Pore pressure as a trigger of shallow landslides in the Western Ghats

Introduction
Pore pressure is considered an important trigger of landslides. Continuous monitoring of pore pressure at locations of landslides is limited by the fact that the initiation locations of landslides are almost never known prior to the occurrence of the events. This is especially true in the case of shallow landslides such as debris flows. Researchers circumvent this constrain by monitoring pore pressure in laboratory scaled models, known active and dormant landslides or hydrologically and topographically similar terrain. This paper presents some initial interpretations of the observations of pore pressure from a network of piezometers coupled with the rainfall-intensity measurements from an automated weather station in the upper Tikkol River basin of the Western Ghats mountain chain of Kerala, India.

Study Area
The study area comprises Aruvikkal catchment, a 9.5 km² sub basin of the Tikkol River, a tributary of the Meenachil River (Figure 1). The area is underlain by Precambrian granitoids which weather slowly, leading to rather shallow sandy soils over a thin layer of sparylite interleaved by lithiargitic clay. The predominant land use is rubber (Hevea Brasiliensis) plantations, which have to be cleared after 20 years, thus exposing the land to the high intensity rainfall. The area has a history of shallow landslides and consequent debris flows that originate in topographical hollows. On 6th October 1993 the region experienced 100 debris flows, the triggering process of which results in the sudden drainage of excess pore pressure in shallow soils for over 9 hours. On the day of the events, the rainfall, while piezometer 2 (P2) shows a delayed response. P3 shows much more fluctuations than P1 which may be attributed to the local characteristics of the location such as saturated hydraulic conductivity, soil depth and slope which results in the sudden drainage of excess pore pressure.

Materials and Methods
Two sub catchments of the Aruvikkal catchment were instrumented with 15 piezometers in the period June to September 2007, as part of an ongoing research to establish the physical characteristics of the landslides. Three piezometers of the 15 were deployed before the onset of the monsoon. The piezometers used were of the type Keller DCK-22 AA which measures and records ground water levels using a two sensor technology. The submersible depth sensor measures the water level. Barometric pressure variations are measured and compensated with the built-in waterproof air pressure sensor which is mounted in the electronics housing at the top of the borehole (www.keller-druck.com). Of the 15 piezometers, 4 were installed in hollows, with at least 0.7 m of overburden thickness, 7 were installed in terraces with rubber plantations, 2 were installed in other landuse types and 2 were installed at drainage outlets. A low cost wireless automated weather station (AWS) branded Vantage Pro2 (www.davisnet.com), capable of measuring all standard weather variables and solar radiation was established at Meladukkam CSI church (see Figure 1) located in the center of the area at an altitude of 660 m. The logger of the AWS was programmed to record data at an interval of 15 minutes, and could store data for about 45 days given this interval. The data from the 3 piezometers that were installed before June 2007 were analyzed in combination with the AWS data.

Results and Discussion
During the south west monsoon season of 2007 Aruvikkal catchment received 1123 mm rainfall which was 16.3% less than the seasonal LPA rainfall of the area. On the day of the events, the region received 199.8 mm rainfall and the 2 day cumulative rainfall for that day was 278.4 mm. The 2 day cumulative rainfall explains the relatively lesser landslide activity in the region on 22nd June when compared to that of the 6th October 1993 events. Figure 3 shows the 2 day cumulative rainfall and maximum daily rainfall intensity recorded by the AWS during the monsoon seasons of 2007. Figure 4 shows the hourly rainfall and the hourly maximum rainfall intensity from 12.00 pm on 21st June to 12.30 pm on 22nd June. However, such absolute values are only of indicative relevance unless substantiated by long term observations. In situations where long term temporal landslide inventory is unavailable, physically based dynamic models of slope hydrology coupled with slope stability is an ideal alternative for hazard quantification.

The pore pressure responses of the catchment also follow the general trend of the rainfall. Table 1 provides the topographic and land use characteristics of the locations of the three piezometers deployed before the critical date. It also provides the maximum, average of the maximum daily and standard deviation of the maximum daily pore pressure observations of the three piezometers during the south west and north east monsoon seasons. It could be seen from the pore pressure data that the hydrological response of the sub surface started between 8.00 and 9.00 pm on 21st June. From the time of the initial hydrological response of the pores at around 8.00 pm to the beginning of the critical time (6.00 am, 22nd June) of the landslide events 9 hrs later, the pore pressure values remained high.

Figure 5 shows the pore pressure response at each piezometer during a continuous rain spell from 21st June 12.00 pm to 22nd June 12.30 pm. A close observation of the continuous response pattern of pressure waves brings out the transient nature of the hydrological response processes. Piezometers 1 (P1) and 3 (P3) behave similarly in their response to the fluctuations of the rainfall, while piezometer 2 (P2) shows a delayed response. P3 shows much more fluctuations than P1 which may be attributed to the local characteristics of the location such as saturated hydraulic conductivity, soil depth and slope which results in the sudden drainage of excess pore water.

Table 1: Location characteristics, maximum pore pressure response, average of the maximum daily and standard deviation of the maximum daily pore pressure observations of the three piezometers during the south west and north east monsoon seasons

References:

For more information:
Mr. Sekhar Lukose Kuriakose (UNU-ITC), Email: sekkhar.lk@gmail.com
Prof. Dr. V.G Jetten (ITC), Email: jetten@itc.nl
Dr. C.J van Westen (UNU-ITC), Email: westen@itc.nl
Dr. L.P.H van Beek (UU), Email: tvanbeek@geo.uu.nl
Ir. G. Sankar (CESS), Email: gsankar@cessind.org

Conclusion
Preliminary analysis of rainfall and pore pressure data for the south-west and north east monsoon season of 2007 leads to the following inferences:
• A combination of prolonged and high intensity rainfall and corresponding pore pressure variations is the main trigger of landslides in the region.
• Thampi et al., (1998) suggested a minimum rainfall of 300 mm in two days as needed to produce landslides in the region. In light of this research continuous rain spell of 9 hours of the order of 195 mm is sufficient to cause landslides. However, it is too far fetched to say that all rain spells lasting 9 hours amounting to 195 mm will cause landslides, as a rainfall characterization analyzed against corresponding temporal landslide inventory is pending for the region.
• Rainfall thresholds also need to be coupled with the continuous monitoring of pore pressure at representative hollows to be useful in an early warning system for landslides as not all rain spells with the same quantity produces landslides.
• Pore pressure measurements in the hollows indicate that persistent high pore pressure in shallow soils for over 9 hours triggered the mass movements of 2007 in the catchment.
• More specifically, it may be the persistence of critical conditions and not the maximum pore pressure attained at the locations which lead to the slope failures on 22nd June 2007. However, a generalization of the pore pressure thresholds needs long term data or physically based dynamic modeling efforts to be proven useful.