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Seasonal variations of soil moisture regime at dry region of lowland Dipterocarp forest in Pasoh forest reserve, Peninsular Malaysia

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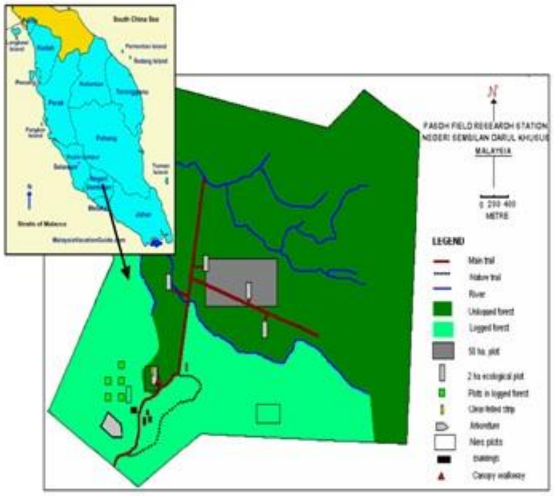
Soil moisture is an essential component in the terrestrial hydrological process and greatly influences nutrient cycle and energy flow. Tropical rainforest sometimes experiences a severe dry period for several months. Soil moisture is responsible for regulating transpiration during this time. This study focuses on the soil moisture in the tropical rainforest by determining soil water content at 6 ha Pasoh Reserve Forest, Negeri Sembilan, Peninsular Malaysia. The study area is located within the drier area in Peninsular Malaysia and therefore is suitable for assessing soil moisture fluctuation during the dry and wet seasons. We measure soil moisture from 39 grid points using Amplitude Domain Reflectometry (ADR-type) soil moisture profile probe from a different soil depth at 0.1, 0.2, 0.3, 0.4, 0.6 and 1.0 meter monthly. This study aims to determine the seasonal soil moisture fluctuation in the Pasoh Forest Reserve as the effect of monsoon season. During the Northeast monsoon season between October 2019 to March 2020, soil water content was higher than the other months of the year. October shows the most rainfall, amounting 364.77 mm month-1. Expectedly, at all soil depth, the moisture revealed the higher as the rain is at most. The soil moisture also increased significantly with a deeper soil depth at 1m, compared to shallower soil depth. This study could be used as a model for developing forests associated with soil moisture and the ecological character of the tropical forest.

Keywords: Soil moisture, Rainfall, Tropical forest, Principal Component Analysis (PCA), Monsoon season

INTRODUCTION

Soil is the crucial element of resource in the ecosystems. Soil moisture can be described as the amount of water in the soil. The awareness of soil moisture and gaining reliable data are essential for many applications such as agricultural production, forestry, drought monitoring and others (Choi, Jacobs, Anderson, and Bosch, 2013). The growth of plants very reliantly on the soil for obtaining water and nutrients. Between the surface of the land and the atmosphere, soil moisture plays a role as temporary storage of water amid rainfall and evaporation, which acts as a regulator of one of the most basic hydrological processes, rainfall infiltration and runoff output (Dubois, van Zyl, and Engman, 1995). One method to measure water content in soil is the ground-based method, which includes gravimetric, electrical, cosmic-ray, radiological and time domain reflectometry, which can provide a single point measurement with very high precision (Zreda, Desilets, Ferré, and Scott, 2008). The mechanisms of deep soil moisture have been an interesting matter in the hydrology and ecology of tropical forests over the last two decades. Water absorption into established deep root systems explains the seasonal loss of deep soil humidity (Toriyama et al. 2013). To effectively handle forests in drought-prone tropical regions, the response of deep soil moisture to vegetation changes and precipitation can be estimated. In the tropical monsoon zone of Southeast Asia, evergreen forests also undergo a dry season. The level of soil moisture will impact the population structure of the ecosystem in a forest environment, and such knowledge would be helpful to assess the suitability of species for restoration and enrichment planting programs (Wang, Fu, Gao, Liu, and Zhou, 2013).



This study was conducted at the 6 ha Pasoh Forest Reserve, Negeri Sembilan. This analysis aims to ascertain the seasonal fluctuation of soil moisture as an outcome of the monsoons in the Pasoh FR. The output from this research could be used as a criterion for constructing forests soil moisture and ecological characteristics.

MATERIALS AND METHODS

Site Description

Pasoh Forest Reserve located in Negeri Sembilan and widely known as the driest region in Peninsular Malaysia, as shown in Figure 1. It is located at 2º 58' N, 102º 18' E, generally between 75 m to 150 m above sea level. The central area (600 ha) of the reserve encompasses the primary lowland mixed dipterocarp forest and numerous Shorea and Dipterocarpus species (Lion, 2018). In 1994, a 6 – ha study area was set up for long-term ecological studies, and a 52-m high tower was constructed for meteorological observation (Noguchi et al. 2016).

Rainfall Data

Using a 0.5mm tipping-bucket rain gauge mounted at the top of the tower above canopy level and a second gauge placed 430 m away in a clearing at the Pasoh Climate Station, rainfall data was gathered at 30 minutes intervals. To avoid evaporation, a double-layered small mouth inner glass bottle was used. The depository rain gauge was buried underground to minimize heating, leading to evaporation (Marryanna et al. 2017). For each 24-hour cycle, the daily amount of rainfall, frequency and period were determined. The maximum intensity of rainfall was the maximum value that happened during each day's 30-minute duration. The period was determined using a 30-minute interval data collection to count the amount of rainfall occurrences in one day.

Soil Moisture Measurement

In the 200 x 300 m plot (6– ha plot) within the Pasoh FR consisting of 39 grid points, the 50-m-interval spatial sampling grids were created as shown in Figure 2. To gather data from soil depths of 0.1 m, 0.2 m, 0.3 m, 0.4 m, 0.6 m and 1.0 m, an Amplitude Domain Reflectometry (ADR-type) soil moisture profile probe (PR2; Delta T Instruments, Ltd.) is used. Inside the plots, one-meter entry tubes fitting for the PR2 sensor access tubes were mounted randomly. Monthly measurements of soil moisture at different depths were taken. To take soil moisture measurements, the sensor was placed into the polypro entry tubing. This tube was made of specially extruded polycarbonate plastic, and its wall dimensions were factored into the functions of calibration and moisture reading of the probe.

Data Analysis

The study's experimental method was a completely randomized design. To analyse the relationship between soil depth and soil moisture and its relation and variations between soil types, exploratory data analysis was performed. The Principal Component Analysis (PCA) in XLSTAT was used to test the variation, loadings and relation of soil moisture at various soil depths and rainfall.

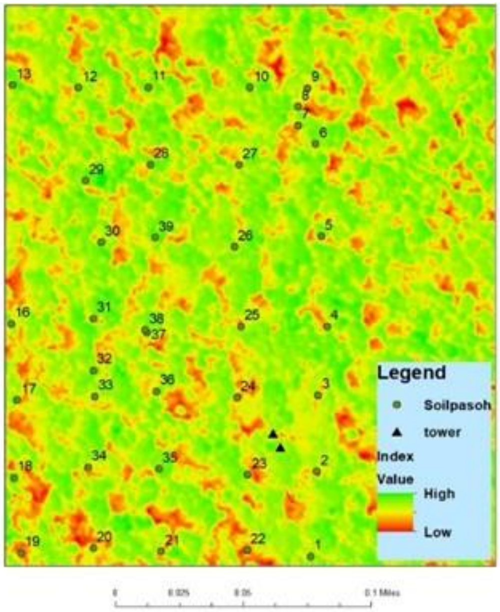


Figure 2: Spatial sampling grids for soil moisture measurement in the 6-ha plot

RESULTS

Rainfall Characteristics

The north-east monsoon usually gives heavy rain to Malaysia, especially to the Peninsular's east coast and east of Sarawak. In order to explore variations between monsoon seasons, each year is categorised into 3 seasons, namely north-east monsoon (NEM), south-west monsoon (SWM) and inter-monsoons (IM) as shown in Figure 3. From November to March categorised as NWM season, May to September as SWM season and April and October are IM season (Marryanna et al. 2017). Study shows that Malaysia received most of the rainfall event in the NEM season with almost 42.6% of rainfall, 39.1% in SWM, and 18.3% from the IM season (Marryanna et al. 2012). A total of 13 months of study period from October 2019 to October 2020 was selected to impact the relationship between seasonal change and soil moisture at the Pasoh Forest Reserve (FR). As visualised in Figure 3, the rainfall recorded was from 2017 until 2020 to see the seasonal rainfall pattern in Pasoh FR. The highest rainfall amount was in 2017, with a total amount of 2254.40 mm per year. The total amount of annual rainfall decreasing for the next two consecutive years (1618.80 mm for 2018 and 1357.85 mm for 2019), could be caused by the El Niño drought consequences but the amount of rainfall has seen a slight increase in 2020 (1929.05 mm). In 2017 and 2018, the NEM recorded the highest percentage of rainfall by seasonal percentage, 46.23% and 51.24%, respectively. In 2019, IM recorded the highest percentage of rainfall amount (37.36%) compared to another season in that particular year. However, in 2020, more than 50% of the rainfall is received during the SWM. The pattern of the monsoon is not consistent for all years. This may occur due to several factors such as severe drought, global warming, El Niño event and others.

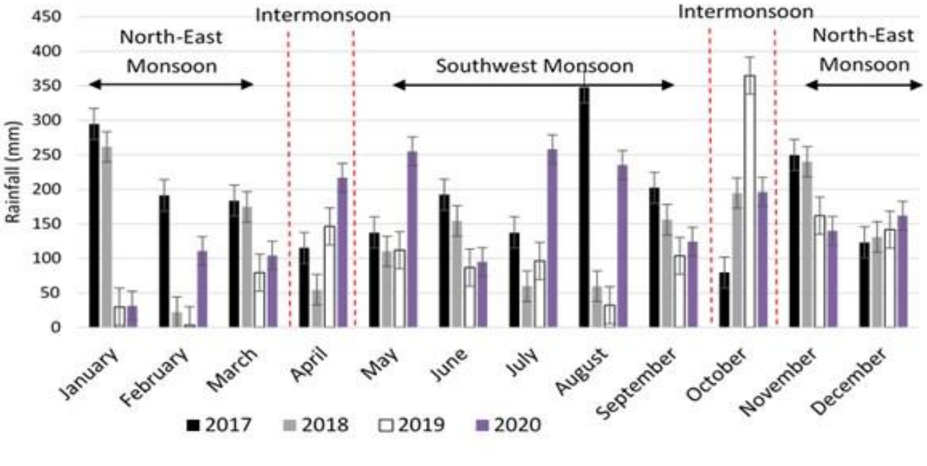


Figure 3: Monthly amount of rainfall in Pasoh FR from 2017 to 2020

Within 4 years, the highest monthly rainfall amount was recorded on October 2019 (364.7 mm) in the IM season. However, the amount of rainfall in October varied every year. In October 2020 the rainfall amount is not the highest but is considerably high (196.3 mm) compared to other months on that particular year. This indicates that on the October IM season, Pasoh FR receives higher rainfall amount in contrast to April IM season. The lowest monthly rainfall amount recorded on the NEM season was in February 2019 with only 3.2 mm. On the last 2 years, 2019 and 2020, the NEM recorded very low annual rainfall, which are less than 30% of rainfall for both years (Table 1). This study focuses on the rainfall amount for year 2019 and 2020 as the soil moisture measurement was obtained on that particular year.

Table 1: The percentage of rainfall amount based on seasons.

Year	NEM	SWM	IM
2017	46.23%	45.13 %	8.64 %
2018	51.24 %	33.36 %	15.39 %
2019	30.63 %	31.75 %	37.63 %
2020	28.42 %	50.17 %	21.41 %

Soil Moisture

The average of the soil moisture measurement for 13 months at six different depths was recorded in Table 2 below. The highest soil moisture content is measured in July 2020 at depths of 1.0 m (51.64%). This moisture remains high until December 2020 at 44.26 %, which might be associated with the high rainfall amount from July 2020 until December 2020, as depicted in Figure 4. Generally, heavy rainfall has a considerable volume and a limited period, leading to high rainfall and large floods that cause severe soil erosion. This can be shown in the topsoil depth of 0.1 m and 0.2 m, where the soil moisture content shows the constant value of reading range from 10% to 25%. The topsoil water content could be less due to the soil porosity that leads to surface water runoff. In the intermediate soil horizon (0.3m – 0.4 m), the soil moisture increased from 15% to 33% and at the deep soil horizon (0.6 m – 1.0 m), which gives a very high percentage of soil moisture content from 18.22% in the dry season and 51.64% during the wet season (Table 2). Deep soil horizon can store more water content because usually, plants take water from the surface horizon for transpiration (Lion et al. 2017). January 2020 to March 2020 can be categorised as a dry season where the monthly rainfall amount was meagre and thus the soil moisture content. The soil water content responded positively to the amount of rainfall received in the Pasoh FR. As the rain amount increase, the soil moisture increases. Deep soil horizon could react as water storage for the tropical forest as the soil moisture content is high even in the dry season. Other than rain amount, several biophysical factors, such as soil cover, soil condition, hydraulic properties and soil surface characteristics, including roughness and crusting, also could affect soil moisture content (Rodriguez-Iturbe, Porporato, Laio, and Ridol, 2001).

Table 2: The monthly average of soil moisture measurement at different depths

Year	Sample	Soil Moisture (%)					
		0.1 m	0.2 m	0.3 m	0.4m	0.6 m	1.0 m
2019	October	16.37	17.83	18.67	20.41	23.33	36.88
	November	23.97	24.27	16.17	33.61	30.84	49.49
	December	25.17	24.22	23.54	28.29	31.15	47.43
2020	January	15.78	17.37	18.08	21.58	24.98	41.31
	February	11.64	14.18	15.65	17.98	18.89	35.77
	March	10.14	15.33	15.44	17.08	18.22	33.67
	April	17.40	19.07	17.78	23.16	24.57	40.76
	May	17.91	25.68	20.02	23.87	26.07	42.95
	June	18.59	22.08	22.99	24.87	28.18	46.02
	July	14.32	17.68	17.17	21.48	24.46	51.64
	August	19.04	21.39	22.04	25.54	28.71	41.98
	September	18.47	20.66	28.62	25.00	29.44	46.20
	October	22.53	23.52	24.12	27.46	30.12	44.26

DISCUSSION

The “The Analysis of Variance of Spatial Pattern in Soil Moisture

To define trends among the calculated variables, PCA was used for this analysis. (Pearson, 1901) invented the system, and (Hotelling, 1933), (Karhunen, 1947) and (Loève, 1948) further improved it. The critical component analysis is a well-known multivariate statistical tool commonly used in several research fields because it provides the ability to decrease the complexity of a data collection (Khalit et al. 2017). A small number of spatial variables that explain much of the variance of soil moisture in the spatial pattern were defined using PCA. The program was loaded the missing value of rows due to the failure of the measurement or processing procedures defined by (Khalit et al. 2017) with the value of the nearest neighbour. PCA also can specify the information on both the temporal and spatial elements. In this study, the estimation of factor loadings were carried out for assessing the correlations between soil moisture at different depths and the extracted factors, which is the rainfall events.

On the multiple observation points, factor (F) scores can be used as an indicator of the capacity of individual Fs. At the same time, the loadings and related variances define the degree of interaction between individual Factors and attributes calculated at different times. The result in Table 3 suggest that Factor 1 can be attributed to time-variant rainfall amount, were discovered to be significant, where the eigenvalue>1 (Kaiser, 1960), and explained 96.98% of the total variance in the data set while Factor 2 that represent other factors such as soil properties only accounted for a negligible fraction as the eigenvalue is<1. The relative value of the factor in describing the variance of each input data variable is represented by factor loadings, which is an essential source of data for the physical understanding of the effects (Samsudin et al. 2018). Based the Table 4, Factor 1 weighted positively on all variables were almost all months recorded >0.9. For Factor 2, loadings on November, December 2019, April, May and October 2020 shows positive loaded (≥0.008) while the rest of the months were negatively loaded (≤-0.291). The observation indicates that Factor 1 explains most of the variance (96.98%) simulates temporally constant factor, which the temporal pattern of soil moisture that attributes from the rainfall in this case study. Factor 2 which had only 2.04% of the variance, is most likely connected to the spatially varying factors with minor effects on the monitoring period, such as type of soil, topography, and other factors that can be studied.

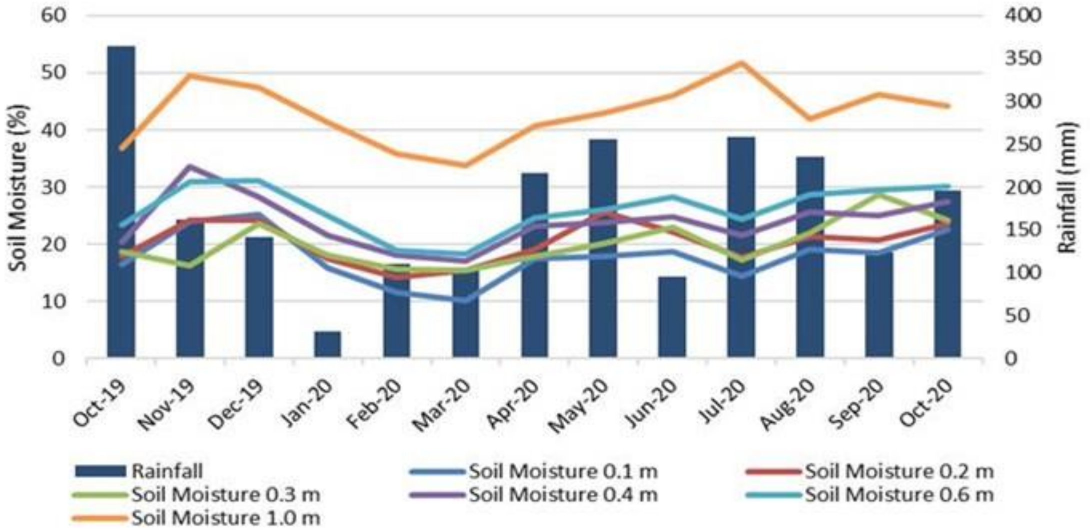


Figure 4: The soil moisture content and rainfall amount on monitoring period for 13 months

The correlation circle (Figure 5) reveals that all the variables represent monthly soil moisture data in the space factors. All the variables are close to each other indicates that the variables are positively correlated (r close to 1). The positively correlated variables are grouped as shown in the figures. Variables that are correlated negatively are placed on the opposite side of plot origin. The variables shown also were away from the origin and they are well represented on the factor map.

Table 3: Eigenvalues, variability and variance cumulative for the first 2 factors

Parameter	Factor 1	Factor 2
Eigenvalue	12.607	0.266
Variability (%)	96.980	2.043
Cumulative %	96.980	99.024

Table 3: Eigenvalues, variability and variance cumulative for the first 2 factors

Year	Sample	Factor 1	Factor 2
2019	October	0.998	-0.042
	November	0.922	0.380
	December	0.988	0.093
2020	January	0.998	-0.006
	February	0.996	-0.062
	March	0.988	-0.095
	April	0.997	0.078
	May	0.971	0.045
	June	0.997	-0.069
	July	0.998	-0.005
	August	0.995	-0.015
	September	0.953	-0.291
	October	0.998	0.008

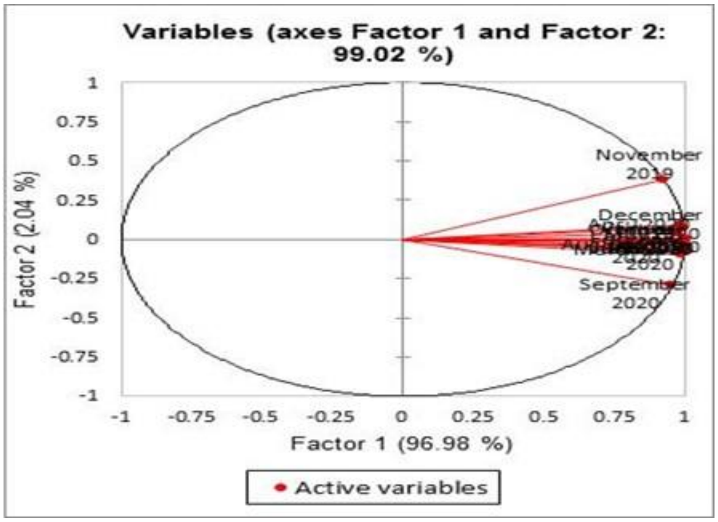


Figure 5: The actives variables represent monthly soil moisture data, Factor 1 represent rainfall event and Factor 2 represent other small factors such as soil properties.

CONCLUSION

Overall, although the rainfall amount is varied by the season, soil moisture content in Pasoh FR is responding positively and a stable pattern was observed even in the dry season. Deep soil horizon stored the water in the soil almost at the same level throughout the year despite variation in rainfall amount. Spatially, Pasoh FR generally obtained their water supply from the top soil horizon (0 – 0.2 m) and during the dry period obtained additional water from deeper layers.

PCA was applied to identify patterns among the measured variables that describe most of the variance of the temporal pattern of soil moisture. Only one factor was found that describes 96.98% of the total variance of the data set. The factor represents the soil moisture noticeable at deeper depths. Factor 1 is the main pattern that reacted to time-invariant rainfall attributes. Factor 2 showed a variable contribution with time and can be represented by other process and factors such as evapotranspiration, infiltration and others. In this study, Factor 1 positively correlated with the rainfall event during monsoon season, while Factor 2 can be attributed to the combined effect of time-invariant soil attributes such as soil properties.

From the current study, the ability of PCA to characterise both spatial and temporal pattern and variables structured by a complex process can be emphasised. The added benefit of the PCA in this sense consists of measuring the influence of the most important trends on the overall variance of the data collection. However, the analysis of the performance of the PCA in terms of controlling factors is closely dependent on general knowledge previously accessible, which can cause the underlying processes to be inferred.

CONFLICT OF INTEREST

The authors declared that the present study was performed in the absence of any conflict of interest

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AUTHOR CONTRIBUTIONS

ML devised the project, the main conceptual ideas and proof outline. NAB contributed to the design and implementation of the research, the analysis of the results, and the writing of the manuscript, with help from SMR. SIK helped supervise the project.

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