Vilímek *et al. Geoenvironmental Disasters* (2016) 3:5
DOI 10.1186/s40677-016-0039-8

Geoenvironmental Disasters

SHORT REPORT **Open Access**

Reassessment of the development and hazard of the Rampac Grande landslide, Cordillera Negra, Peru

Vít Vilímek[1*], Jan Klimeš[2] and Marco Torres Zapata[3]

Abstract

Background: The initial investigation analysed the complex Rampac Grande slope deformation from April 2009 (Landslides 8(3):309-320, 2011). The primary research in 2009 also identified an unrealistic explanation (raw mineral exploration) of the triggering of the landslide and the intention of the local authorities (from the administration centre of Carhuaz) to take measures to minimize the possible future risk to the local population. We also examined the adaptation measures introduced by the local authorities to reduce the risk for the local community.

Findings: Unstable landslide material has been left after the 2009 event in the sources and transportation zone and several blocks were described as being only in a temporarily stable state. Landslide propagation could also follow the already existing lateral tension cracks identified in 2009. Areas of reactivation from 2012 were localized and triggering precipitation was evaluated.

Conclusion: This study concluded that there is still a hazard of remobilization of specific parts of the landslide in Rampac Grande with potentially damaging effects on the buildings located close to the accumulation area.

Keywords: Landslides, Natural hazards, Cordillera Negra, Peru

Findings

Introduction

The aim of this article is to describe the recent state of development of the catastrophic Rampac Grande complex landslide (Fig. 1) and to use newly available information to reassess the hazard level of this landslide for the local community, because we suppose that this experience might be useful for other landslide prone areas in Calleyon de Huaylas (Department Ancash). This landslide occurred on the 25th of April 2009 and was studied by Klimeš and Vilímek (2011). Several slope deformations were described in the close vicinity of the village of Rampac Grande in the past (e.g. Barrón 1972). Two landslides were reported as having destroyed houses directly within the neighbouring Rampac Chico community (Zapata 1966). The surrounding area in general is landslide prone, with several landslides also being identified in Cordillera Negra after a significant rainy period during the El Niño of 1997/98 (Vilímek et al. 2000).

The area of Rampac Grande landslide is located within sediments of Middle/Upper Cretaceous age (INGEMMET 1995). The rocks contain argillite and schist interlaid with sandstones, limestone and small amount of gypsum. Sediments are highly permeable due to fracturing and their weathering (Gutierrez et al. 2004). The Rampac Grande has been classified as a complex landslide with rotational character in the most upper part and significant translational character transforming into flows in the middle and lower sections (Klimeš and Vilímek 2011). The complex landslide exaggeration is 383 m and maximum length and width are 863 and 450 m.

Water infiltrates the landslide area through superficial sediments and deep gullies, which in some places cut up to 20 m into the massif enabling the water to reach deeper layers of the bed rock. The topographic infiltration area of the complex landslide is only about 3 Km^2, but based on our field observations and morphology of the surrounding slopes, it may be more than twice as large

---

* Correspondence: vit.vilimek@natur.cuni.cz
[1] Department of Physical Geography and Geoecology, Faculty of Science, Charles University, Albertov St. 6, Prague 2 128 43, Czech Republic
Full list of author information is available at the end of the article

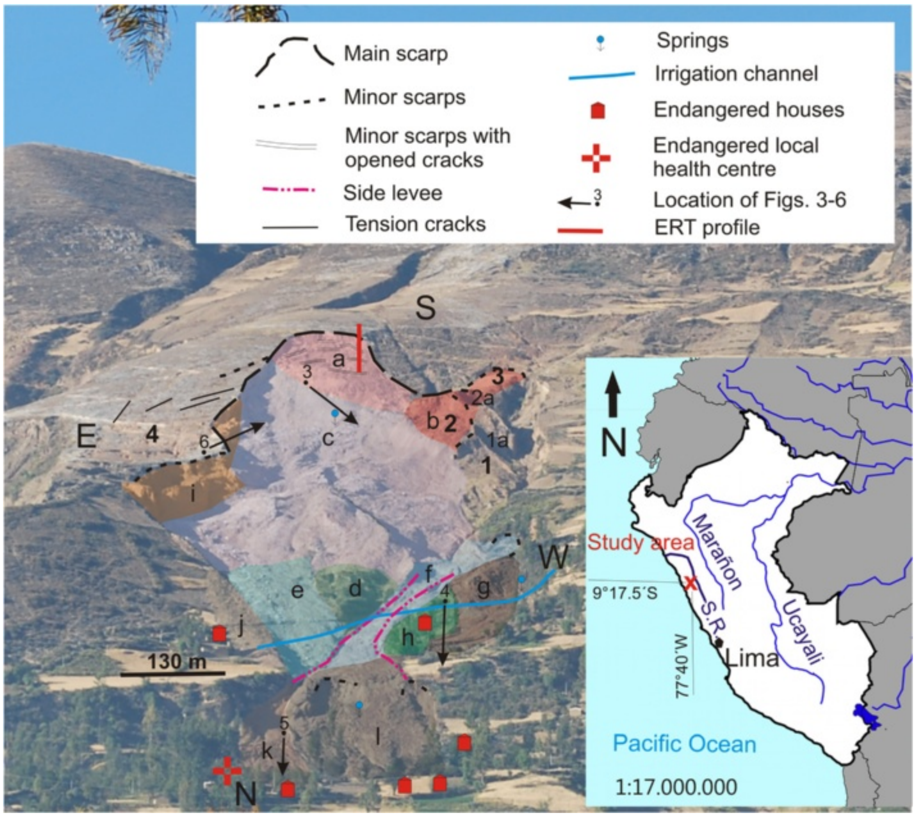

Fig. 1 An oblique photo of the complex landslide (after Klimeš and Vilímek, 2011). Different parts are categorized according to their prevailing character: a) scarp; b) hanging blocks in an unstable position; c) zone of depletion; d) stable part probably without any movement; e) and f) transport area; g) accumulation zone; h) stable part probably without any movement; i) detached rock block; j), k) and l) accumulation zones. Unstable blocks (1, 2, 3 and 4); partial landslides 1a, 2a

as the topographic infiltration area. Observation of the fissure spring at the NW border of landslide with measured outflow of 0.07 l/s supports this opinion (Klimeš and Vilímek 2011). This water infiltration may occur deeper into the massif.

All natural hazards in the department Ancash were analysed (Vilímek et al. 2013) in terms of frequency of recurrence (in the period 1971-2009). The analyses revealed that the most frequent type of natural hazard was "alluvion" (a local term for debris flow), followed by floods and extreme rainfall. If we group various forms of mass movement together, they comprise a dominant portion among natural hazards. A major portion of natural hazards are generated by the direct impacts of extreme hydrometeorological events.

The research carried out on landslides which maintains a state of marginal instability (e.g. Carey et al. 2015) revealed the importance of the relationship between the level of groundwater and pore water pressure. With respect to the fact, that our area of study does not allow us to equip the landslide like in less remote areas, we are looking at the influence of precipitation on slope movement reactivation. For instance Longoni et al. (2016) combined geological, geomorphological and geophysical data for the Ronco landslide study (Northern Italy). They also stressed the necessity of diverse sources in study of complex landslides because of the possible data uncertainty what is also true for our locality in the Cordillera Negra.

There are several reasons why we returned to this area and by using field research and a comparative study of photos we tried to reassess the landslide hazard. In general we consider the area as being unstable because some material has been left in the transportation zone; moreover some blocks are still in only a temporarily stable state. The rainy seasons following 2009 were analysed and compared with the triggering conditions in 2008/2009. Landslide propagation could follow the already existing lateral tension cracks identified in 2009.

Methods

We carried out field research focusing on the use of previously gathered data (Klimeš and Vilímek 2011) to assess the processes (their type and intensity) that occurred within the landslide since the first investigations and also to collect new information, which may be useful in evaluating the recent hazard level that the landslide imposes on the local community. In order to achieve this we first compared field photographs from the primary research (July 2009) with recent ones (May 2014) to identify processes ongoing within the landslide and in its close surrounding. Four pairs of pictures (Figs. 2, 3, 4 and 5) are presented here to reveal the main morphological changes; we tried to take the pictures from more or less the same distance and angle.

The rainy seasons following 2009 were analysed and compared with landslide triggering conditions in 2008/2009. The precipitation record was analysed from the point of view of cumulative data as well as short term precipitation. Unfortunately, no station exists directly around the landslide. We had to use the Yungay (22 km to the NW, 2 530 m a.s.l.) and Huaráz (27 km to the SE, 3 050 m a.s.l.) stations, which are both available on www.senamhi.gob.pe.

Electric resistivity tomography (ERT) was used to investigate subsurface conditions within and outside the 2009 landslide, searching for potential sliding planes susceptible to reactivation. We constructed one profile across the main scarp (Fig. 1) in a place where we suspected possible future sliding activity due to the location of a spring just below the main scarp. We used a 4point light hp 10w (Grinat et al. 2010) instrument with 27 electrodes on three chains with a 3 m electrode spacing and maximum depth penetration of 12 m. Different arrangements of electrodes (e.g. Schlumberger, Wenner and dipole-dipole) were used and the obtained apparent resistivity values were processed in RES2DINV software using the least-squares inversion method in order to represent the true resistivity of the subsurface. We performed a maximum five iterations, keeping the root mean square (RMS) error below 10 %.

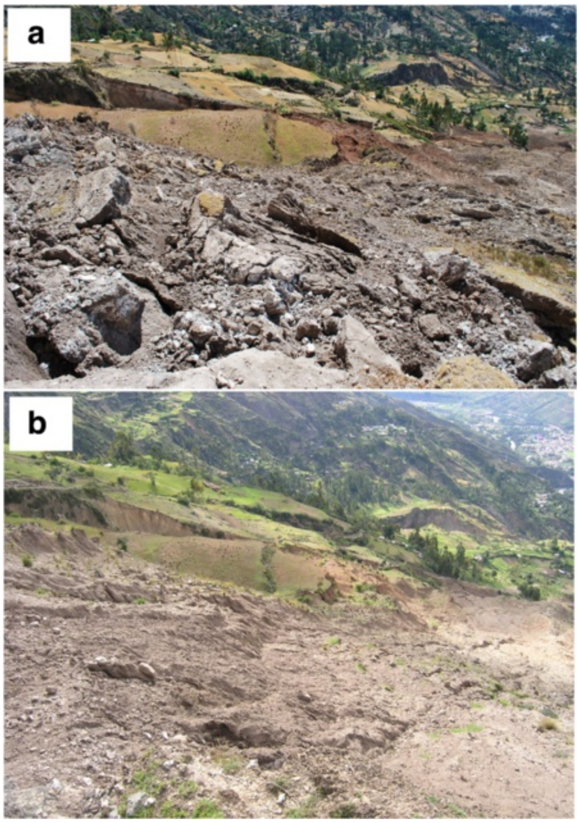

Fig. 2 a from 2009, **b** from 2014. Some material in the source area has been washed out down the slope since 2009

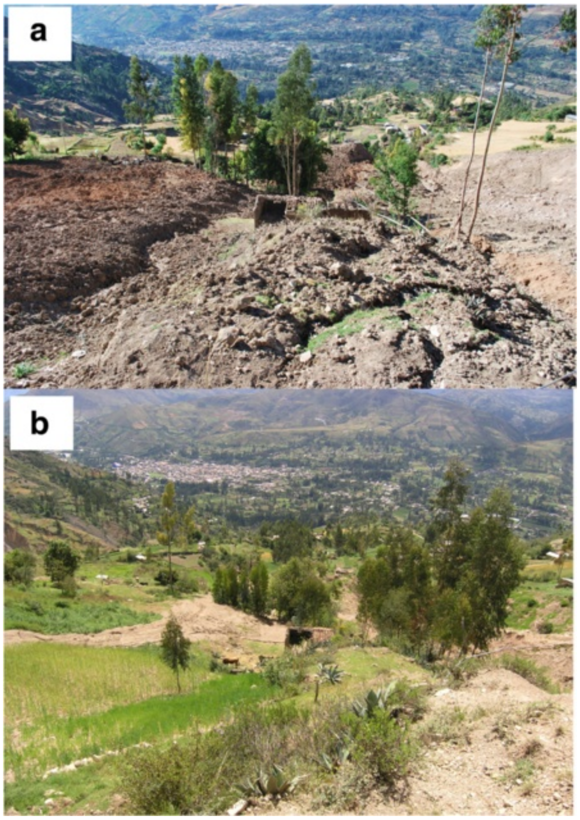

Fig. 3 a from 2009, **b** from 2014. A new flow accumulation was placed on the body of the complex landslide from 2009 – this time it arrived from a ravine located in the close vicinity of the complex landslide

Results

Precipitation data analysis

The deep-seated movement at the end of the 2008/09 rainy season was due to significant cumulative precipitation, reaching 950 mm, with the precipitation reaching a total of 229.6 mm during March 2009 (Klimeš and Vilímek 2011). During the periods 2011/12, 2012/13 and 2013/14 the monthly totals during the rainy season were much lower, with the highest being between 100 and 200 mm at the Yungay station (January to March). The level of precipitation in March 2013 reached only 205.7 mm and January 2013 was rather dry.

Fig. 4 **a** from 2009, **b** from 2014. The younger photo (**b**) shows fresh vegetation on the surface of the flow from 2009, but also a young accumulation in the right part of the depositional area

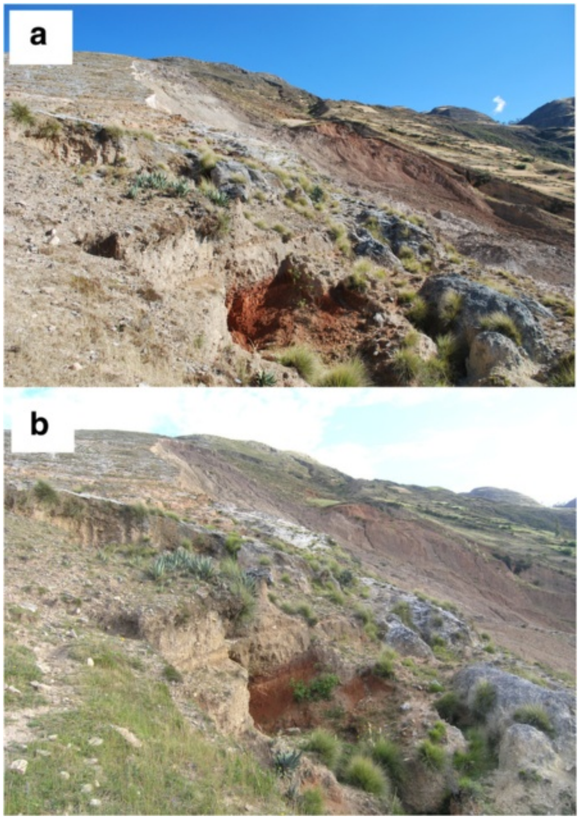

Fig. 5 **a** from 2009, **b** from 2014. The erosion activity in the direction of tensional crack in the lateral parts of the complex landslide is possible to see by comparing pictures **a**) and **b**)

According to Mejía and Meza (2012) complex landslide reactivation occurred on the 19th of April 2012 at 9.00. First of all we checked short term precipitation, because the reactivation affected only surficial part of the former complex landslide from 2009. Surprisingly, the short term precipitation was very low at both of the nearest stations in the surrounding area (daily amount of 6.1 mm at the Yungay station and 2.3 mm at the Huaráz station). One week precipitation totals reached 45.1 mm in Huaráz and 35.9 mm in Yungay; 30 day totals were 142 mm in Yungay and 177.5 in Huaráz. These rainfall intensities were reached several times per year during the last decade and therefore they seem unlikely to be responsible for this reactivation. For instance, the precipitation record for the 9th of March 2012 reached 48.9 mm (see Table 1) and no reactivation was reported. Also the other months during the rainy season were without any exception from the average—for Yungay station: February total 136.6 mm; January total 91 mm and for Huaraz station: February total 142.6 mm; January total 104,3 mm. To explain the reactivation during the 19th of April 2012 (Mejía and Meza 2012) we assume that there must be a large difference in the volumes of short term precipitation and that the triggering event during the 19th of April (or the day before) was not registered at the nearest stations. The fact that there large differences in short term precipitation were registered at both stations in the past can be documented in Table 1.

Areas of reactivation

Some areas of the Rampac Grande landslide were reactivated but the activity could not be compared with the 2009 event. We identified remobilization of the landslide material in the scarp area—'a' (Fig. 1) which was considered as being highly unstable by Klimeš and Vilímek (2011). In addition to Mejía and Meza (2012), local people confirmed the sliding of this material, which probably occurred during the 2013/14 rainy season. The reactivation also involved the head scarp, which retreated by at least

Table 1 Some examples of variation in daily precipitation between the 2 nearest stations to the landslide locality in Rampac Grande

Station	19/11/2010	9/3/2012	24/3/2012	4/1/2014
Yungay	40.2 mm	7.5 mm	27.5 mm	0 mm
Huaraz	1.1 mm	48.9 mm	2 mm	27.5 mm

1 m. We were not able to distinguish the accumulation of the slide material from the original one.

The main reactivation in Rampac Grande happened during the 19th of April 2012 (Mejía and Meza, 2012) and is probably based on the intensive, short term precipitation which activated only the near surface layers in zone 'c' (Fig. 1). Remobilisation of accumulation produced two smaller debris flows which we identified in the eastern as well as western part of the landslide area—'k' and 'g' (Fig. 1).

Geophysical research across the main landslide scarp revealed the highly variable properties of the slide mass with regions of higher resistivity probably formed by more compact rocks and low resistivity patches which could be related to a spring observed some 10 m to the east of the profile. Sharp transition of resistivity values from high to low across short depth along with modelled geometry of this boundary suggest presence of water saturated material which may. It may represent possible future sliding plane of a shallow (approximately 6 m deep) landslide (Fig. 6). Due to the limited depth penetration, the main sliding plane could not be identified.

A comparison of historical photographs (from 2009) revealed a large remobilization of the landslide material to the left of the transportation zone (Fig. 2a,b). Processes responsible for this remobilization are mainly water erosion starting as sheet erosion and propagating to rill and gully forming erosion. The most prominent gully formed along the east side of the landslide ('e', 'k' in Fig. 1) reaching a depth of up to 6 m in the accumulation area. This gully re-established the main drainage which existed before the landslide formation (Klimeš and Vilímek 2011) and now drains the whole landslide body. A similar process is responsible for considerable removal of the material from the western part of the landslide ('b' in Fig. 1) and in the place where the irrigation channel crosses the landslide. A freshly looking debris flow (200 m long) with a source area outside the landslide probably appeared during the 2013/14 rainy season. It deposited a thin layer (0.4 m) of material reaching the main landslide accumulation area ('l' in Fig. 1).

Along the incision of the 'traditional' stream, an accumulation of new material was deposited in the accumulation part of the landslide (Fig. 4a,b). We assume it was deposited by reactivation in 2012. The major process involved the removal of material from the landslide area is water erosion—flows with high sediment loads.

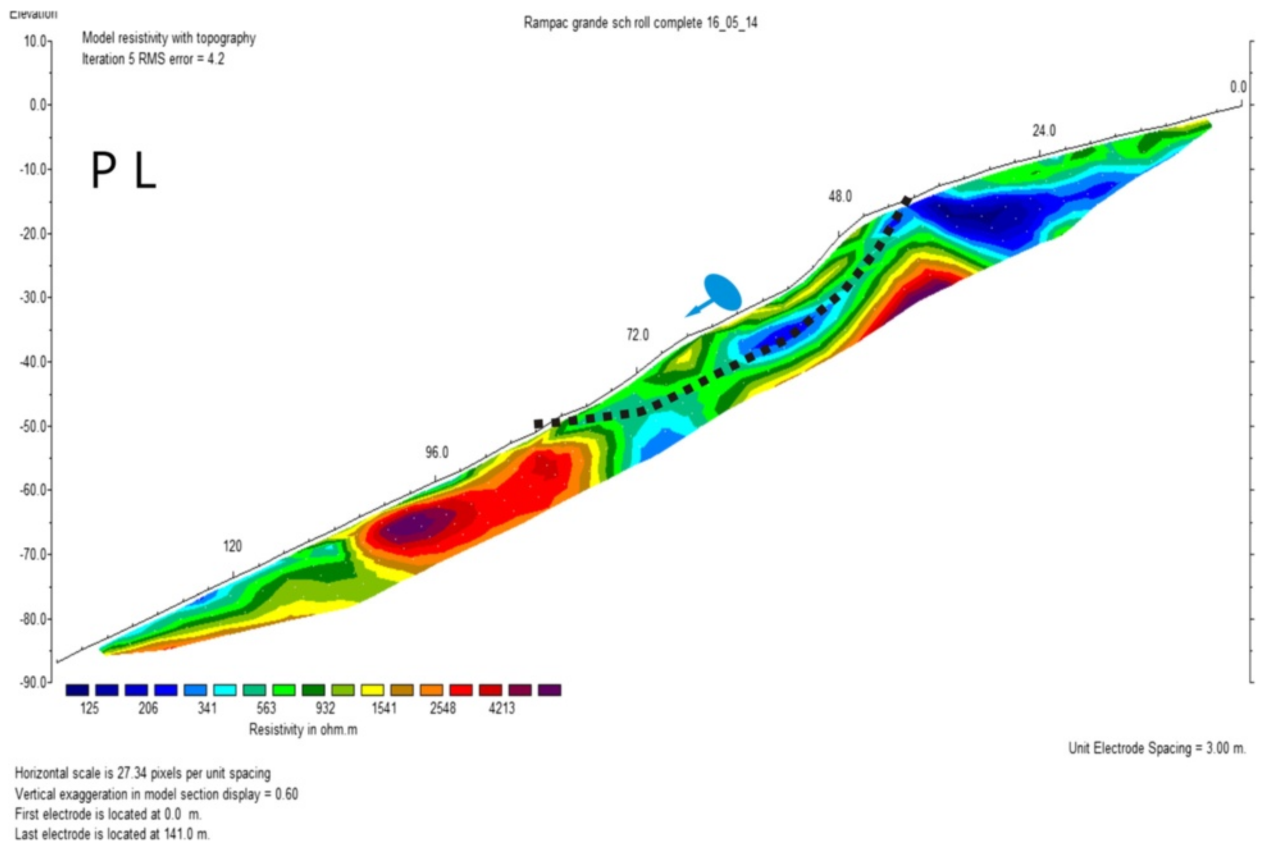

Fig. 6 The ERT profile (Schlumberger electrode array) across the main landside scarp. The dashed black line shows the suggested slip surface of the shallow landslide below the main scarp where the spring is also shown

Geomorphological characteristics

The main changes in the landscape evolution of the landslide area are connected with fluvial erosion. The un-vegetated surface began to be modulated by rill erosion and the former water drainage created just after the landslide event is specified by deep-ward erosion (up to 5 m). The identification of types and intensity of fluvial erosion is important because it works as a destabilising process for possible future mass movements. Many open cracks were identified on the eastern margin of the complex landslide but not in the uppermost part. Future propagation of cracks will destabilise the side areas (Fig. 5).

Removal of the landslide material which occurs mainly by water erosion results in steepening of the slopes within the scarp and upper transportation area of the landslide and also creates longer slopes below landslide parts that were described as unstable in 2009 (numbers 1, 2, 3 and 4 in Fig. 1). We consider this process to be especially dangerous in the case of three individual landslides (numbers 1, 2, 3 and 4 in Fig. 1) as landslides 1 and 2 are exposed to continuous and quite intensive unloading at their toes. They have clear scarps with evidence of vertical movements of 5 m (landslide 1) and 7 m (landslide 2), which occurred during 2009. There are also two temporarily stable landslides (1a, 2a on Fig. 1) just next to them. Along with the toe unloading, we assume that weathering of the loosened landslide material mainly along the shear planes further diminishes their stability. Considering these recent processes and the long history of landsliding in this area, we consider it highly probable that landslide 1 or 2 (Fig. 1) will undergo major movement in the next 50 years.

Mapping of tension cracks (4 on Fig. 1) suggests a deep discontinuity crossing the narrow ridge to the east of the Rampac Grande landslide. Possible future propagation of these cracks may result in mobilization of approximately 25,000 m^3 of the estimated volume of the rocks causing a smaller scale disaster than the landslide in 2009. Recent knowledge does not allow us to estimate the hazard degree of such a scenario. Nevertheless, the 2009 landslide proves it is feasible; therefore, we recommend establishing a long term project of monitoring of this part of the landslide, whose main requirement is a positive approach of the local community and their active involvement in the monitoring.

Interaction of the community and natural hazards

Despite the large attention the event attracted in the days following its occurrence and the largely proper rescue action of the local authorities, all of the governmental organizations on various different levels failed to take any effective action to lower the possible future risk caused by the event. The local community still largely believes that the landslide occurred due to mineral exploration; there are no signs informing of the danger the landslide still possess (e.g. new material in the accumulation area) and only minor technical measures were taken to try to stabilize the landslide. Unfortunately, no changes have been made in the settlement and several houses are directly endangered by a similar event to 2009 (see Fig. 1). Also, there are no signs warning the local inhabitants that the landslide area still poses a danger to them and they should be ready to evacuate or should consider this hazard when using the land for agriculture or when living directly below the landslide.

The local community begun to grow small trees over the landslide accumulation where the slope inclination is lower and some small areas are covered by crops (according to the field visit in 2014); nevertheless, the density of the vegetation cover is still low. Moreover, the local community has begun to utilize the landslide area (e.g. establishing fields, planting fruits, and crossing it with cattle) for everyday use, which may strengthen their understanding of the landslide as an integral part of their environment. Such a mental image does not contribute towards vulnerability reduction.

To change these unfavourable conditions with respect to possible future landslide risk mitigation, development project of the Czech Development Agency will be conduct during 2016. It aims on landslide hazard dissemination among the local inhabitants, identification hazardous and safe areas around the landslide placing evacuation signs to show the proper evacuation rotes in case of the landslide reactivation. Simple but reliable manual tape extensometer monitoring of the most dangerous landslide parts will be also established involving also placement of rain gauge station on convenient site near the landslide. The provincial government of Carhuaz is involved and supports these activities.

Discussion

The uncertainty of the precipitation analysis is not only due to the small differences of the positions between the landslide head scarp and the rain gauge stations (elevation and position inside the valley) but also the local differences in the precipitation records even within short distances because of the high mountains in the surroundings. During the time when the Yungay station registered very high short-term precipitation (see Table 1) the Huaráz station which is 48 km away from Yungay showed only low amounts per day (and also no significant rains occurred a few days before or after). This means that the local differences in precipitation in such a high mountain area are very significant, and we cannot be completely sure of the exact triggering totals of precipitation. Similar situation we already described in another part of Peruvian Andes (Vilímek et al. 2006).

Conclusion

Five years on from the main Rampac Grande landslide only small reactivations have been identified; nevertheless, several parts of the complex landslide were unstable in 2009 and continuing fluvial erosion enhanced this hazard. The comparison of precipitation revealed that the reactivation identified by local people as taking place on the 19th of April 2012 did not match any enormous precipitation event at the nearest stations.

The anthropogenic measures are both positive and negative. The revegetation could be considered as positive measure even if it is not sufficient. The negative influences unfortunately prevail e.g. a simple water pipeline is crossing the landslide body and in the case of any rupture the concentration of water into the landslide area will be a problem, and on the other hand the local people avoid the possibility of concentrating the water flow out from the landslide area (western margin). They have also not refused any directly endangered houses (Fig. 1) and have even not informed the local residents about the hazard. The wrong idea about the triggering factor in the village is still evident—they are afraid of mining, the effects of which have not been confirmed and are not too worried about high precipitation, which will be of greater importance in the future (especially during El Niňo). It seems that the local population are not sufficiently educated about the landslide hazard and do not reflect it in their everyday lives, which creates negative conditions for future disasters.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

All of authors performed the field research. Vít Vilímek analysed the precipitation and Jan Klimeš with Marco Zapata Torres carried out the geophysical investigation. All of the authors drafted, read and approved the final manuscript.

Acknowledgements

This work was carried out thanks to the support of the long-term conceptual development research organisation RVO: 67985891.

Author details

[1]Department of Physical Geography and Geoecology, Faculty of Science, Charles University, Albertov St. 6, Prague 2 128 43, Czech Republic. [2]Institute of Rock Structure and Mechanics, Academy of Sciences, V Holešovičkách 41, Prague 8 182 09, Czech Republic. [3]Pontificia Universidad Catolica del Peru, Av. Universitaria 1801, Lima, Peru.

Received: 16 November 2015 Accepted: 8 April 2016

References

Barrón G 1972. Deslizamentos de tierrasen Rampac Chico, provincia de Carhuaz. *Unpublished report* Electroperu S.A., Glaciology y Seguridad Lagunas, Huarás, Ancash, Peru. I-Geotec-007, p 3

Carey JM, Moore R, and Petley DN 2015. Patterns of movement in the Ventnor landslide complex, Isle of Wight, southern England. *Landslides* 12(6): 1107–1118.

Grinat M, Südekum W, Epping D, Grelle T, and Meyer R 2010. *An Automated Electrical Resistivity Tomography System to Monitor the freshwater/saltwater Zone on a North Sea Island*, Extended abstracts. Zurich: 16th European Meeting of Environmental and Engineering Geophysics.

Gutierrez FM et al 2004. Mapa de peligro, plan de usos del suelo y medidas de mitigacion ante desastres, ciudad de Carhuaz. *Unpublished report* Proyecto INDECI PNUD PER/02/051, Carhuaz, Ancash, Peru, p. 222

INGEMMET: Carta Geologica del Peru, *Map* 19-h Carhuaz, M 1:100 000, 1995, Lima

Klimeš J, and Vilímek V 2011. A catastrophic landslide near Rampac Grande in the Cordillera Negra, northern Peru. *Landslides* 8(3): 309–320.

Longoni L, Papini M, Brambilla D, Arosio D, and Zanzi L 2016. The role of the special scale and data accuracy on deep-seated gravitational slope deformation modeling: The Ronco landslide, Italy. *Geomorphology* 253: 74–82.

Mejía JMS, Meza LR. Informe No. 102 – PMS/DATYDC. Informe Tecnico de Defensa Civil, *Unpublished report*, 2012, p. 6

Vilímek V, Zapata ML, and Stemberk J 2000. Slope movements in Callejón de Huaylas, Peru. *Acta Univ Carol Geogr* 35(Supplementum): 39–51.

Vilímek V, Klimeš J, Vlčko V, and Carreño R 2006. Catastrophic debris flows near Machu Picchu village (Aguas Calientes), Peru. *Environ Geol* 50(7): 1041–1052.

Vilimek V, Hanzlík J, Sládek I, Šandová M, Santillán N 2013 . The Share of Landslides in the Occurrence of Natural Hazards and the Significance of El Niño in the Cordillera Blanca and Cordillera Negra Mountains, Peru. – In Sassa K, Rouhban B, Briceno S, McSaveney M, He B (eds.): *Landslides: Global Risk Preparedness*, 133-148, Springer, 385 p.

Zapata ML 1966. Deslizamento de tierras en Rampac Chico (Carhuaz). *Unpublished report* Electroperu S.A., Glaciology y Seguridad Lagunas, Huarás, Ancash, Peru. I-Geotec-002, p 4