P38

GROUNDWATER DYNAMICS IN HUMID TROPIC HILLSLOPES WITH CONTRASTING SOIL DEPTHS AND TOPOGRAPHIC CONDITIONS: A CASE STUDY IN SUMATRA ISLAND, INDONESIA

○Eilif Kurnia Deda DJAMRES, Takahiro SAYAMA, Eva Mia Siska YAMAMOTO, Yoshito SUGAWARA, Kodai YAMAMOTO, and Apip

1. INTRODUCTION

This study builds up on our previous work assessing the GW and surface soil moisture dynamics at a hillslope in humid tropical forest in Sumatra Island in Indonesia (Sayama et al., 2021). Even though the soil in the area consists of loamy to clayey deposits with approximately a few meters thick, the forest soil layer exhibited rapid and large variation of GW table during storm events.

In order to further investigate the mechanism and the generality of the rapid GW response, we decided to conduct the GW monitorings at the adjacent hillslope with different land cover condition (palm oil plantation which is the other typical land cover condition in this region). Because of the two monitoring sites are apart only 2km each other, they share the same climate conditions. At each site, we measured GW at three positions along the hillslopes together with soil characteristics and depths. The objectives of this study is to compare the GW responses in the adjacent hillslope and clarify the main reason of the high GW response in the forest hilllope.

2. METHODS

2.1. Site description

The two study hillslopes are located in the Batanghari watershed, Sumatra, Indonesia (Figure 1(a)), and are characterized by different land cover types: a forested hillslope in Sekancing township (SK), and a 15-year-old palm plantation in Pulau Raman township (PR).

Soil depths were measured at five points along the SK slope, and one point at the ridge of the PR slope using a portable dynamic cone penetrometer, with the weight of 5 kg and falling distance of 50 cm. The 20 hits for penetrating 10 cm (i.e. Nc > 20) can be regarded as an indicator of the boundary between soil and weathered bedrock (Hosoda et al., 2016). Weathered bedrock was ~450 cm below the soil surface at SK1, 415 cm below at SK2, 100–150 cm below at SK3, 90 cm and 220 cm below for SK4 and SK5 respectively. The Nc values of PR2 was remained < 20, even after 5 m penetration depth. Then, due to the limitation of the cone penetration stick used, the depth of weathered bedrock in PR2 could not be ascertained; however, the soil layer's thickness was also confirmed during the well drilling at PR2, located ~800 cm below the soil surface.

Based on soil particle analyses of samples from 5, 30, 60, and 90 cm depths, the soil textures were classified as clay at SK, and silty clay at PR according to the using sieve and hydrometer methods and USDA definitions. The Ks of the soil ranged between 0.08 and 12.41 cm·h-1 in SK, and 0.19–8.45 cm·h-1 in PR, while the porosity at both sites ranged from 57.5% to 65.6%.

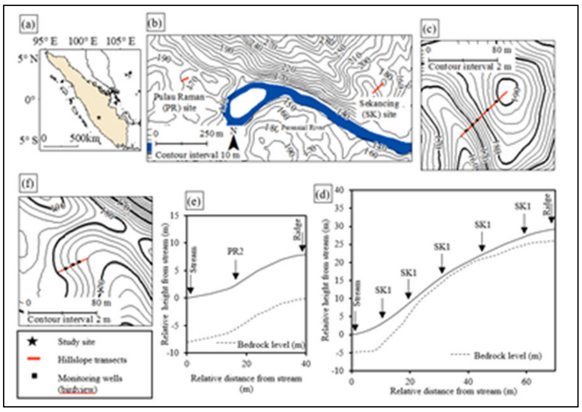

Figure 1 (a) Sumatra island, (b) Location of the studied hillslopes, (c) Topography of the forest hillslope, (d) Cross-sectional views of the transect on forest hillslope, (e) Cross-sectional views of transect on oil palm hillslope, (f) Topography of the oil palm hillslope.

2.2. Field monitoring of hillslope GW

The monitoring period was from August 2017 to December 2020 in SK, and from November 2018 to December 2020 in PR. Ten-minute rainfall data were gauged with a tipping bucket (CPK-RAIN-1, Climatec; Phoenix, AZ, USA). Pressure sensors (DIK-615A-B1, Daiki; Tokyo, Japan) were used for gauging GW levels in boreholes, and these levels were recorded every 10 minutes from the three observation boreholes (SK1–SK3 and PR1–PR3) installed along the each hillslope (Figure 1(d, e)).

2.3. Hillslope hydrologic modeling

The rainfall-runoff-inundation (RRI) was employed in this study. Sugawara and Sayama (2021) developed an unsaturated flow component for the RRI model based on measured water retention curve parameters determined by experimental and observational data. This model assumes an equilibrium water distribution along vertical infiltration throughout the hillslope. This model uses the Brooks-Corey and Mualem model for estimating water retention curves and unsaturated hydraulic conductivities.

3. RESULTS AND DISCUSSIONS

3.1. Seasonal GW patterns

Figure 2 shows the observed GW patterns at SK and PR hillslopes, where the former fluctuated more greatly, and the latter was smoother. The GW table at the foot of the SK hillslope (SK1) indicated the persistent existence of GW in the soil layer. Likewise, the GW table remained at a depth of ~300 cm from the soil surface at SK2 in the early dry season (June), and decreased to 415 cm during the driest period (August–September), even reaching nearly 500 cm in 2019. Alternatively, such a dynamic GW table was not observed at SK3, where GW was observed at depths of 100–200 cm from the surface.

The PR hillslope maintains a comparatively deeper soil depth (800 cm), particularly for PR3 located near top of the hill, where the borehole recorded until ~800 cm below the soil surface (September 2020). Similarly, the GW in PR2 showed more steady pattern at depths between 300–500 cm, whereas the GW in PR1 showed the least variation in depth (at ~50–150 cm), likely influenced by the short distance of PR1 to the stream.

3.2. Model based sensitivity analysis to understand the groundwater dynamics

To better understand the dominant controlling factors of the different groundwater dynamics at the two adjacent hillslopes, a numerical experiment was conducted using the RRI model. The model was employed for simulating the GW level from four scenarios. Those were "Control" that used the original parameters and also as a reference, "Switching Ks", "Switching SWRC", and "Switching soil depth". To more easily on interpreting the results, we focus only simulating a year period (December 2019 to December 2020) and selected SK1 and PR3 for simulation.

The model results confirms that the GW at SK1 (control) fluctuated more rapidly with rainfall compared to GW at PR3 (Figure 3). The flashiness index value in PR3 (control) was 0.004. It was slightly more than half of that at SK1 (control), which comprised 0.009. By replacing the Ks of SK1 and PR3, the GW at SK1 became shallower, while that at PR3 became deeper.

When switching the SWRC between the two sites, the effects were unclear. By adjusting the soil depth in SK1 to 8 m, the GW depths also gained depth (5–7 m), with much smaller magnitudes of fluctuation. Further, the FI became 43% that of the control case. Alternatively, by decreasing the soil depth at PR3, the range of

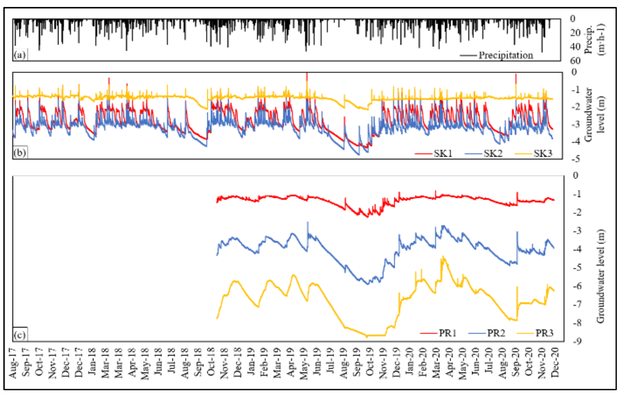

Figure 2 (a) Precipitation, observed groundwater of (b) SK hillslope, and (c) PR hillslope.

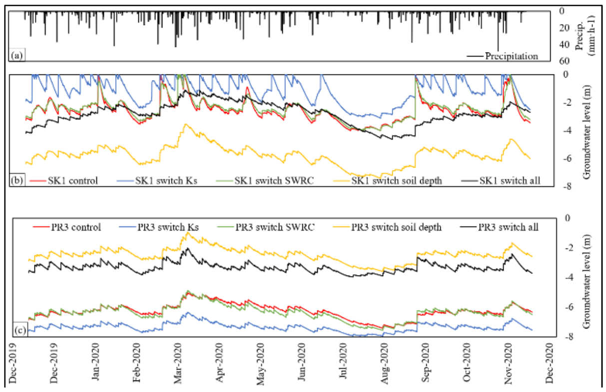

Figure 3 Precipitation (a) and the model simulation results from some scenarios of (b) SK1 in SK hillslope, and (c) PR3 in PR hillslope.

GW also became shallower, and as a result, the FI increased by 28.2%.

Lastly, all parameters in the model were switched between the two sites. As a result, PR3 showed a slightly higher FI value than SK1; however, a perfect exchange from the original case was not observed, meaning that factors other than soil depths also contribute to the higher fluctuation of GW at SK1, and lower fluctuation at PR3. Potential other controlling factors include the topography, such as slope lengths and gradients, as well as the position of SK1 and PR3.

4. Conclusion

An important findings of this research was that in the Sumatra humid tropics hillslopes the soil depth and position of weathered bedrock play important roles in the dynamic response of GW. The Ks and soil depth were the key parameters controlling GW patterns in both SK and PR. Nevertheless, the patterns still remained, even after switching the parameters, suggesting the position and topography also play dominant roles to differentiate the stability of GW dynamics.

REFERENCES

1) Hosoda I, Tani M (2016) Influence of moisture fluctuation in thick, weathered bedrock layer on rainfall–runoff response in a small, forested catchment underline by Paleozoic sedimentary rocks in Japan (in Japanese with English abstract). Trans Jap Geomorph Union 37(94):465–492.
2) Sayama T, Araki R, Yamamoto K, Apip (2021) Characteristics of soil and hillslope responses in hu-mid tropical forests in Sumatra, Indonesia. Hydrol Res Lett 15(2):23–30.
3) Sugawara Y, Sayama T (2021) Development of a storage discharge relationship to reflect water retention curve, and its application to a distributed runoff model. J Jap Soc Civil Eng Ser. B1 (Hydraul Eng) 77(1):124–135 (In Japanese with English abstract).
4) Yamamoto EMS, Sayama T, Sugawara Y, Yamamoto K, Apip (in press) Effects of Measured Soil Properties in Hydrological Simulation in a Humid Tropical River Basin. Journal of JSCE., Ser. B1 (Hydraulic Engineering).