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## Abstract

In this paper an initiative of the Peruvian Geological Survey, INGEMMET, is shown to promote the research on geomorphology and climate change in Peru. The plan is to elaborate geomorphological maps of the Lima Metropolitan Area and its watershed headers (Chillon, Rimac and Lurin rivers), in order to generate analytical instruments to achieve the following objectives: (1) Decode the record of climatic changes in landforms. (2) Delimit water reserves stored as ice masses (cryosphere). (3) Recognize the relationship between the geomorphology and the geological hazards which may affect people and their economic activities. (4) Design a methodology that can be extrapolated to others Peruvian regions. To reach this objective, geomorphological mapping will be integrated into a GIS, so the morphoclimatic units and the related genetic processes will be identified. Also, their relative chronologies will be proposed. Then, the absolute dating of key units will be established, to confirm or correct the relative chronologies. The information will be compiled into databases, to be contrasted with other evidences and paleoclimatic proxies. This is intended to produce models of climate evolution, to contribute to the assessment of geological hazards, and the knowledge of current state of cryosphere, including recent trends and future forecasts.

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## Keywords

Climate change • Glacial geomorphology • Fluvial geomorphology • Lima metropolitan area

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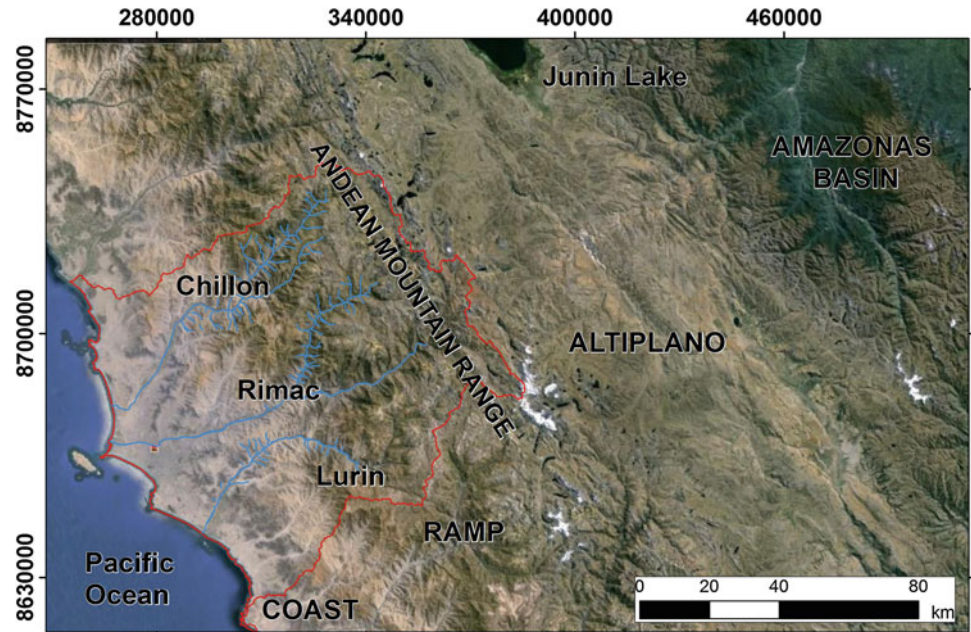
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## 3.1 Introduction

Climate change and exceptional phenomena, such as El Niño—Southern Oscillation, ENSO, have been recorded in geomorphological processes related to temperature and precipitation (Ubeda and Palacios 2009). The research of these processes is useful for understanding the geological risks, while their evolution can be evidenced by geoindicators (permafrost, pollen, moraines, river terraces or landslides, etc.). On scales between decades up to a century, these studies provide information of the current impact of climate change and are the basis to develop forecasts on its future evolution (Ubeda 2012). In Western Central Peruvian Andes these researches have great socio-economic implications; because 55 % of Peruvians live on the Pacific slope

**Fig. 3.1** Delimitation of the study area, indicating the location of the macro-geomorphic units, watersheds and the city of Lima



(INEI 2008) and much of its water reserves are stored as ice in the glaciers of the Andes (IPCC 2007). During the last century there has been a strong process of deglaciation, accelerated for the last 30 years (IPCC 2007). It is therefore imperative that the Peruvian authorities take action to mitigate their effects, which should be based on research to design and prioritize policies to be implemented.

In this context the INGEMMET is leading a joint initiative between INGEMMET, the Research Group of High Mountain Physical Geography of the Complutense University of Madrid (GFAM-UCM; Spain), the Institut pour la Recherche et le Développement (IRD, France) and the Geological Survey of Spain (IGME), which seeks to collaborate with the problem explained and promote research on geomorphology and climate change in Peru.

### 3.2 Background

This research proposal is the sequel to the work begun by INGEMMET between 2008 and 2012 to develop and create the geomorphological map of Peru. During the year 2013 INGEMMET has accorded a strategic alliance with GFAM, the IRD and the IGME to incorporate studies on the evolution of climate during geological past times, as well as research on floods in Peru related to extreme events, such as ENSO.

The Western Central Peruvian Andes have been chosen as the pilot area to test the research methodology to be applied thereafter throughout all the country.

### 3.3 Pilot Project Area

The study area (Fig. 3.1) is a band trending SW-NE with an area of approximately  $100 \times 100 \text{ km}^2$ , where the three macro-geomorphic units of the western facade of the Central Andes are represented: the Andean Mountain Range and Altiplano (the Puna plateau), the steep ramp leading down to the ocean (with height differences over 5,000 m) and the Pacific coast.

The landforms present in these macro-geomorphic units allow differentiating, at different scales, five morphoclimatic areas: glacial, periglacial, temperate forest, semi-arid and hyper-arid (Ubeda and Palacios 2009; Ubeda 2011, 2012).

The ramp between the Pacific coast and the Puna plateau is deeply dissected by the drainage network, which may have been regularly fed by the glacial melting of the range for most of the Pleistocene. This has generated a wide range of landforms (Fig. 3.2) related to erosion and river sedimentation, fans, floodplains, river terraces and gullies.

### 3.4 Methodology

Geomorphological and paleo-hydrological techniques will be used for this purpose, as they have the advantage of extending the periods of observation, measurement and recording of geological past events. Applied to floods, provide information on hydrologic variability and extraordinary floods in time intervals between 100 and 10,000 years (Benito et al. 2004). It is planned to develop

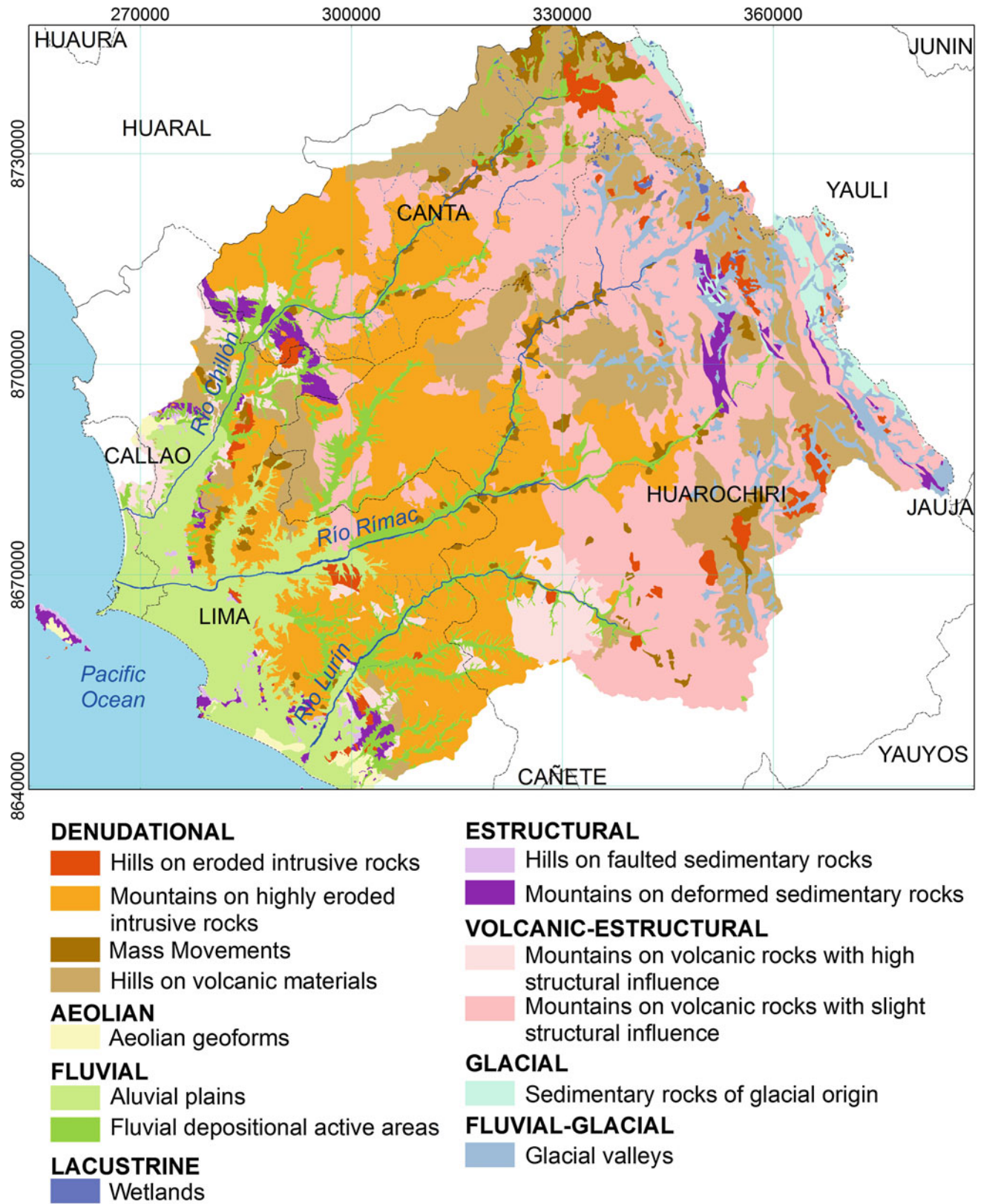


Fig. 3.2 Landforms of the study area (Villacorta et al. 2014)

the following fieldwork: (1) Making of stratigraphic columns, (2) Characterization of landforms and their constituent materials, (3) Sampling for isotopic dating and thermoluminescence, and (4) Installation of data loggers. Whilst the laboratory work will be: (1) Dating of fluvial units by aminoacid racemization (in the Polytechnical University of Madrid), (2) Paleohydrology and dendrogeomorphology (in IGME), and (3) Dating of glacial and periglacial units measuring the isotopic abundance of chlorine-36 on the surface of rocks (in laboratories of the Complutense University of Madrid).

### 3.5 Expected Results

#### 3.5.1 Geomorphology and Climate Change

- A standardized methodology that can be used in other regions of Peru.
- Geomorphological maps of glacial and fluvial units in the Central Andes of Peru West, with their absolute datings and paleo-climate correlations.
- Forecasts of the evolution during the XXI century of water reserves stored in the mountain cryosphere, testable with the predictions of the experts group of the Intergovernmental Panel on Climate Change (IPCC 2007).

#### 3.5.2 Geological Hazards

- Flood risk analysis in the Rimac River basin (Lima), with periods of relapse and numerical simulations of avenues calibrated with geomorphological evidence of actual events.
- Scientific based recommendations to apply in planning policies to mitigate the effects of a more than expected reduction in water availability and the risks related to floods and landslides.

### 3.6 Conclusions

The project aims to encourage research on Geomorphology and Climate Change in Peru, as well as to contribute to the investigation of climate change scenarios related to the

occurrence of disasters, a subject which has not yet been analyzed conveniently in Peru.

The geomorphological map availability will more effectively address the assessment and modeling of geological hazards affecting population and their economic activities.

Although the initiative is still in its early stages of development, these interagency joint efforts have begun to generate useful tools for planning, disaster prevention and investigation of the impact of Climate Change on the cryosphere. The expected final products are geomorphological maps and numerical modeling of geological hazards that will contribute to the management and territorial planning in Peru. It is expected to obtain these results by the year 2015.

Finally, it is important to note that the assessment of geological hazards, not only involves analyzing threats, but also the causes of the increase of the vulnerability of populations. Therefore, an interdisciplinary effort is completely needed to articulate the different actors. For this reason the proposal is opened for cooperation to any institution wishing to participate and work together towards the fulfillment of the objectives of this project.

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