HIGH RESOLUTION SPACE- AND AIR-BORNE IMAGERY PROVIDES INSIGHT INTOSLOPE HYDROLOGY AND INSTABILITY

Janusz Wasowski[1], Marina Dipalma Lagreca[2], Caterina Lamanna[3] and Guido Pasquariello[4]

1. National Research Council, CNR-IRPI, Bari, Italy; j.wasowski@ba.irpi.cnr.it
2. Dipartimento di Scienze della Terra e Geoambientali, Università degli Studi di Bari “Aldo Moro”, Bari, Italy; m.dipalma@ba.irpi.cnr.it
3. c/o CNR-IRPI, Bari, Italy; cate.lama@tiscali.it
4. National Research Council, CNR-ISSIA, Bari, Italy; pasquariello@ba.issia.cnr.it

ABSTRACT

We usehigh resolution multispectral imagery focusing on water as a critical factor of the recurrent instability of poorly drained slopes in a 15.3 km^2 catchment area in the Apennine Mountains (Italy).The present work expands on our recent study that exploited IKONOS-2 imagery of April 2006 for mapping active landslides, investigating their association with seasonally wet zones (areas covered by free surface-water including ponds, migrating surface-water, seeps), and for inferring surface-subsurface water relationships in unstable slopes. We use 0.5 m resolution multispectral orthophotos acquired in March 2011 to map the distributions of active landslides and wet zones. While the former are mapped via visual interpretation of the imagery, the latter are first identified using supervised classification and two commercial remote sensing software, and then cross-checked via visual interpretation. The comparison of the results indicates that semi-automatic methods can assist in mapping wet areas, but controlsvia visual analysis along with a good knowledge of local slopeconditions are necessary to extract reliable information.A comparative analysis of 2011 and 2006 inventories demonstrates significant recurrence of active landslides and wet areas, as well as their close spatial associations. This represents important input for temporal and spatial landslide hazard assessments. Thus it is suggestedthat high resolution multispectral space- and air-borne imagery should be more often exploited in landslide investigations.

INTRODUCTION

Remotely sensed data are typically used for landslide detection and mapping, and ultimately for generating digital landslide inventories(1,2). Our review of recent literature on landslides (3 and references therein) indicates that only few slope instability investigations attempted to use high resolution multispectral imagery to estimate moisture or water content of ground surface materials. The main purpose of this work is to show that,if such imagery is acquiredtowards the end of the wet season (higher groundwater levels and susceptibility to landsliding), it can provide useful information about surface-water conditions on slopes and thus be better exploited in landslide studies. We also test the applicability of supervised classification methods, available through commercial software, for semi-automatic identification and mapping of wet areas on slopes.

This work builds up on our recent studies that exploited IKONOS-2 imagery of early spring 2006 for mapping active landslides, investigating their association with seasonally wet zones (areas covered by free surface-water including ponds, migrating surface-water, seeps), and for inferring surface-subsurface water relationships in unstable slopes (3,4). In particular, for comparative reasons we exploit another set of data, i.e. sub-meter resolution multispectral orthophotos acquired over the same study area in late winter of 2011 to map the distributions of active landslides and wet zones, and to investigate their associations.

The study area is located in the southern portion of the Apennine Mountains (southern Italy), called the Daunia Apennines and known for recurrent slope instability problems (3,4). We consider a 15.3 km^2 catchment area traversed by a mid-slope road, which is now closed to traffic because of landslide damage (Fig. 1).The area has moderate relief topography, with elevations below 800 m and modest slope inclinations (~10° on average). The climate is Mediterranean subhumid (sub-Apennine) with annual rainfall values from 400 to nearly 1000 mm. The predominance of clays with weak geotechnical properties and poorly drained slopes are the main causes of landsliding (3,4).

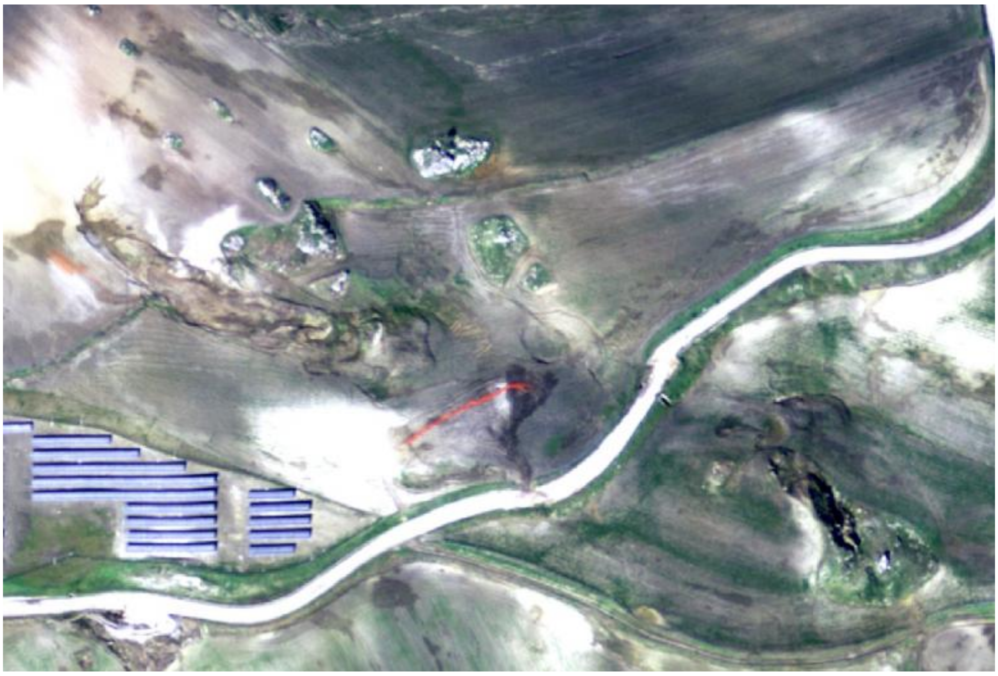


Figure 1 : Orthophoto from March 2011 showing an example of about 100 m wide and few hundred meters long road-damaging landslide that extends from upper left to lower right corner of the image; associated wet areas can be recognized through the tonal differences (darker tones).

MATERIALS AND METHODS

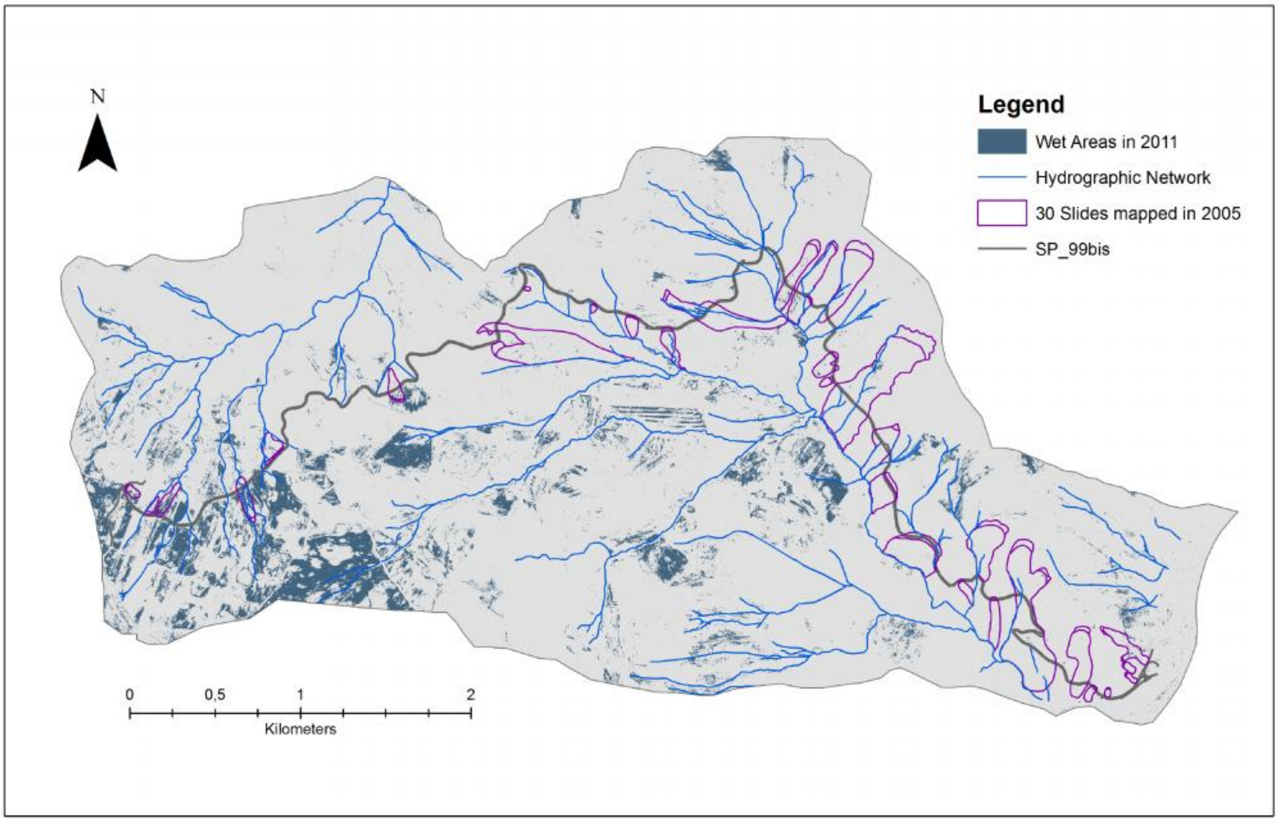
The imagery and spatial information used in the present work included:

- IKONOS-2 multispectral imagery acquired in April 2006
- 0.5 m resolution multispectral orthophotos acquired in March 2011
- Inventory maps of 30 landslides that in 2003-2005 damaged the road in the catchment and of landslides active in 2006 (from 3,4)
- Digital Elevation Model (DEM) derived from 1:5000 scale topographic map (from 2002)
- Inventory of wet areas in 2006 based on visual (on-screen) interpretation of IKONOS-2 imagery (from 3,4)

In addition, we compiled inventories of wet areas and active landslides (in March 2011)via visual interpretation of the orthophotos. Furthermore, using ERDAS7.09 and ENVI6.12 software and supervised classification methods, we compiled maps of wet areas in 2006 and 2011. The spatial datasets were collated and analyzed using ArcGIS10.1 software.

RESULTS

Figure 2shows the outcomes of supervised classifications of 2011 orthophotosaimed at detecting wet areas. The comparisonof the results obtained using ERDAS and ENVI indicates similar distributions and percentages of wet areasin the catchment (respectively 7.1 and 6.1%). Figure 2 also shows close associations between some of the road-damaging landslides, identified in the field in 2005 and re-mapped using 2006 IKONOS-2 imagery, and the wet areas.



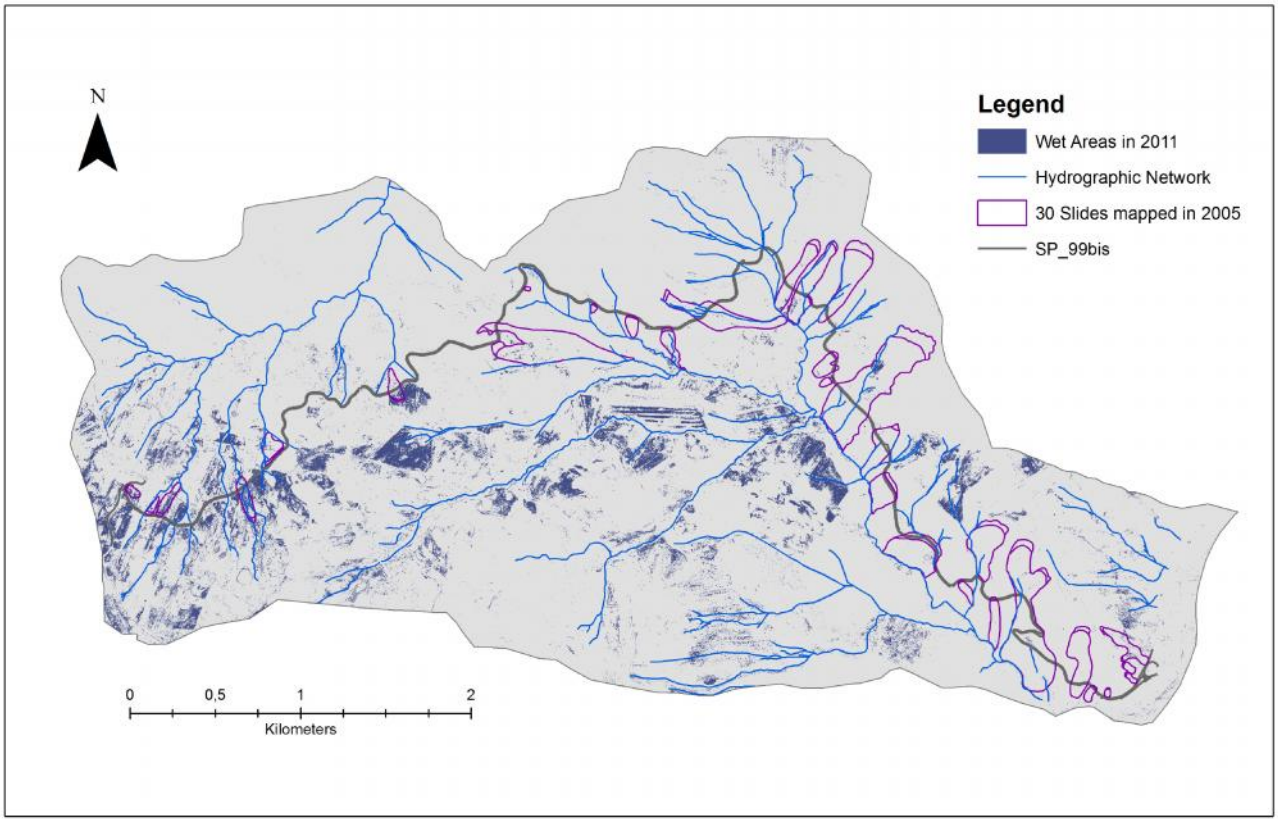
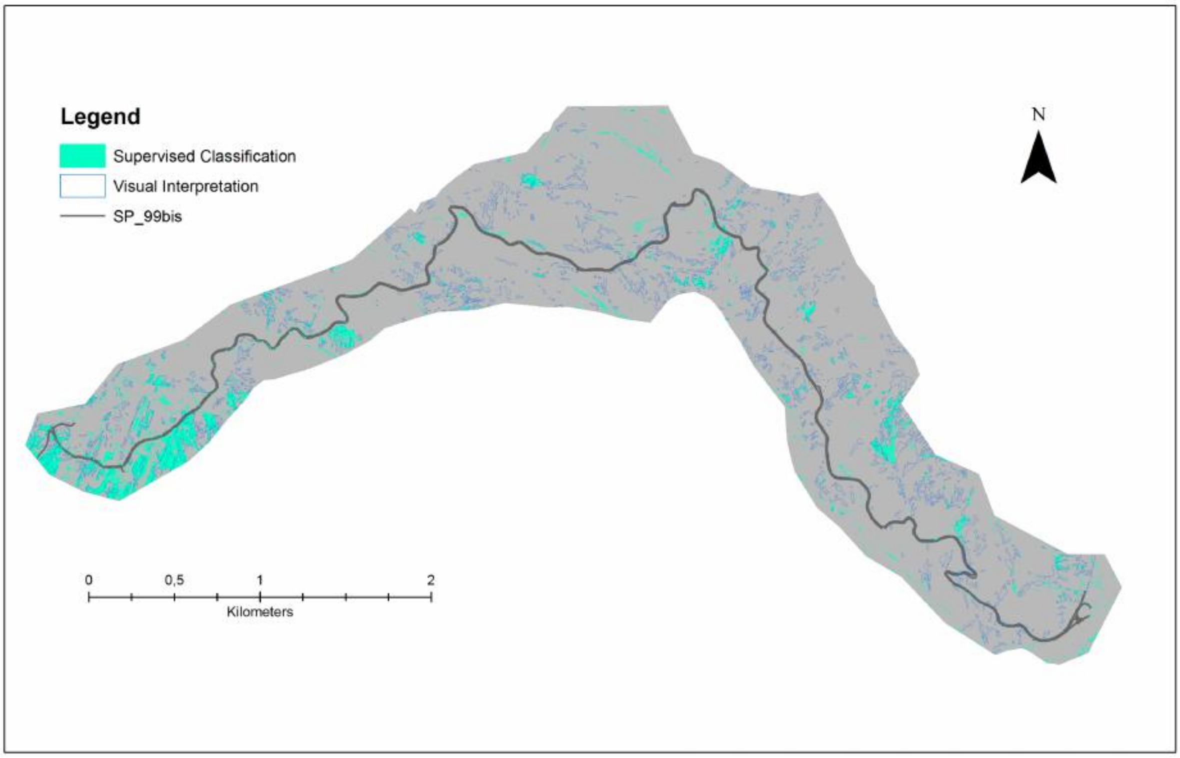


Figure 2: Distribution of wet areas on 11 March 2011 from supervised classification of 0.5 m resolution multispectral orthophoto using ERDAS (Upper figure) and ENVI (Lower figure) software. Note also 30 road-damaging landslides; SP_99bis = name of the road.

We also performed visual interpretation of 2011 orthophotos to compile a map of wet areas for a 5.6 km^2portion of the catchment centred around the road (Fig. 3). The intentionwas to provide an additional check of the results obtained via supervised classification (using ENVI software).



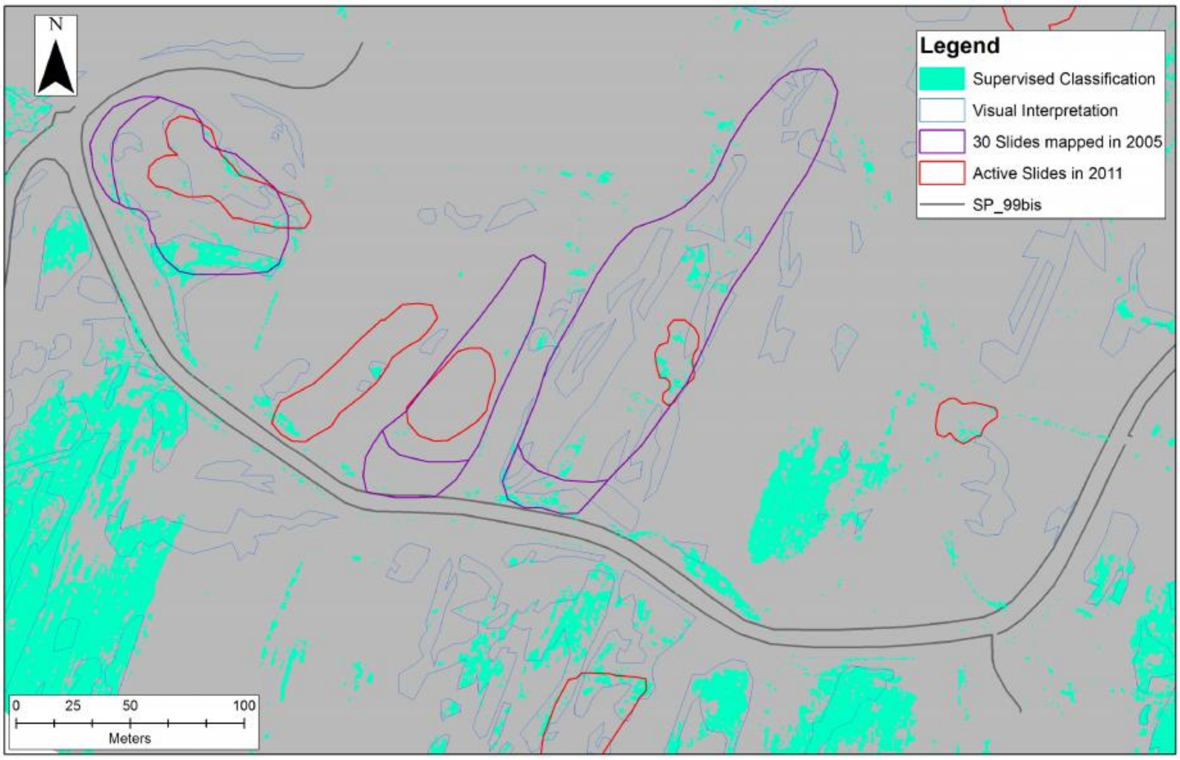


Figure 3:(Upper) Distributions of wet areas in March 2011 on slopes traversed by SP_99bis road,from supervised classification and from visual interpretation;(Lower) Close-up of the western-most part of the Upper figure showing also major 2005 landslides and landslides active in 2011.

The comparisonof the distributions of wet areas obtained from supervised classification and visual interpretation shows that there are significant differences, especially at a local scale (Fig. 3).

Nevertheless, in many cases there is considerable overlap of the wet areas. Furthermore, a persistent association of wet areas and unstable slope portions can be indicated by consideringthe distributions of 2005 landslides and landslides active in 2011.

We also attempted to quantify the degree of overlap between the wet areas identified via supervised classification and those obtained from visual interpretation. The results show that over 50% of the wet areas classified semi-automatically fall within the wet areas mapped via visual interpretation (Fig. 4). Furthermore, a close association can be indicated for an additional ~35% by considering a 10 m wide buffers around the visually interpreted wet zones.

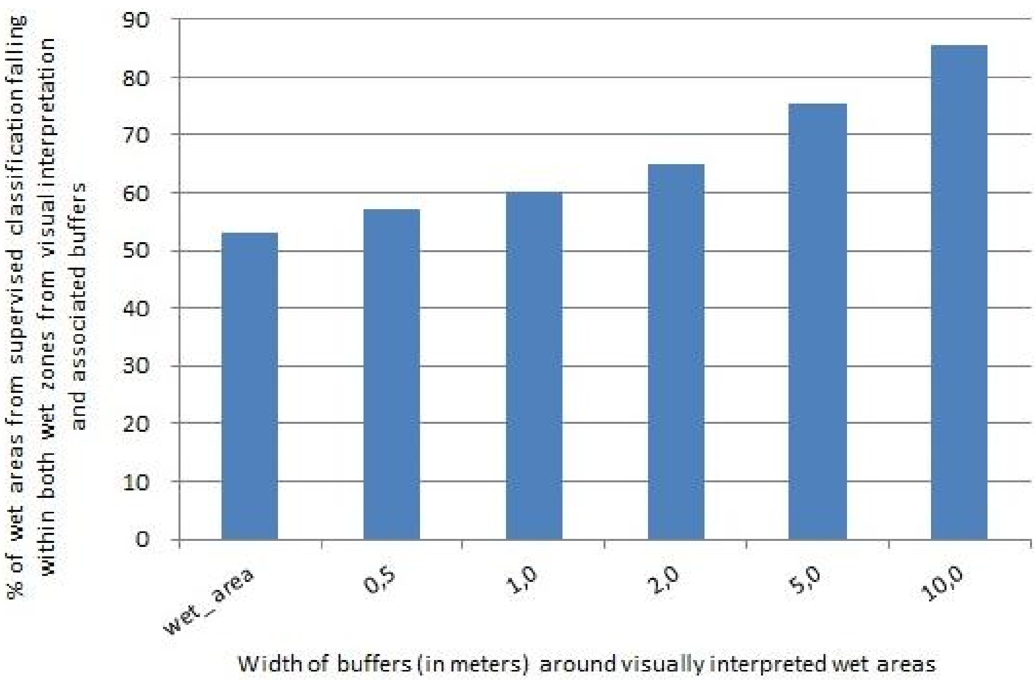


Figure 4: Diagram based on the intersection of wet areas obtained from supervised classification (using ENVI) and from visual interpretation of March 2011 orthophoto. Over 85% of classified wet areas can be associated with the visually recognized wet areas by adding10 m wide buffers.

Furthermore, we examined the spatial recurrence of wet slope conditions in late winter-early spring period using intersection of the results obtained from visual interpretation of 2006 IKONOS-2imagery and supervised classification of 2011 orthophoto. At the catchment scale it would appear that a spatio-temporal recurrence, i.e. the repeated presence of wet areas in the exactly the same locations, is limited (Fig. 5). Nevertheless, locally there is a considerable overlap of the wet areas, i.e. surface-water or wet ground conditions are recognized on the same slope portions on both 2006 and 2011 imagery.

Finally, a simple overlay of three temporally distinctive landslide inventories (from 2003-2005, 2006 and 2011) and the 2006-2011 wet area intersection shows once again that some slopes with recurrent landslide activity are closely associated with seasonally persistent wet ground conditions (Fig. 5). For example, this is evident in the western-most portion of the studied catchment, especially when examined on a local scale. Indeed, as previously shown through an extensive borehole piezometer investigation (2), a number of remotely sensed wet zones are indicative of sites with seasonally persistent very high groundwater levels within landslide-prone slopes and on intermittently active landslides.

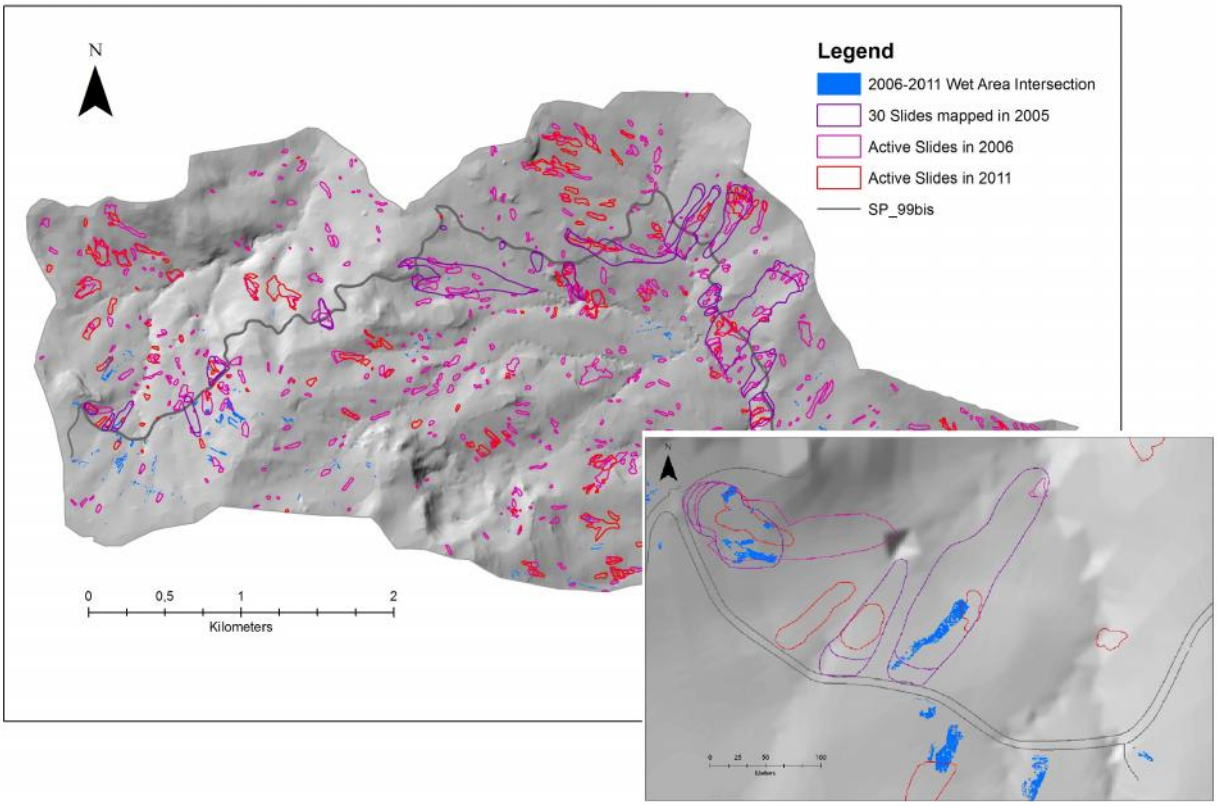


Figure 5: Distribution of recurrently wet areas based on intersection of 2006 (IKONOS-2) and 2011 (orthophoto) results obtained, respectively, from visual interpretation and supervised classification. Close-up of the western-most portion of the larger figure highlights associations of wet zones withroad-damaging landslides imapped in 2005 and landslides active in 2006 and 2011.

CONCLUSIONS

The results of our case study suggest that high resolution multispectral space- and air-borne imagery can be used not only for compiling landslide inventories, but also provide valuable insight into slope instability processes by assisting in the identification of seasonally recurrent wet areas on slopes susceptible to instability. However, further efforts are needed to test performance of semi-automatic classification of wet areas in different settings. The present work indicates that useful information about surface-water conditions can be obtained in settings with shallow slope topography, clay-rich lithology and land use/land cover dominated by agricultural soils (with little woodland).

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