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Identifying pyroclastic and lahar deposits and assessing erosion and lahar hazards at active volcanoes using multi-temporal HSR image analysis and techniques for change detection

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The increasing availability of high-spatial resolution (HSR) remote sensing images leads to new opportunities for hazard assessment in the case of active volcanoes. Object-oriented analysis (OOA) of HSR images helps to simultaneously exploit spatial, spectral and contextual information. Here, we identify and delineate pyroclastic density current (PDC) and post-eruption lahar deposits on the south flank of Merapi volcano, Indonesia, after the large 2010 eruption. GeoEye-1 (2010 and 2011) and Pleiades (2012) images were analyzed with an adjusted object-oriented method. The PDC deposits include valley-confined block-and-ash flows (BAFs), unconfined, overbank pyroclastic flows (OPFs), and high-energy surges or ash-cloud surges. We follow up the evolution of the pyroclastic and lahar deposits through changes in the spectral indices calculated in segmented features, which represent the principal units of deposits and devastated areas.

The object-oriented analysis has been applied to the pseudo image comprising of three spectral indices (NDWI water index; NDVI vegetation index; and NDRSI Red Soil Index). This pseudo image has enabled us to delineate fifteen units of PDC and lahar deposits, and damaged forests and settlements in the Gendol-Opak catchment (c.80 sqkm). The units represent 75% of classes obtained by photointerpretation of the same image and supported by field observations. A combination of NDWI and NDVI helps to separate areas affected by surges (NDWI <0.2 and $0.1<\text{NDVI}<0.3$) from unscathed vegetation ($0.2<\text{NDWI}<0.4$ and $\text{NDVI}<0.16$). NDRSI and NDWI separate the overbank PFs ($\text{NDRSI}<-0.3$ and $0.1<\text{NDWI}<0.2$) from wet or lahar deposits ($\text{NDRSI}>0.3$ and $\text{NDWI}<0.1$). NDRSI values close to 0 are assigned to scoria-rich PFs darker than other PF deposits.

Bivariate analyses of three spectral indices, NDWI, NDVI and NDRSI, show the temporal evolution of the delineated deposits and areas between 2010 and 2012. The NDVI/NDWI 2010 plot shows two clusters: NDVI and NDWI close to 0 are assigned to BAFs deposits while NDWI close to 0 and $\text{NDRSI}<-0.3$ distinguish forests and paddy fields from areas affected by ash-cloud surges. The NDWI/NDRSI 2010 plot displays two clusters: NDRSI close to 0 is assigned to scoria-rich PFs while NDWI close to 0 and $\text{NDRSI}<-0.3$ characterize BAFs. In 2011 and 2012, bivariate analyses reveal two clusters: forest and paddy fields are well separated whereas the broad range of lahar and OPF deposit values overlaps in the NDWI/NDRSI plot.

High-resolution DEMs from low-altitude photographs and pairs of PLEIADES (0.5-2 m) and IKONOS (1 m) images have aimed to measure the mass balance of sediment transported in the Gendol-Opak catchment prior to, and after, the 2010 eruption. Two years after the eruption, lahars have remobilized more than 65% of the PDC deposits. Calculated differences between pre- and post-eruption DEMs reveal high sediment yields (>4 x106/km2/year) from erosion acting in the Gendol valley, which characterize composite volcanoes after a large eruption. HSR images have also helped to measure geomorphic characteristics (channel capacity/wetted section; longitudinal change in channel confinement, and channel sinuosity) of river channels, which favor overbank and avulsion of lahars on a densely populated volcano.