ river discharge. Two stations were selected where each represent different monsoon climate region in Malaysia (Fig. 1).
Low satellite derived rainfall and entropy would indicate a low discharge and vice versa. We evaluated the scenario during the drought and non-drought.

2.5 **Quantity-entropy matrix to assess the sustainability of the catchment**

We used the quantity-entropy matrix to graphically assess the sustainability of the catchments. There were four regions in this 2D matrix, Class 1 to 4. Each region in this matrix represents different scenarios for the catchment. Table 1 provides the detail. Because we plot two sets of samples in different scenario (drought and non-drought), this entropy hypothetically could indicate the condition of the catchments more intensively besides detecting the rainfall deficit. The changing disorder of the temporal rainfall especially the skew distribution can influence the infiltration of the rainfall which affects the quantity of the reservoir’s volume.

| Class | Description |
|-------|-------------|
| 1     | The rainfall is considered as abundant and perennially available |
| 2     | The rainfall quantity is assumed to be large, however characterized by concentrated heavy rainfall on certain period. Plausible to experience flood. |
| 3     | The rainfall is assumed to be moderate but perennial |
| 4     | The water resources is considered low and not perennially available |

**3. Results**

Table 2 informed us that drought had affected the sustainability of the rainfall in majority catchments in Peninsular Malaysia. During the drought, 63% of the catchment were classified into class 4, compared to only 14% during the non-drought condition. Figure 2 had graphically support this claim. Only 4% of the class 1 catchments remained including Bernam, Batu, Tinggi and Selangor catchments (Figure 3). Maps of the catchments sustainability class indicated that the 1998 drought had affected most of the areas (Figure 3). The intense areas that were severely affected was the southern where most of the catchments score dropped from class 1 and 2 to class 4. The less affected area is the east coast.

Both in-situ river level in the southern and west Peninsular Malaysia agreed with the entropy-quantity matrix scores (Fig. 4). In Sg. Lenggor, the river level for the first six months was relatively low compared to the non-drought season. This finding was in common with Sg. Rui in the northwest that experienced decreasing entropy-quantity score. This evidence had indicated that the remote sensing based computation of entropy and rainfall quantity was capable to represent the actual condition on the site although the observation was having non-direct contact with the subject.

| Condition | Class 1 | Class 2 | Class 3 | Class 4 |
|-----------|---------|---------|---------|---------|
| Non drought | 36      | 30      | 13      | 13      |
| Drought   | 4       | 15      | 15      | 58      |
4. Discussion

Our results demonstrated that the remote sensing based entropy and quantity was able to assess the sustainability of the catchments and comparable with actual on-site condition. This indicates that by only relying on the satellite precipitation data, a robust evaluation of the catchments productivity can be achieved. In addition, the assessment can evaluate the spatial impact of drought. Critical information regarding its intensity, geolocation and spread can be obtained. Our method can be cost-effective, operational and reliable assists to the respective users (scientist, hydrologist, hydro-engineers, managers, etc.) in supporting the primary observation method of rain gauge or precipitation radar.

Nonetheless, the improvisation was required. Our results needs to be confirmed with larger temporal samples with appropriate partition according to the monsoon season. It is suggested that the weekly and daily rainfall can be taken into account. This might accurately revealed the behavior of the catchments prior to any hydro-meteorological changes. Our main concern is that this early experiment showed promising result and subjected to further studies. Therefore, we recommend that this work to be conducted in the future.

Acknowledgements

The authors would like to thanks all the stakeholders and respective agencies particularly the Department of Irrigation and Drainage for their support regarding the in-situ data. Our utmost gratitudes goes to Universiti Teknologi Malaysia for supporting this study through the potential academic staff grant (QJI30000.2727.02K83) and Ministry of Higher Education awarded national grant (QJI30000.7827.4F773).

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