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RELATIONSHIP OF BESERAH SOIL ON PHYSICAL AND MOISTURE PRONE TO EROSION IN TROPICAL LOGGED-FOREST

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Abstract: The influence of forest operations on forest soil and water continues to be an issue of concern in forest management. The availability of water in the soil is always depending on soil characteristics, plant species that cover the land surface and amount of radiation that reach the surface. Soil physical characteristics and moisture content has direct relationship and the source of water influences the saturation levels. Beserah Series has a loose soil structure characteristic. Hence, its moisture retention capacity is low and the soil cohesion and adhesion are low too. Soil moisture contents were measured at various depths ranging from 20 to 80 cm below the ground. The Automatic Weather Station (AWS) with soil moisture probe was used to measure the soil moisture directly at the site. Four moisture sensors tubes were installed at 2 meters intervals at each location in the open canopy area. Two upper soil layers of the study site hold less than 2 % of soil moisture. Soil textures below 40 cm contain more than 30 % clay and hold moisture over 15 %, getting more stable downward. Soil moisture has coefficient relationship with temperature and wind in all depths respectively. However, the moisture sometimes relies on pressure and wind in the depth of 0 to 40 cm.

Key words: Soil Moisture, Automatic Weather Station (AWS), Hill Forest, Beserah Series

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Introduction

Site preparation and harvesting are forest operations which typically associated with intensive management. Commonly, these forest operations involve large mechanized equipment to perform management activities. Soil is important for plant growth as a source of water and minerals, as the anchorage for plants and as a medium for development of the root systems essential for absorption and anchorage (Paul & John, 1995).

Generally, Malaysian soil is a parent material, highly weathered; acidic which is mainly fall under Ultisol and Oxisol. A wide range of soils are found in the steep areas from an elevation of 76 m.a.s.l. to beyond 2,000 mean above sea level (m.a.s.l) representing major differences in parent material, climate, vegetation and terrain conditions. Many of the soils in the hilly and mountainous areas are highly weathered. These soils which can be classified as Oxisols were dominated by kaolinite, gibbsite, goethite and hematite in the clay fraction (Tessens & Shamshuddin, 1983). Oxisols in Malaysia were developed on shale, schist, basalt, andesite, granodiorite, serpentinite and limestone, but the most weathered of them are those formed on basalt, andesite and serpentinite (Shamsuddin & Markus, 2008). According to Paramananthan (1977), the climo-biotoposequence study of soils derived from granitic parent materials in the Cameron Highlands illustrates the influence of these major factors on soil formation. Lim et al (1980) description of the soil survey of the KESEDAR Region provides a wealth of information on soils properties on steepland dominated by shale parent materials. Ad hoc soil surveys in other states have also yielded information on the nature and properties of soils on steep areas.

Most of the soil series that found at Pasir Raja Selatan Forest Reserve is Beserah Series based on the soil map (MACRES, 2005). The Beserah Series is a member of the Beserah Family which is a clayey-skeletal, kaolinitic isohyperthermic red-yellow Tipik Tempalemoks (Paramananthan, 1977). The soils are deep, friable and have weak, coarse to medium subangular blocky structures. The A horizon have a fine sandy clay to fine sandy clay loam textures with dark yellowish brown colours while the B horizon gravelly coarse sandy clay loam to gravelly coarse sandy clay textures and strong brown to Brownish yellow colours. The textures in B horizons are often characterized by the presence of quartz gravels. The fine earth fraction (<2mm) has a texture ranging between a coarse sandy clay to a coarse sandy clay loam. The range of clay content is from 30% to 45%. It has a loose structure characteristic with clayey-skeletal, kaolinitic isohypertermic red-yellow soils (USDA) characteristics. This phenomenon is common for soils derived from granitic parent materials. The soil has good water permeability and well-drained. The soil temperature regime is isohyperthermic (>22^{o}C) up to 1200 mean above sea level (m.a.s.l) isothermic (15-22^{o}C) between 1200 to 1600 m.a.s.l. and isomesic (<15) at elevations exceeding 1600 m.a.s.l. The soil moisture regime is udic below 300 m.a.s.l. and perudic above this elevation. However, the soil type has high susceptibility to erosion on sloping condition which limits the forestry acitivities in this hilly region.

Soil moisture information is valuable to a wide range of government agencies and private companies concerned with weather and climate, runoff potential and flood control, soil erosion and slope failure, reservoir management, geotechnical engineering and water quality. Knowledge of soil water content is important for management of and hydrological studies (Lukanu & Savage, 2006). Soil moisture often been used in agriculture as indicates the Agroclimatic Map is the map showing the various zones with the same duration of moist/wet months and zones with similar duration of moist/wet different month (Anon, 2000). Agroclimatic map is useful in the determination of the suitable planting time for various crops and also to determine the types of crops suitable for an area.

Moreover, in forestry, studies had shown that soil moisture was associated with species growth and spatial distribution (Diez & Ronald, 2007). Compared to other components of the hydrologic cycle, the volume of soil moisture is small; nonetheless, it of fundamental importance to many hydrological, biological and biogeochemical processes. Soil moisture is a key variable in controlling the exchange of water and heat energy between the land surface and the atmosphere through evaporation and plant transpiration. As a result, soil moisture plays an important role in the development of weather patterns and the production of precipitation. Soil moisture also strongly affects the amount of precipitation that runs off into nearby streams and rivers. Soil moisture information can be used for reservoir management, early warning of droughts, irrigation scheduling, and crop yield forecasting.

At Pasoh, topographic associations have been attributed to differences in soil-moisture gradient between slopes, wet and dry area habitats (Noguchi et al. 2002). Several studies in the BCI plot have revealed the association of topography, soil and moisture regime. For example, Becker et al. (1988) showed that soil-water potentials are maintained at higher levels on the BCI plot slopes compared to the principal plateau. Daws et al. (2001) showed that slopes experienced a shorter duration drought period during the dry season. Variation in soil-moisture availability across topographic gradients in tropical forests might also potentially maintain a substantial fraction of local diversity if species differ in their 'hydrological niches'.

The objective of this study was to determine the relationship between soil physical parameters and its association with moisture content in the hill/lowland forest which influence soil erosion.

Material and Method

Site Descriptions

The study plot was established in Compartment 70, Pasir Raja Selatan Forest Reserve, Terengganu between longitude 4^{o} 31' N and latitude 102^{o} 51' E. The study site covers an area of 428 ha. The entire forest reserve iscovered by virgin and secondary forest expanding nearby state of Pahang border. The topography varies from hilly areas to rugged mountainous with an elevation ranges from 420 to 620 meters above sea level. The geology of the study area is commonly weathered-limestone and granitic that formed the Beserah soil series. Pasir Raja Selatan F.R. was selected for this study due to the topography and its physical environment that reflects a typical hilly terrain. Logging activities in the upland catchment had affected the downstream especially in the nearby village Kampung Pasir Raja. Figure 1 shows the study area of Pasir Raja Selatan Forest Reserve.

Two sites were selected and monitored for the study. Plot A represented the logged area whilst Plot B established on the unlogged forest, considered as control plot. Both plots had about identical soil physical characteristics (Table 1). The soil profile description of the Beserah series is shown in Figure 2.

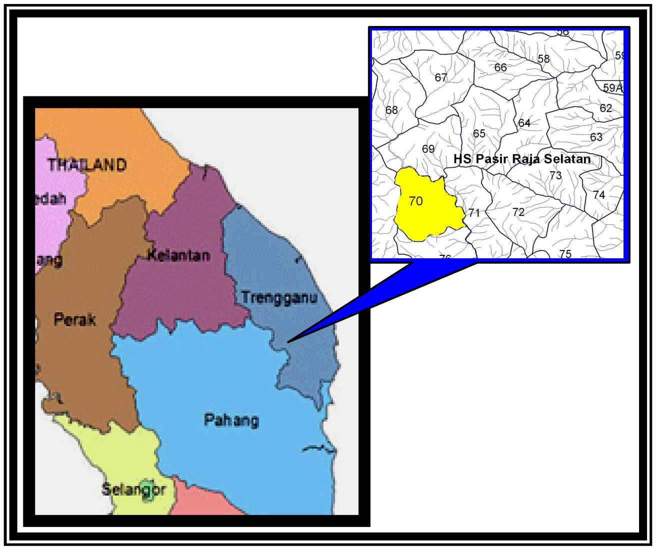
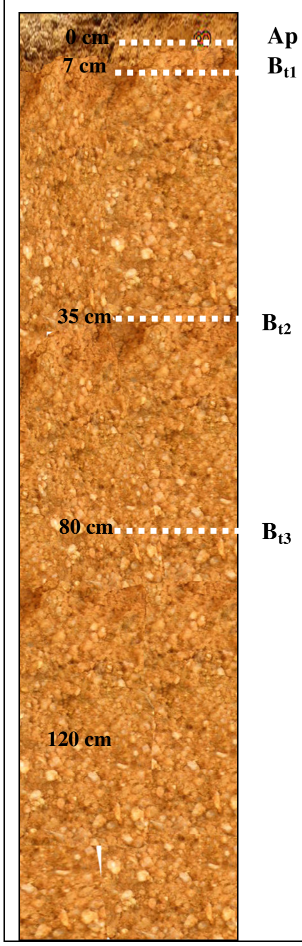


Figure 1: The study area of Compartment 70, Pasir Raja Selatan Forest Reserve, Terengganu Malaysia.



Horizon	Soil Depth (cm)	Descriptions
Ap	0 – 7	Dark yellowish brown (10YR 4/6), fine sandy clay to fine sandy clay loam; very friable, medium and fine subangular blocky and weak, fine crumbs; few fine rotts; diffuse boundary.
B_{t1}	7 – 35	Strong brown (7.5 YR 5/8), gravelly coarse sandy clay loam; weak coarse to medium subangular blocky, friable; very few fine roots; diffuse boundary.
B_{t2}	35 – 80	Brownish yellow (10YR 6/8) and yellowish red mottles (5YR 5/8), gravelly coarse sandy clay; weak coarse to medium subangular blocky, friable; no roots; diffuse boundary.
B_{t3}	80 – 120	Brownish yellow (10YR 6/8) and pale yellow mottles (2.5Y 8/3), gravelly coarse sandy clay; weak medium to fine subangular blocky, friable; no roots; diffuse boundary.

Figure 2: The soil description of the Beserah series in the Compartment 70, Pasir Raja Selatan Forest Reserve, Terengganu Malaysia.

Sampling Methods

Weather information was gathered through data logger were installed at the study site. Rainfall, relative humidity (RH), wind (WD), pressure (BAR) and air temperature (TM) were detected automatically. Recorded data were transferred to the computer for analysis. We ran the statistical analysis using R and Rattle R package [source of references].

Soil moisture content was measured daily using moisture sensors at 20 cm depth intervals each. from 20 to 80 cm below the ground. The Automatic Weather Station (AWS) with soil moisture probe was used to measure the soil moisture directly at the site. Four moisture sensors tubes were installed at 2 meters intervals at each location in the open canopy area. The measurement began in September 2007 and ended in August 2008. The reading was taken daily and summarized as monthly data.

Soil properties for the profiles were initially determined based on augering and core sampling taken during harvesting in February 2007. Soil samples were collected to study the physical characteristics and moisture content. Sampling for physical characteristic was done based on the difference of soil horizon in eight locations randomly. Soils were taken from three different spots in each location and combined into one composite sample and properly mixed. These samples were brought back to the laboratory and analyzed for the mechanical size distribution. A centibar reading standards of soil moisture content is used to describe the soil saturation condition (Table 1).

Table 1: Centibar reading with soil condition from soil moisture sensor

Centibar Reading	Soil Condition
0-10	Saturated Soil. Occurs for a day or two after irrigation.
10-20	Soil is adequately wet (except coarse sands which are drying out at this range)
30-60	Usual range to irrigate or water (except heavy clay soils). Irrigate at the upper end of this range in cool humid climates and with higher water-holding capacity soils.
60-100	Usual range to irrigate heavy clay soils
100-200	Soil is becoming dangerously dry for maximum production. Proceed with caution.

Source: http://www.davisnet.com/weather/products/weather_product.asp

Results

Soil physical characteristics

Table 2 shows the result of random assessment for soil sampling conducted to determine the soil physical characteristics. The average percentage of coarse sand, fine sand, silt and clay in the soil are 37%, 12%, 14% and 37% respectively.

Soil moisture

During the water year measurement which occurred from July to June the next year, there was only 5 % moist condition difference between monsoon period and normal period. As the result, the soil moisture showed in the monsoon period recorded a bit higher in normal period as well. The soil organic matter (SOM) content is less than 2 % and the average soil permeability is less than 0.2 cm/hour. As the result, the soil structure can be grouped in two categories namely medium or coarse granular. The average of soil surface elevation ranges from 420 m to 430 m above sea level with different average slopes of 10 %, 20 %, 30% and 40 %.

The clay content is less than 30 % showing that on sloping area it is prone to soil erosion [Table 2]. The soil structure below 40 cm from the surface is more stable, has clay content of more than 30 %, hold moisture more than 15 % and getting more stable downward.

Soil 1 and soil 2 has sandy clay loam while Soil 3 and Soil 4 have sandy clay texture. It means that the upper soil layer was sandy as compared to the lower horizon. Overall, this soil has low water holding capacity. Further, it holds less water towards the end of the year with accordance to rainfall pattern

Table 2: Soil Physical Characteristics at Compartment 70, Pasir Raja Selatan Forest Reserve, Terengganu.

PLOT A (soil depth)	Coarse sand 0.10-2.0mm (%)	Fine sand 0.01-0.15mm (%)	Silt 0.05-0.002mm (%)	Clay <0.002mm (%)	Organic Matter (SOM) (%)	Soil Structure	
						MSLE code (S)	Description
0-20 cm	31	12	25	30	2	3	medium or coarse granular
21-40 cm	36	16	21	30	0	3	medium or coarse granular
41-60 cm	34	12	15	42	0	3	medium or coarse granular
61-80 cm	32	14	17	39	0	3	medium or coarse granular
PLOT B (soil depth)							
0-20 cm	49	11	13	28	0	3	medium or coarse granular
21-40 cm	42	11	10	40	0	3	medium or coarse granular
41-60 cm	38	10	5	49	0	3	medium or coarse granular
61-80 cm	40	11	8	43	0	3	medium or coarse granular

Soil moisture across soil depth

To examine the differences in soil moisture between soil depths, we visualize it using boxplot. There is a difference in soil moisture between the soil depth (Figure 3). The soil moisture decreases with soil depth. However the soil moisture is similar at 20 and 40 cm depth.

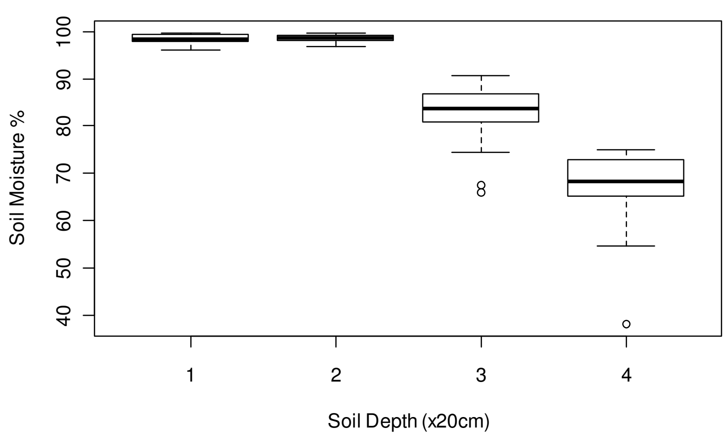


Figure 3: Difference in soil moisture and soil depth using Boxplot

Table 3 shows the soil moisture content. Two upper layers of the soil on the study site hold less than 2 % of soil moisture. Monthly average of soil moisture was lowest in February at 74.6 % (Table 3).

Table 3: Soil moisture content in different depths of Pasir Raja Selatan Forest Reserve

MONTH	Soil Moisture (%)				
	Soil 1 Depth (0-20) cm	Soil 2 Depth (21-40) cm	Soil 3 Depth (41-60) cm	Soil 4 Depth (61-80) cm	Average
Sep-07	0.26	0.49	4.60	13.55	4.72
Oct-07	0.13	0.22	5.58	16.98	5.73
Nov-07	0.30	0.32	7.05	17.46	6.28
Dec-07	0.48	0.41	8.51	17.93	11.32
Jan-08	0.51	0.35	6.63	13.30	5.20
Feb-08	2.00	1.55	17.01	30.92	12.87
Mar-08	0.75	0.66	7.07	12.51	5.25
Apr-08	0.84	0.63	8.11	13.49	5.77
May-08	1.26	1.18	12.83	17.15	8.11
Jun-08	1.00	0.97	9.55	14.93	8.11
Jul-08	0.92	0.83	8.35	15.51	6.40
Aug-08	1.92	1.45	16.20	22.65	10.56
Average	0.86	0.76	9.29	17.20	7.52

Table 3 shows the monthly average soil moisture at different depth from the surface. The average soil moisture from 0 to 80cm soil depth was lowest in September at 4.72% and highest in February at 12.87%. On the other hand, soil at 61-80cm depth contains the highest moisture content followed by 41-60cm depth soil and the peak point in February (Figure 5) where the rainfall and relative humidity were the highest. Both soil 0-20cm and 21-40cm depth contained the lowest moisture content and it was almost uniform through the year. Figure 4 shows the difference between monthly percentage of relative humidity and rainfall. Relative humidity of the area was high. Nevertheless, when the difference on percentage of relative humidity was below the percentage of rainfall, the soil will experience moisture stress. Due to sandy nature of the soil, vegetation in this area had experienced moisture stress throughout the year except for March 2008.

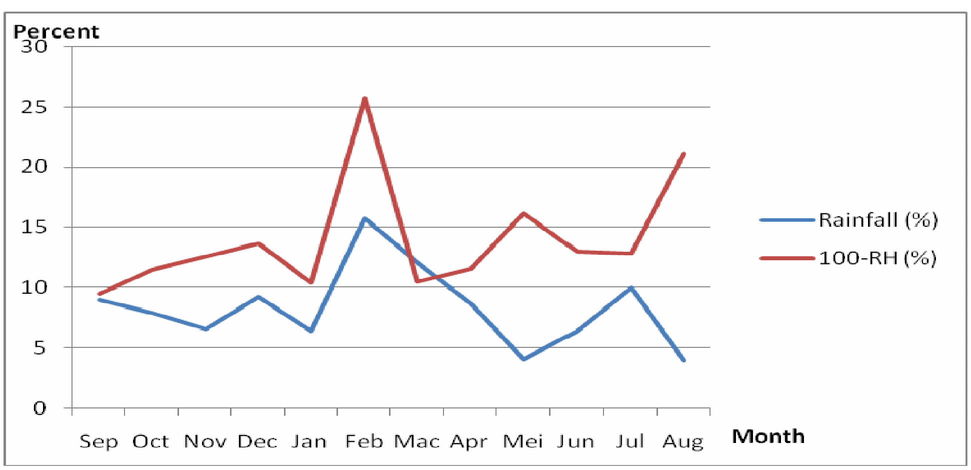


Figure 4: Minus percentage relative humidity (RH) and percentage rainfall of Pasir Raja Selatan Forest Reserve

We run analysis of variance to determine the differences of soil moisture between soil depth and followed TukeyHSD multi-comparison test. We ran multiple regression analysis to determine the soil moisture association with microlimate parameters taken in the same site and time interval for a period of one water year from September 2007 to August 2008. We applied a mixed effects regression model with time treated as random effects.

Mentioned below is the new analysis for data set. The Soil Depth has been treated as a factor. The model is as follows:

SM ~ -154.06590 + 2.08574*RH + 3.19831*AT -0.01596*RF SD1

SM ~ [-154.06590+0.16308] + 2.08574*RH + 3.19831*AT -0.01596*RF.......SD2

SM ~ [-154.06590-16.31154] + 2.08574*RH + 3.19831*AT -0.01596*RF......SD3

SM ~ [-154.06590-32.56462] + 2.08574*RH + 3.19831*AT -0.01596*RF......SD4

where

SM is soil moisture,

RH is relative humidity,

RF is rainfall,

SD is soil depth

Table 4 shows that the regression model indicated that soil moisture is strongly associated with the Relative Humidity (RH) (Pvalue<0.001), Air Temperature (AT) (Pvalue < 0.01) and Rainfall (RF) (Pvalue <0.05). There is an indication that the slope of this relationship is significantly different between soil depth especially for SD3 (Pvalue <0.001) and SD4 (Pvalue<0.001), but not for SD2, although slightly for SD1 (Pvalue<0.05).

Table 4: Regression analysis through R analytical software

Descriptions	**Estimate**	**Std. Error**	**t-value**	**Pr(>|t|)**
Interception	-154.0659	72.65658	-2.12	0.039513 *
RH	2.08574	0.55023	3.791	0.000444 ***
AT	3.19831	1.15201	2.776	0.007984 **
RF	-0.01596	0.00716	-2.229	0.030817 *
as.factor (SD)[T.2]	0.16308	2.19704	0.074	0.94116
as.factor (SD)[T.3]	-16.31154	2.19704	-7.424	2.40e-09 ***
as.factor (SD)[T.4]	-32.56462	2.19704	-14.822	< 2e-16 ***

Where

Significant codes: 0 ׀***׀ 0.001 ׀**׀ 0.01 ׀*׀ 0.05 ׀.׀ 0.1 ׀ ׀ 1

Multiple R-squared: 0.8772; Adjusted R-squared: 0.8608

Relationship between soil moisture and other micro climate parameters

The relationship between soil moisture and other micro climate parameters found that soil moisture is strongly associated with relative humidity (t-value 3.791) followed by air temperature (AT) (t-value 2.776). This mean soil moisture content of the area is affected most by the relative humidity. However the association of soil moisture and rainfall was less (t-value -2.229). As the analysis of the regression model showed that the R-squared value is 0.8772, the soil moisture is very strong relationship with the soil depth of the study area.

Conclusions

Physical characteristics of soil have a bearing on erodibility. Soil properties like texture, structure and cohesion had an influence on soil erodibility. Texture refers to the size or combination of sizes of the individual soil particles. The soil characteristic of Pasir Raja Selatan Forest Reserve has sandy clay loam to clay texture. The upper soil layer has less physical bearing capability getting more stable towards the parent materials. Soil moisture retention capacity was low and further aggravated by low monthly rainfall at second half of the year. High percentage of relative humidity and low percentage of rain on certain month lead to moisture stress for the vegetation. During this time, plants start to fall the old leaves and the soil cohesion, adhesion also lower than the other half year. Soil moisture has coefficient relationship with temperature and wind in all depths respectively.

However, the moisture sometimes relies on pressure and wind in the depth of 0 to 40 cm. Human activity will make erosion impact of this soil more vulnerable. Proper management practice is important to maintain the sustainability of this area.

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