Climate change and debris flow: hazards maps in Matucana village Peru under IPCC scenarios

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Abstract In this document, the possible effects of climate change on flood and vulnerability of Matucana Village in the next 90 years are discussed based on existing data and projected changes in precipitation until 2099. This village is located in the lowest zone of Paihua ravine and continuously suffers the effects of floods and debris flows. The analysis was made using changes projected by the ECHAM4/OPYC3, GFDL R30, HadCM3 and NCAR DOE PCM models because these models have the highest spatial resolution. The interval defined by these models was considered, such as the variability interval. The analysis considered three scenarios: mean scenario, with mean changes projected; and minimal and maximum scenarios, defined by the lowest and highest changes projected. The final results suggested no significant increment in magnitude or affected area by debris flow in the next 90 years under the A1FI emission scenario.

Key words AOGCM; climate change; flood; hazard map; IPCC scenarios; debris flow; Peru

INTRODUCTION

Matucana village is located on the left bank of the Rimac River around 2375 m a.s.l in the Western Chain of the Central Peruvian Andes, where two tributary streams' alluvial fans impact on urban areas. On the left bank is Chucumayo ravine and on the right bank is Paihua ravine. Both streams have an accelerating geodynamic activity, i.e. debris flows becoming more frequent and with higher volumes and intensities through time.

Paihua is a high slope basin with much accumulated material in its bed, with large increases in flow due to runoff causing landslides and collapses. This ravine does not act directly on the urban area, but its effects are directly on it because the debris flow material falls directly into the Rimac River producing floods on Matucana urban area, which is at a lower level than the river.

Climate change suggests a possible increment in precipitation and consequently, an increment in debris flow occurrence and increment in magnitude and intensity. This situation determines the necessity of studying the possible effects of climate change on the magnitude and recognition of the possible hazard zones and re-organize and prepare mitigation plans.

STUDY METHODS

Data

Analysis of extreme events requires maximum precipitation time series. CESEL (2004) realized this in their analysis by fitting a Gumbel distribution. Parameters of this probabilistic distribution function were taken from the Estudio hidrológico de la quebrada Collana (CESEL, 2004).

Arithmetic mean values for the period 2010–2099 were estimated by using projected percentage changes according to ECHAM4, NCAR PCM and HADCM3 models and the A1FI emission scenario. These models were selected because they have the highest spatial resolution; GFDL R30 model was discarded because it did not include the mentioned emission scenario. Projected changes are for the period 1961–1990 and are available in Ruostenoja *et al.* (2003).

Topography and other main stream and basin characteristics were estimated from National Maps from the Instituto Geográfico Nacional (IGN): the main channel slope was estimated to be 0.39 m/m and lag time as 1.2 h.

To estimate infiltration volume, analysis from Castillo (2006) was taken. According to this work, the Paihua ravine shows a characteristic such as hydrologic soil type "B" and 79 could be assigned as the weighted curve number.

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METHODOLOGY

The IPCC projected changes of precipitation (ΔP) are the percentage changes related to the period 1961–1990. For this analysis only ECHAM4, NCAR PCM and HADCM3 models were considered. Table 1 shows the percentage variation for the December–February period for 2010–2099 according to these models. Months between March to November were not considered because they form to the dry season in the Southern Hemisphere.

Table 1 Percentage variation for December–February period according to different climatological models and time periods. Emission scenario A1FI. Region 11.

Time	2010–2039	2040–2069	2070–2099
ECHAM4	2.02	2.63	8.80
NCAR PCM	–0.86	4.93	6.77
HADCM3	–1.41	–6.50	–14.28

Source: from Ruostenoja *et al.* (2003).

Historical data have a standard deviation s = 24.4 and arithmetic mean value μ = 13.9. Considering that all the time series will be affected by a projected change, we can assume that all data will be displaced, but the scatter (standard deviation) will be maintained. Arithmetic mean value will be affected by this projected change by:

$$\mu_{proy} = (1 + \Delta P).\mu \tag{1}$$

where ΔP is projected changes of precipitation (%) to the interval "n"; μ is historical mean value, and μ_{proy} is projected mean value. These could be: 2010–2039, 2040–2069 or 2070–2099.

This assumption is acceptable because this region is climatologically homogeneous (Rau *et al*., 2011). These two new parameters define a Gumbel probability distribution function for every period in the analysis. Then we can estimate the new maximum precipitation for Tr = 100 years using the following expression:

$$P_{proy} = \mu_{proy} + K * S \tag{2}$$

where K is the "frequency factor" and depends only on the time of return:

$$K = -\sqrt{6}/\pi \{0.5772 + \ln[\ln(Tr/(Tr-1))]\} \tag{3}$$

This maximum precipitation and main stream parameters, slope, concentration time, lag time, curve number) were input to HEC-HMS software to evaluate peak flows.

Finally, the hydrograph from HEC-HMS, maximum precipitation and topography was input to FLO2D software to simulate correspondent debris flow. Other basin characteristics such as Manning's roughness, viscosity and yield stress, were taken from Castillo (2011). The output showed affected areas, maximum depth and the water and solid volumes.

RESULTS AND DISCUSSION

Precipitation probabilistic distribution

The Gumbel distribution was assumed and fitted to historical data. Considering that this region is climatologically homogeneous (Rau, 2011), the standard deviation will maintain the same value, but new mean values were estimated for every one of the three time periods in evaluation; in this way, nine new distributions are created, three of them distributed to minimal change projections (minimal scenarios), three to the mean change projections (mean scenarios) and finally, three to maximum change projections (maximum scenarios). Also, the precipitation for the 100 year return period was estimated for every distribution. A summary of these values is shown in Table 2.

As the minimal scenarios showed a reduction in precipitation, these three scenarios were discarded. The remaining scenarios were analysed to estimate the corresponding hydrographs and

Table 2 Mean values and maximum precipitation to Tr = 100 years to different scenarios and different time periods.

	2010–2039		2040–2069		2070–2099	
	μ (mm)	P_{100} (mm)	μ (mm)	P_{100} (mm)	μ (mm)	P_{100} (mm)
Maximum projected change	14.05	90.68	14.13	90.76	14.98	91.61
Mean projected change	13.76	90.39	13.82	90.45	13.83	90.46
Minimal projected change	13.57	90.21	12.87	89.50	11.80	88.43

Table 3 Peak flows for every scenario to be analysed.

	Peak flow (m^3/s)		
	2010–2039	2040–2069	2070–2099
Maximum projected change	34.8	34.8	35.5
Mean projected change	34.6	34.6	34.6

peak flows (see Table 3). Results showed similar values for the mean scenarios and only one simulation was considered for this group of scenarios. In a similar way, the maximum scenarios have two similar values and this was also considered as one.

According to this result, only three scenarios were analysed: one mean scenario (2010–2099) and two maximum scenarios (2010–2069 and 2070–2099). The similarity in peak flows and maximum precipitations (P_{100}) suggested that simulations would have similar output in debris flow volumes, depth and inundated area. These values are also similar for the reference period, as shown in Fig. 1.

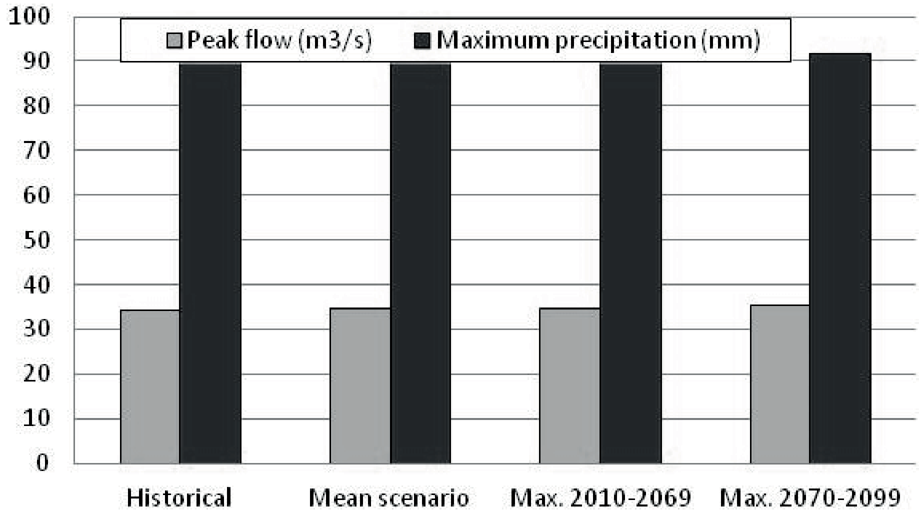

Fig. 1 Peak flows and maximum precipitation to different scenarios. Emission scenario A1FI.

Debris flow simulation

Simulation of the debris flow was made by applying FLO2D software and considering 22% to 35% sediment concentration (Castillo, 2006). Results show similar output for the different scenarios with respect to the maximum inundated area; this means that the effect of climate change will not increase maximum inundated areas in an important way, as seen in Table 4.

A comparison with historical data analysis is summarized in Table 5. There is a consistent similarity between the different scenarios and consequently the plots are similar too (see Fig. 2).

Figure 2 shows the maximum depth on the analysed surface for different scenarios. These plots show similar inundated areas and similar maximum depth along the area and are coherent with output tables and suggest that the hazard maps do not vary in a significant way.

Table 4 summarizes the water and sediment volumes and maximum inundated area for every scenario.

	Mean scenarios 2010–2099		Maximum scenarios 2010–2069		2070–2099	
	Water (m^3)	Bulked w/sediment (m^3)	Water (m^3)	Bulked w/sediment (m^3)	Water (m^3)	Bulked w/sediment (m^3)
Inflow hydrograph	656 028	971 190	527 730	797 512	475 795	742 559
Floodplain storage	3545	4663	11937	15 433	12 201	17 591
Floodplain outflow hydrograph	652 526	966 554	515 836	782 107	463 626	724 980
Maximum inundated area (m^2)		33 600		33 536		33 728

Table 5 Comparison between expected debris flow to historical data analysis and projected data analysis.

	Peak flow (m^3/s)	Maximum precipitation (mm)	Maximum inundated área (m^2)
Historical data	34.3	90.0	33 492
Mean scenario 2010–2099	34.6	90.4	33 600
Maximum scenario 2010–2069	34.8	90.7	33 536
Maximum scenario 2070–2099	35.5	91.6	33 728

Fig. 2 Maximum depth of debris flow. Left, mean scenario 2010–2099. Middle, maximum scenario 2010-2069. Right, maximum scenario 2070–2099. Emission scenario A1FI. Region 11.

CONCLUSIONS

This climate change analysis did not produce an increment in the magnitude of debris flow in the results produced. This means that climate change will not have a significant effect on this basin. However, a downscaling process is recommended to verify these results.

This methodology could be applied in a similar way to other basins to evaluate risk and prepare prevention and mitigation plans for vulnerable regions.

REFERENCES

AGRIFOR Consult. (2009) Climate Change in Latin America. Les Isnes – Belgium, 118 pp.

Bates, B. C., Kundzewicz, Z. W., Wu, S. & Palutikof, J. P. (eds) (2008) Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change. IPCC Secretariat, Geneva, 210 pp.

Cabrera, J. (2011) Statistical Analysis of Climate Change Effects on Agricultural Drought occurrence: The Case of Candarave Village, Tacna – Peru. MAS Thesis. ETH-Zurich. Zurich, Switzerland.

Castillo, L. (2006) Aplicación de un modelo numérico de flujo de escombros y lodo a una quebrada en el Perú. Civil Engineering Thesis. Universidad Nacional de Ingeniería. Lima, Perú.

CESEL Ingenieros S. A. (2004) Estudio hidrológico de la quebrada Collana. Lima, Peru.

Elmahdi, A., Shahkarami, N., Morid, S. & Massah Bavani, A. (2009) Assessing the impact of AOGCMs uncertainty on the risk of agricultural water demand caused by climate change. In: *18th World IMACS / MODSIM Congress*, Cairns, Australia 13–17 July 2009.

Geneva International Academic Network (2009) Climate Change, Mountain Hydrology and Institutional Constraints: International and Local Dimensions. Final Report: The Effects of Climate Change on Mountain Waters – Hydrological and Socio-Economic Considerations. Université de Genève, Faculté des Sciences. January 2009.

IPCC (2007a) Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change", Cambridge University Press. New York, USA.

IPCC (2007b) Climate Change 2007: Synthesis Report. Contribution of working groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, New York, USA.

Japan International Cooperation Agency (1988) The Master Plan Study on the disaster prevention Project in the Rimac basin. Lima-Perú.

Julien, P. & O'Brien, J. (1988) Laboratory analysis of mudflow properties. *Journal of Hydraulic Engineering* 114(8), 877–887. ASCE.

Manning, M., Petit, M., Easterling, D., Murphy, J., Patwardhan, A., Rogner, H. H., Swart, R. & Yohe, G. (2004) IPCC Workshop on Describing Scientific Uncertainties in Climate Change to Support Analysis of Risk and of Options. IPCC Workshop Report. Kildare, Ireland. May, 2004.

Mitchell, T. & Hulme, M. (2000) A country-by-country analysis of past and future warming rates. Tyndall Centre Working Paper No. 1, November 2000, UEA, Norwich, UK

Rau, P. (2011) Correlation study between different phenomenon ENSO and precipitations indexes over the Peruvian Pacific coast. Institut National Polytechnique de Toulouse. Paul Sabatier University Toulouse III. M2 Report. France.

Ruosteenoja, K., Carter, T., Jylhä, K. & Tuomenvirta, H. (2003) Future climate in world regions: an intercomparison of model-based projections for the new IPCC emissions scenarios. The Finnish Environment Institute. Helsinki, Finland.