Understanding the hydrology of tropical Andean ecosystems through an Andean Network of Basins

ROLANDO CÉLLERI[1], WOUTER BUYTAERT[1,2], BERT DE BIÈVRE[3], CONRADO TOBÓN[4], PATRICIO CRESPO[1,5], JORGE MOLINA[6] & JAN FEYEN[1]

1 *Unidad de Estudios de Montaña, Universidad de Cuenca, Av. 12 de Abril s/n y Loja, Cuenca, Ecuador*
rcelleri@gmail.com

2 *School of Geographical Sciences, University of Bristol, UK*

3 *International Potato Center – CONDESAN, Ecuador*

4 *Universidad Nacional de Colombia, sede Medellín, Colombia*

5 *Institute of Resources Management, Justus Liebig-Universität* Gießen*, Germany*

6 *Laboratorio de Hidráulica e Hidrología, Universidad Mayor de San Andrés, Bolivia*

Abstract During the last decade several initiatives aiming at conserving and protecting the water provision of Andean ecosystems have started. However, their application have faced a number of limitations from the technical side mainly due to the lack of knowledge of hydrological processes and Andean-specific developed and tested hydrological models for scenario analyses. The large variability found in ecosystems, climates and geomorphological settings makes hydrological research a complex task and answers to these societal problems therefore may take too long, unless a well coordinated collaboration between research centres, NGO's and local governments take place. This manuscript outlines the goals of a regional initiative on participatory-based networking of data monitoring; describes how researchers can help local and regional stakeholders and vice-versa with data collection, processing, storage and dissemination; highlights the benefits of the collaboration for the scientific community and policy makers; and proposes measures to make the collaboration effective and sustainable.

Key words: Mountain hydrology; Andean ecosystems; Páramo; Montane and cloud forests; Participatory environmental monitoring; Andes

INTRODUCTION

Tropical Andean ecosystems consisting mainly of páramo, jalca, puna, montane and cloud forests play a key role in the water supply of most Andean cities and towns, e.g. providing the 85% and 95% of Quito and Bogotá water needs, respectively. Páramo, jalca and puna are high altitude neotropical ecosystems localized above the tree line. Geographically páramo is found from Northern Colombia and Venezuela to Northern Perú; jalca is found in Northern to Central Perú, and puna spans from Central Perú to Northern Argentina and Chile. Andean montane forests are the characteristics forests found in the Andes above ca. 1000 m. In those places where cloud presence is permanent, montane forests are called cloud forests. The elevation range where these ecosystems are present is highly variable, mainly depending on the latitude.

However, despite their role as main water source, the hydrology and water balance of these mountain basins is still poorly understood. The main obstacles for the advance of hydrological knowledge have been the difficulty to implement and maintain research-grade observation networks in these complex, remote environments, and the lack of recognition of these ecosystems as water providers. Besides these, regional monitoring networks have been in decline during the last years.

In addition to this, a major challenge is the large variability found in bio-physical properties of the basins and most importantly in the meteorological conditions in space and time (Bendix, 2000; Vuille *et al.*, 2000; Célleri *et al.*, 2007) which complicates data collection for an adequate prediction of precipitation and discharge at operational scales. As illustration of this variability, Andean páramos covering an area of approximately 35000 km^2, are found between Northern Colombia and Venezuela down to Northern Peru. Páramos are located in an altitudinal range spanning above the tree line (~ 3000 m a.s.l.) and the permanent snow line (~ 4500 m a.s.l.) and its precipitation can vary from below 1000 mm/year to well above 3000 mm/year.

The effects of lack of data and knowledge are twofold. First, it has hindered the development of hydrological models and has led to the misuse of available models developed for other regions, whose results are accepted without a proper model implementation. Indeed, based on the authors' experience, even model calibration (not to say validation and uncertainty analysis) is still a very uncommon practice in many model applications performed in the region. Second, it has put severe constrains to sustainable water resources management and therefore to the development of the region. For instance, nowadays there is an increasing interest in the application of schemes of payments for environmental services (PSA) (e.g. CONDESAN, 2009; Asquith & Wunder, 2008) as an alternative for watershed protection and conservation. While water provision is probably the most important service provided by Andean ecosystems, the lack of knowledge of the ecosystems' hydrological functioning is limiting the application of PSA initiatives aimed at water conservation.

During the last decade a number of research initiatives were initiated aiming to better understand the water yield mechanism of small-scale, pristine and human-altered catchments. For the identification of the human impact on the páramo ecosystem (Buytaert *et al.*, 2006) the paired-catchment approach has been used while the nested-approach has been applied for studying the functioning of montane and cloud forests (Breuer *et al.*, 2006). Those and other efforts yielded important knowledge on the effects of land use change on storm runoff generation and water yield (e.g. Buytaert *et al.*, 2006 & 2007; Fleischbein *et al.*, 2006; Tobon, 2008; Wilcke *et al.*, 2009).

However, given the extreme variability in Andean topography and climate it is still problematic to derive generic knowledge, to extrapolate findings to non-monitored or data scarce catchments, and to up-scale findings to the target scale of interest (Célleri & Feyen, 2009). In addition, it is becoming more and more frequent that local stakeholders are looking for answers to their questions (consisting mainly of land use and climate change impact analyses), just to find many gaps in science.

This manuscript, therefore, presents a proposal for a regional approach for the advancement of hydrological knowledge.

AN ANDEAN NETWORK OF RESEARCH BASINS

Increasing the knowledge of climate and the hydrology of the tropical Andean mountain systems requires the establishment of new and the linking of existing monitoring networks enabling the functional and systematic collection of data. The monitoring tasks, given the extent of the Andean mountain range and the spatial variability, are immense; therefore research institutions alone will not be able to monitor all target basins suggested by groups of interest. A solution requires a well-designed and coordinated collaborative action between many partners, comprising research groups, local and regional stakeholders.

Whereas research groups collect climate and hydrologic data in specified basins as a function of research objectives, local and regional stakeholders collect data because of pressing water-related problems. Indeed, research groups are in charge of research-grade monitoring networks in a number of representative basins, mainly smaller than 3 km^2, using process-based monitoring for the development and testing of hypotheses and protocols to compute spatially distributed water fluxes over the basin. On the other hand, local stakeholders are starting to implement basic monitoring systems in their basins of interest. The basin scale at which local stakeholders are working is normally smaller than 100 km^2. However, basin management projects are normally applied in a smaller scale, ranging from tens to hundreds of hectares (e.g. reforestation programmes) to less than 10 km^2 (e.g. ecosystem protection). Therefore predictions at these scales are needed.

Given the difference of objectives the type and set-up of equipment and monitoring network are different, as well as the monitoring frequency and the length of the observation period. The challenge is to derive from the variability in data. and number of data. the maximum useable and consistent information serving the needs of local and regional stakeholders and the scientific community. However, first of all consistency and context of data collection for knowledge generation, model applications and various water resources decision-making purposes are needed.

To merge and optimize the interest and effort of all stakeholders a participatory environmental monitoring framework is suggested. In this collaborative framework research groups and local stakeholders work together to solve the most pressing water-related problems. Research groups help local and regional stakeholders with the network design; instrument selection and installation in well defined conditions; elaboration of guidelines for station maintenance and data downloading, and; data processing, storage and distribution at several levels where reports about the local meteorological and hydrological conditions will be generated for distribution among the communities. Local and regional stakeholders (often supported by local NGOs with the necessary expertise) will be responsible for station maintenance, data downloading and transmission to a central database and funding research projects. They should make data available to research groups and assist the latter in their monitoring endeavour. It is strongly suggested that all equipment be automatic to avoid manual measurement errors and to minimize time investment.

Whereas the data collected in research basins will be used for process knowledge and model development, data collected by local and regional stakeholders will be used for analyzing and developing solutions to water-related problems and, for instance, to test extrapolations and up-scaling hypothesis.

PUTTING IDEAS INTO ACTION

At this moment the bridge between the research groups and the local stakeholders is the Proyecto Páramo Andino, managed by International Potato Centre’s Consorcio para el Desarrollo Sostenible de la Ecoregion Andina (CONDESAN), a regional consortium of NGO’s and research institutes. Funding for the implementation of this proposal is coming from CONDESAN and national initiatives. The project is in the stage of setup and training, but local interest has far exceeded expectations with currently about 15 interested projects in Venezuela, Colombia, Ecuador and Peru. People’s interest is primarily stimulated by the return of concisely formatted and easily interpretable data, something that is lacking in large monitoring schemes by state agencies. A second advantage is the embedding of the local efforts within a larger monitoring community, allowing for sharing experiences and data.

It is suggested that research groups implement a nested monitoring approach in mid-size basins (< 100 km^2), where they can monitor from the plot scale to the basin scale, including hillslopes and small basins (< 2 km^2) with different land uses. In this way it will be possible to understand the effects of land use change on the hydrology as well as testing upscaling hypotheses. While the instrumentation of stakeholders’ basins consists mainly of rainfall and discharge stations, research basins will include additionally meteorological stations and sensors to measure state variables such as soil moisture.

CONDESAN effort is supported by local projects such as the recently started “Quantification of the hydrological services of Andean basins” PIC-08-460’s project funded by the Ecuadorian Secretary of Science and Technology (SENACYT) and the Universidad de Cuenca. This project plans to implement two mid-size nested research basins, monitoring from ~1 km^2 small basins with different land cover (mainly páramo, montane forests and non-native forest plantations) to ~50 km^2 basins, and in addition will provide basic rainfall-discharge monitoring to 5 community-based action research projects situated all along the Ecuadorian Andes. The latter are projects managed by local communities in their efforts to secure their water supply, and one of the key objectives is to understand the effects of reforestation on water yield. However, given there are many believes and perceptions on the effects of forests, they have realized the importance of measuring discharge (in small experimental and control basins) and precipitation (as to remove the effects of climate variability: wet years versus dry years) in order to determine the impact of their land use practices..

CONCLUSIONS

An Andean Network of Research Basins is proposed within a participatory environmental monitoring framework as mean to improve the hydrological knowledge of Andean ecosystems. This network will be comprised by (a) densely-instrumented basins for identifying and quantifying hydrological processes and its spatial variability and (b) basic-instrumented basins managed by local stakeholders. Such an approach, funded on the premise that technology has advanced to the extent that local communities can easily be involved in the monitoring process, allows for monitoring in many regions that would otherwise be prohibitively expensive or practically infeasible for research institutions alone.

Research basins implemented on different ecosystems using a nested approach, monitoring at several scales of hydrological significance from the plot scale to the basin scale (< 100 km^2) and including hillslopes and small basins (< 3 km^2) with different land cover, will be used to generate knowledge, test hypotheses and derive new models. Small basins will be used to identify the effects of land use change on the water balance, as well as the mechanisms of runoff generation. On the other hand, basins run by stakeholders will have basic rainfall-discharge monitoring at the scale of the project of interest and normally would be smaller than 10 km^2 (although in a few cases basins up to 100 km^2 can be expected). Information obtained at local basins will be used to test and validate the knowledge obtained at the research basins. Thus, by combining knowledge and local data, robust solutions to the local groups' problems will be found.

Although the data from the basic-instrumented basins will be likely of lower quality than their research counterparts, an improved spatial and temporal coverage (e.g. different rainfall regions and geomorphological settings) may provide information of higher usefulness to researchers and policy makers. Finally, this collaborative research framework will allow bringing real-life problems and quality-controlled data sets to scientists while providing science-based solutions to the problems of society.

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