DETERMINATION OF WATER ORIGIN AND DISTRIBUTION FOR LOWLAND TROPICAL RAINFOREST IN PENINSULAR MALAYSIA

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ABSTRACT

This paper is presenting the isotopes analysis of oxygen (δ18O) and hydrogen (δ2H) for determination of water origin in lowland tropical rainforest at Pasoh Forest Reserve (FR), Peninsular Malaysia. Pasoh FR is located at the drier region in Peninsular Malaysia, therefore changes in rainfall pattern and amount are an important aspect to be investigated to maintain the hydrological cycle in this forest with respect to future climate change. The previous study reveals that the forest maintained stable evapotranspiration even in a prolonged dry season. The aim of this study is to determine the origin of precipitation in this forest with the engagement of stable isotope analysis. We investigated the daily and seasonal variability of stable isotope signatures in precipitation, particularly in relation to the effects of monsoon seasons, rainfall characteristics and larger-scale trends compared with those at nearby Global Network of Isotopes in Precipitation (GNIP) monitoring stations. The findings suggested that the isotopic composition in the study area was the result of a rainout on a larger scale in addition to the local scale and specific rain events. We also use the stable isotope to distinguish the compartmentalisations of precipitation in this forest for determination of forest water use and distribution. It was found that Isotope signatures for water sources of the plants, soil, and stream were all different. This is the initial stable isotope study for this forest. The result would be beneficial to investigate further water usage in the forest as the potential impact of climate change. The information obtained from this study would be also useful as fundamental references for further advancement in forestry research.

Keywords: South-west monsoon, north-east monsoon, antecedent precipitation index, deuterium excess, Global Network of Isotopes Precipitation (GNIP)

INTRODUCTION

In Peninsular Malaysia, rainfall pattern assumed to be among the most important environmental factors determining gas exchanges in a tropical forest (Kosugi et al, 2012). Compared to the Amazonian forest, Southeast Asian rainforest did not experience distinct dry and wet seasons during the year in spite of dry and wet period's occurrences with considerable variability between years (Tani et al. 2003, Kumagai et al. 2005). It is important to trace the stable isotope in precipitation for comprehending vapour sources of a different region or at a specific location. The weathering process of generating condensation is closely related with the abundance stable isotope composition in precipitation. It is also related to the initial conditions in vapour origin which often fluctuates with space and time (Dansgaard, 1953, 1964; Araguas et al. 1998). Stable isotope plays an important role as an environmental tracer for water element serve as indices of site-dependent rainfall and climate characteristics (Fleitmann et al. 2003). The source of rainfall can be detected by the relationship between $\delta^{18}O$ and $\delta^{2}H$ in comparison with Global Meteoric water Line (GMWL). The best-fit equation for the GMWL is denoted with $\delta^{2}H=8* \delta^{18}O+10$ of all the data points as introduced by Dansgaard (1964). The value of 10 is the offset called deuterium excess (d). The global average is 10 but it varies according to local conditions known as Local Meteoric Water Line (LMWL). Increased in deuterium excess of rainwater reflect the addition of re-evaporated moisture from continental basins to the water vapour moving inland (Kondoh & Shimada, 1997). Through isotopes analysis, we can also determine the compartmentalization or distribution of water in the ecosystem.

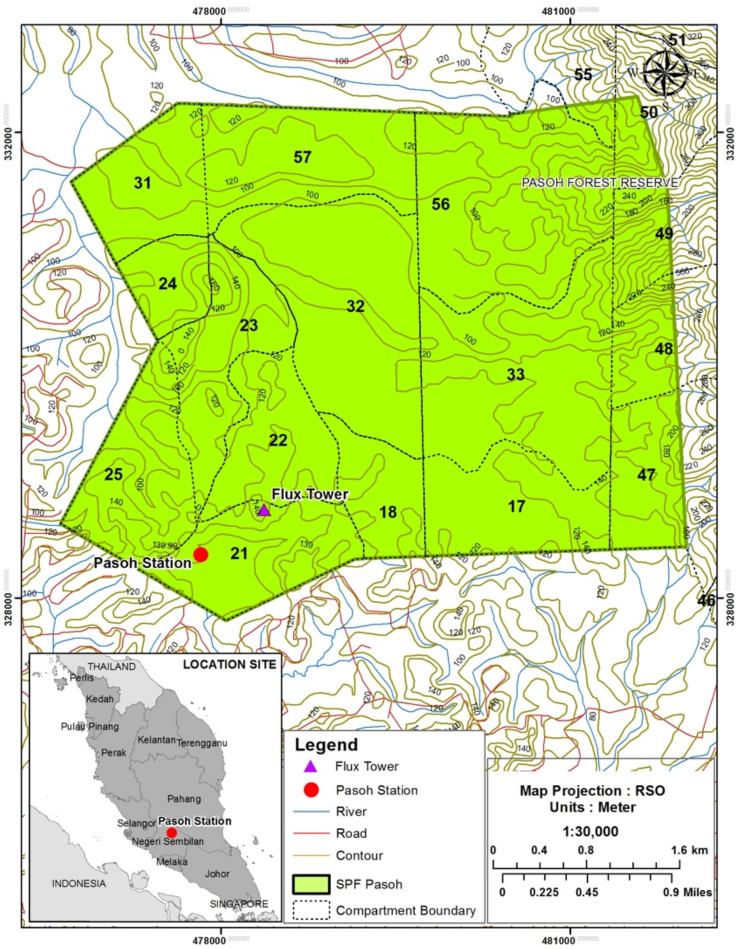
Realizing that tropical forests sometimes stressed due to inter-annual rainfall variability and prolonged dry period (Marryanna et al., 2017), hence it is important to investigate water sources and distribution in the forest. In the other hand, studies in tropical forest reveals that forest maintains evapotranspiration even during the dry period (da Rocha et al., 2004, da Costa et al., 2010, Kume et al., 2011, Kosugi et al., 2012, Marryanna et al., 2017). In this regards, analysing isotopes signatures from rain, soil, plant and stream water could help in understanding how water precipitated in the forest are distributed. The relationship between the isotopic signature of precipitation and weather/climate at a high altitude is relatively well known (Rozanski et al., 1992), however, still less is known about this issue in tropical areas especially in lowland tropical forest. Therefore, the objective of this study is to identify the isotopic signature of rain, stream, and plant and soil water for the determination of water distribution in the forest. The similarities of the isotopes signatures amongst the parameters observed indicate that the same pool of water originated from the same source. Isotope values matching also represent the distribution of water in the ecosystem which indicates how much water from precipitation and which rain event was used for every forest ecosystem components. By doing so, we could separate each water usage in a forest ecosystem with less destructive to the forest. This paper reports the isotope signature of rain, soil, and plant and stream water from lowland tropical forest in Pasoh Forest Reserve (FR).

MATERIALS AND METHODS

SITE DESCRIPTION

The study was conducted at Pasoh FR (Figure 1) located at 2° 58′ N, 102° 18′ E at approximately 75–150 m above sea level. It is a lowland dipterocarp forest with 30–40 m canopy height (emergent trees at ~45 m). The core area (600 ha) of the reserve is primarily lowland mixed dipterocarp forest, consisting of various *Shorea* and *Dipterocarpus* species. Mean annual rainfall based on 19 years data at the study site was 1801 mm (Kosugi et al. 2008) and was characterised by its short duration and high intensity (Noguchi et al. 2003). Mean annual air temperature was 25.4 °C (1997–2011) (Noguchi et al. 2016).

Figure 1: Location of the study site in Pasoh Forest Reserve in Negeri Sembilan, Peninsular Malaysia



RAINFALL MEASUREMENT AND RAINWATER SAMPLING

Rainfall was measured at 30-min intervals using a 0.5-mm tipping bucket rain gauge. Rainwater was collected using storage type and tipping bucket rain gauges in an observatory located 430 m away from the flux tower. The storage rain gauge was buried in the ground to prevent heating which would cause evaporation. A double-layered small-mouth inner glass bottle was also used to prevent evaporation. Water samples for the isotope analysis were collected daily from this bottle at 8–9 a.m. using 10-mL polyethylene terephthalate or glass bottles with no air space to prevent evaporation. We collected 465 samples and eliminated samples that are very small (<0.5 mm) and samples collected more than one day to prevent evaporation effect.

STREAM, SOIL AND PLANT SAMPLING

Stream water samples were collected from an ephemeral stream about 2km distance from the study plot. Samples collected for storm flow (within 24 hours after rainfall) and base flow (no rainfall occurrences within a week). Soil and plant samples were collected at four sampling campaign that covers wet, very wet, dry and very dry periods are surrounding the flux tower at Pasoh FR. Soil samples obtained from different soil depth starting at of 0.05, 0.3, 0.75, 1.5, and 3.0 m. Eight plant species with different height were randomly sampled. The tree species selected from emergent trees to the forest floor trees were *Dipterocarpus sublamellatus, Xanthophyllum stipitatum*, *Ptychopyxis caput-medusae*, *Syzygiium rugosum*, *Diplospora malaccensis*, *Homalium dictyoneurum*, *Baccaurea parviflora* and *Macaranga lowii*. Four samples of each soil depths and plant species for water extraction were collected in every sampling campaign.

WATER EXTRACTION AND STABLE ISOTOPES ANALYSIS

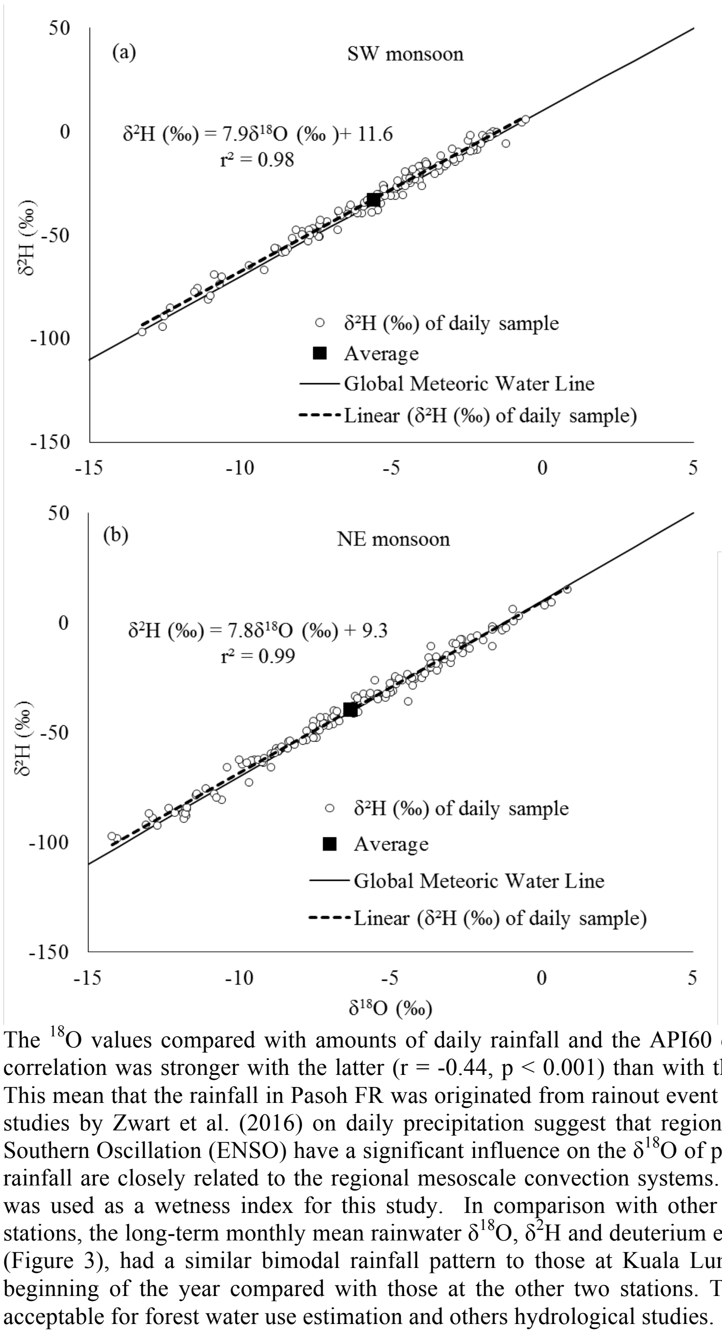
We used cryogenic vacuum distillation system (West et al., 2006) to extract water from soil and plants samples. A cavity ring-down spectrometer (CRDS) with specific analytical precision of 0.06‰ for $\delta^{18}O$ and ≤ 0.11‰ for $\delta^{2}H$ (Katsuyama, 2014) used to analyse isotope composition in the samples.

RESULTS AND DISCUSSION

ISOTOPE SIGNATURE VALUE OF RAINWATER

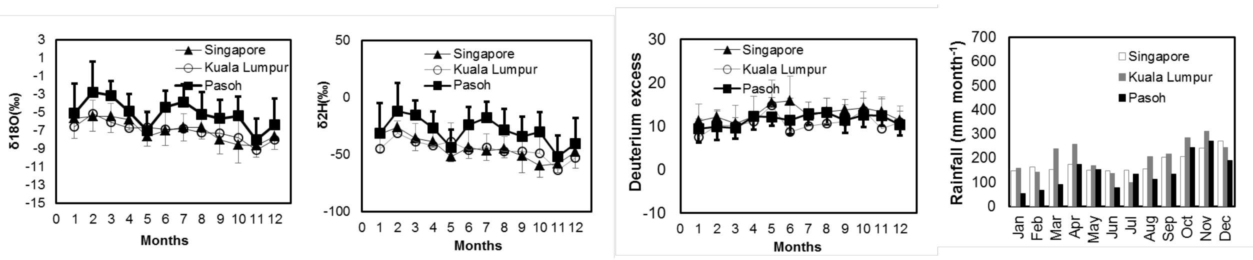
Seasonally, there was no different between isotope signature for southwest (SW) and northeast (NE) monsoon in Pasoh FR. The regression lines between the NE and SW seasons including all data points were indistinguishable. The relationships between δ^2H and δ^{18}O, defined as the Local Meteoric Water Line (LMWL), were δ^2H (‰) = 7.9 δ^{18}O (‰) + 11.6 (r^2 = 0.98) for SW monsoon season and 7.8 δ^{18}O (‰) + 9.3 (r^2 = 0.99) for NE monsoon season (Figure 2). The LMWL for Pasoh FR is almost similar to GMWL but slightly deviated from Peninsular Malaysia LMWL which defined as δ^2H (‰) = 8.0 δ^{18}O (‰) + 13.0 as reported by Shahid & Daud (1998). Based on Belgaman et al. (2016), a slope near 8 is corresponded to the isotopic equilibrium condition. The intercept d (deuterium excess) value was slightly lower during the NE monsoon season than during the SW monsoon season. Both values fit the GMWL well (r^2 = 0.98). Means and standard deviations of daily δ^{18}O, δ^2H and deuterium excess values were -5.90 ± 3.0 (median = -5.40), -35.4 ± 24.1 (-31.5) and 11.7 ± 3.0 (11.9) respectively. Daily means and standard deviations of δ^{18}O and δ^2H values for SW monsoon were -5.60 ± 2.75 and -32.7 ± 22.0‰ respectively and were slightly greater during the SW monsoon than during the NE monsoon season (δ^{18}O = -6.32 ± 3.36‰ and δ^2H = -39.7 ± 26.3‰).

Figure 2: Relationship between δ^2H and δ^{18}O in daily rainfall samples fitted with the local linear regression line and Global Meteoric Water Line, SW = south-west, NE = north-east



The ^{18}O values compared with amounts of daily rainfall and the API60 detected to have significant correlations however, the correlation was stronger with the latter (r = -0.44, p < 0.001) than with the amount of rainfall each day (r = -0.30, p < 0.001). This mean that the rainfall in Pasoh FR was originated from rainout event at the larger scale beside some amount effects. Recent studies by Zwart et al. (2016) on daily precipitation suggest that regional convective activities associated with the El Niño–Southern Oscillation (ENSO) have a significant influence on the δ^{18}O of precipitation in tropical regions, and low δ^{18}O values in rainfall are closely related to the regional mesoscale convection systems. The API60 was calculated as cumulative rainfall and was used as a wetness index for this study. In comparison with other Global Network of Isotopes in Precipitation (GNIP) stations, the long-term monthly mean rainwater δ^{18}O, δ^2H and deuterium excess values and monthly rainfall amount at Pasoh FR (Figure 3), had a similar bimodal rainfall pattern to those at Kuala Lumpur and Singapore, but received less rainfall at the beginning of the year compared with those at the other two stations. Thus, the data obtained from this study is useful and acceptable for forest water use estimation and others hydrological studies.

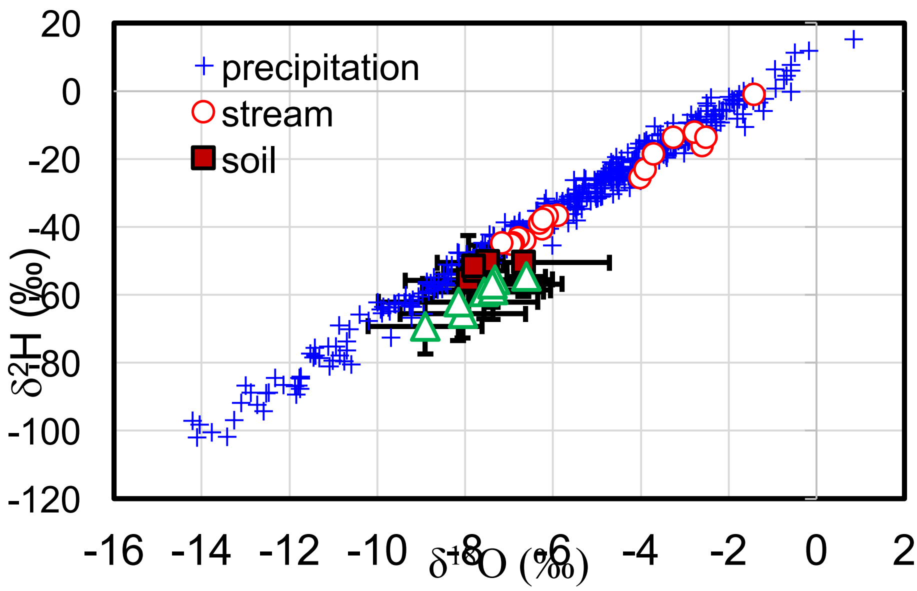
Figure 3: The isotope value of Pasoh FR in comparison with GNIP station at Kuala Lumpur and Singapore



COMPARTMENTALIZATION OF RAINWATER IN THE FOREST ECOSYSTEM

The distribution of isotope signatures of precipitation, stream, soil and plant water is depicted in Figure 4. This provides an overview of how water is compartmentalised for different uses in the forest ecosystem. As seen in figure 4, water from stream, soil and plant are plotted separately from the rainwater LMWL and are separated from each other. The $\delta^{18}O$ values of the occasional stream water samples had a similar trend to the rainwater isotope value (-4.97 ± 1.9, $n = 19$). A substantial fluctuation in $\delta^{18}O$ in stream water was detected, corresponding well to those in precipitation. Considering the relationship between $\delta^{18}O$ and $\delta^{2}H$ (Figure 4), stream waters had isotope values corresponding more closely to rainwater, while isotope signatures in surface soils (0.05 and 0.3 m) and plant water tended to deviate to the right side of the local meteoric water line (LMWL) of rainwater isotopes. This phenomenon indicates the influence of evaporation. The values of isotope signatures for plant water also indicates that most plants did not use the new precipitated water but rather use precipitated water from the previous rainfall event. High-resolution soil and plants samples should be obtained to strengthen this results for future prediction.

Figure 4: Isotope signature of precipitation, stream, soil and plant water depict the compartmentalization of water usage in the forest ecosystem



CONCLUSION

There is no increase in the deuterium excess in rainwater was detected. It means that the rainwater in the study site was not mainly result from re-evaporated moisture added from the land surface. The seasonal isotope values were more closely correlated with the 60-day antecedent rainfall index than with the amount of rainfall each day. In general, the results suggested that rainfall at the study site resulted from the degree of rainout on a larger scale, including upstream and antecedent conditions, in addition to that on a local scale and on specific rain events. The precipitated water also distributed well to mainly surface runoff replenish the stream, soil water and water that are used by the trees for transpiration and its physiology processes. These are the new findings from Pasoh FR and this would be new addition to hydrological processes and scientific literature. Longer term study would be needed to access forest water use especially in occurrence of prolong dry period. The data from this study would be useful for the determination of potential climate change. Isotopes study are increasingly important in helping and supporting policies on water resources management, especially in forested catchment areas. Information generated from this study could also use as a references for agencies that involved in isotope study and could be used as a comparison with available GNIP monitoring stations in Malaysia. The results presented in this paper is limited for the few years observation period and therefore needed longer observation. More frequent soil and plant sampling events would give more precise and comprehensive results.

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