Imperial College London

Grantham Institute
Briefing note No 4

March 2017

Citizen science and web-based modelling tools for managing freshwater

DR BHOPAL PANDEYA AND DR WOUTER BUYTAERT

The headlines

- Involving local communities in monitoring water and land resources – so-called citizen science – can create new data and knowledge, improve conventional decision making and optimise water resource benefits.
- The use of low-cost hydrological sensors in Nepal allowed local stakeholders to generate useful data on freshwater resources in partnership with scientists, and to apply this data more effectively in participatory decision making.
- It is important to use the right mapping and modelling methods for ecosystem services (the benefits people obtain from ecosystems) so that information on service production, distribution and consumption is expressed at a spatial scale that is relevant to decision making. These methods are even more important in regions where limited data is available.
- The integration of appropriate citizen science practices as well as mapping and modelling tools into water and land resources-based decision making could facilitate sustainable development activities, particularly in the Himalayan region.

Introduction

Mountains are often referred to as 'water towers' as they provide freshwater to people in upland and downstream areas[1,2]. Rivers originating from the Himalayas carry a vast wealth of water-related benefits (also described as ecosystem services) that directly underpin local livelihoods and the wellbeing of societies in the region.

Freshwater is a very scarce resource in the Himalayan uplands. Agricultural practices depend on timely rain and snowfall in the upper mountains. The resulting water availability in local streams is crucial to maintaining local livelihoods. The region's water supply is also highly vulnerable to natural disasters and climate change[3].

In the face of these water security challenges, it is important to ensure water is supplied to households in sufficient quantity and quality, as well as maintaining agricultural production and safeguarding habitats and the environment[4]. These priorities are becoming even more important to the Himalayan region in the context of unprecedented land use and climate change impacts.

However, a significant shortage of useful data and information about these water systems has seriously undermined their sustainable use in the local area. As a result, changing hydrological cycle and climatic patterns may be poorly reflected in water and land resources management practices. In a highly uncertain and vulnerable environment such as the Himalayas, involving citizens in monitoring water resources, land use changes and resource management practices can create new knowledge that directly supports local decision making. The use of mapping and modelling tools at appropriate spatial and temporal scales[5] is vital to understanding the current state of water and land resources as well as the future threats they face. In addition, vulnerability assessments can help target activities to improve resilience.

Citizen science and web-based mapping and modelling tools in decision making

Public participation in environmental data collection has a long history. However, recent advances in affordable technologies such as low-cost monitoring equipment[6], the availability of open-source databases and modelling tools[7], participatory mapping of resources[8] and good communication networks have expanded the potential to engage citizens in these activities[9, 10]. There is also untapped potential to build transformative research on the links between human activity and natural systems[11]. Citizen science could therefore bridge the current science-policy impasse and ensure water resources are managed more effectively.

In water resources management policy, a number of key questions are constantly raised, such as defining freshwater resources services at appropriate spatial and temporal scales and the influence of eco-hydrological processes in water services production. These questions lead to inquiries about the trends and flows of services production over time and space and how human interventions have affected them. To answer these questions, a detailed valuation of ecosystem services including mapping and modelling of services is essential. This includes the application of relevant technologies, for example, the use of low-cost hydrological monitoring sensors in coordination with local stakeholders and ordinary citizens. The goal of valuation exercises is to provide information needed to support policy and decision making. However there is a profound gap of data and knowledge, especially at a local scale and in data-scarce mountainous regions. An innovative approach of citizen-centric data gathering activities and knowledge co-generation can be placed at the heart of the water resources management in those areas[12] (see figure 1).

Since water resources based services are spatially distributed, their current flows and trends can be better described by using appropriate mapping and modelling tools such as the WaterWorld[7, 13], and the InVEST[14] models. These tools include time dimensions to integrate a range of natural processes into their models and can be used at a range of scales – from local to basin scales. The majority of mapping and modelling tools in use now are web-based and some include free datasets (for example, the Simterra database is embedded within the WaterWorld model and consists of a range of hydro-climatic and socio-ecological data). These features make it easier for mapping and modelling of water related services relevant to policy and decision making.

Maps are useful for prioritisation and problem identification, especially in relation to synergies and trade-offs among different ecosystem services, and between ecosystem services and biodiversity protection. In general, mapping and modelling visualisations are the most useful way to illustrate the value of water resources based services, and thereby support decision and policy making.

Remotely-sensed data, available from global and regional data repositories, can be used together with citizen-based approaches to improve our understanding of the ecosystem services available. Remote-sensing data can also support the analysis of uncertainties in relation to land use and climate change scenarios.

Web-based mapping and modelling tools are beginning to have a greater impact in water resources management. Although some of these tools are provided with a great deal of spatio-temporal data for water and land resources assessment, such data does not always accurately reflect the real resources situation on the ground, especially for remote and mountainous environments. Citizen science based monitoring of water resources monitoring can, however, create locally relevant data, and support mapping and modelling of local ecosystem services.

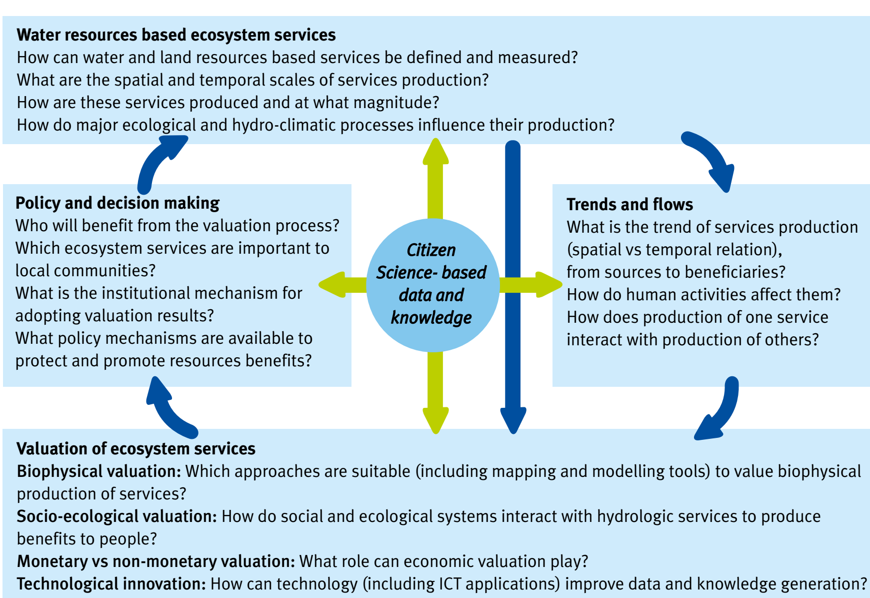


Figure 1: Citizen science can contribute towards answering policymakers' questions and supporting water resources management

Policy relevance

A lack of applicable data and knowledge has seriously hindered water resource management in the Himalayan region. Policy and decision makers rely on sparse and potentially inaccurate data and 'rule of thumb' based decision making to try to support the sustainable use of water resources. The integration of citizen science and web-based mapping and modelling tools described above can be enormously valuable for policy makers.

Mountain regions experience a particularly higher degree of uncertainty in relation to their water resources. This uncertainty is a result of the combination of changing hydrological cycle and climatic pattern, natural hazards, and human driven land use and climatic changes. Web-based mapping and modelling tools can also help with this uncertainty dimension. By using plausible future scenarios, these modelling tools can explain the potential change in water availability at a local scale.

The Upper Kaligandaki Basin – a case study site in Nepal

We have tested citizen science practices and web-based mapping and modelling tools in a trans-Himalayan river basin system in central Nepal (see figure 2). Located in a rain shadow of the Himalayas, the Kaligandaki Basin receives very low precipitation (less than 250 mm per year), mainly from snowfall. The increasingly unpredictable water supply in local streams is making farming even more challenging. Local people are concerned about the changing snowfall in upper mountain areas and its impact on water availability in downstream areas. Sudden and unpredicted glacial melting can also create water-induced hazards such as landslides, flooding and sedimentation in these areas.

"Our farmlands are highly productive (...) but there are some big problems. The water supply is becoming more disrupted, soil loss is extensive. (...) We need to address these problems immediately so we can improve agricultural production and increase our household incomes." – Local community member

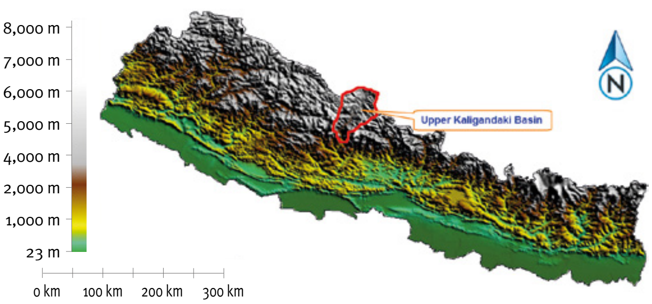
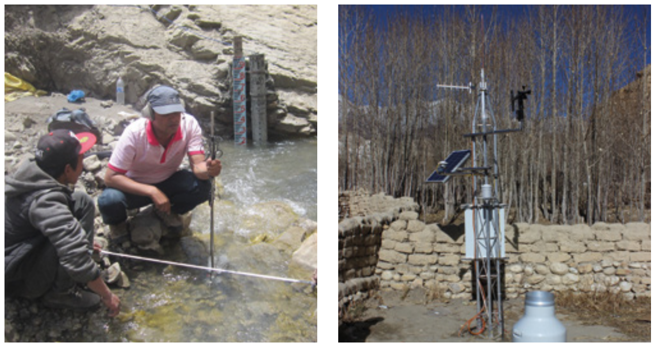


Figure 2: Altitude map and location of the Upper Kaligandaki Basin in Nepal[13]

In addition to natural causes of water resource uncertainty, land use change has a significant impact on ecosystem services. The development of road networks, hydroelectric projects and the expansion of human settlements have been the main drivers of land use change in recent decades. Socio-economic factors such as changes in lifestyle and diet patterns have also been critical.

The region has seen changes in local demographics, including rapid migration, and an increase in eco-tourism businesses. All of these changes may have detrimental impacts on water quality, land productivity and natural beauty. Therefore, a detailed understanding of water and land resources is paramount in sustaining and improving local livelihoods.



A: Water level sensor B: An Automatic Weather Station

Figure 3: Local participation in hydro-meteorological monitoring

Our experiments in test sites in the region have shown that the combination of citizen-based water resources monitoring and real-time publicly available data is making a real impact on water resources management (see figure 3). Integrating this new approach into local decision making could contribute to better management of water resources and help adapt agricultural practices to changing water availability in the long term.

Using appropriate web-based mapping and modelling tools (WaterWorld), water services have been assessed at basin and sub-basin scales (see figure 5). The results show a variation in hydrological characteristics within the basin. The spatial details of rainfall, water balance, evapo-transpiration and fog input (cloud water) can provide useful information to local authorities. There is a higher rate of evapo-transpiration in the upper catchment and similarly a higher level of fog input (up to 25% of total precipitation) in lower parts of the basin. Notably, there is more water available for human and crop use along the southern parts of the basin.

The modelling results could also provide useful information on water resource distribution within a small sub-catchment. Experiments also showed that these approaches can be equally robust for data scarce regions, although it depends on the spatial and temporal resolution of the available data. Certainly, locally generated data can significantly improve the hydrological database for mapping and modelling of water resources.

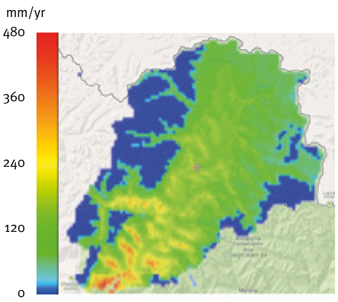

A


B

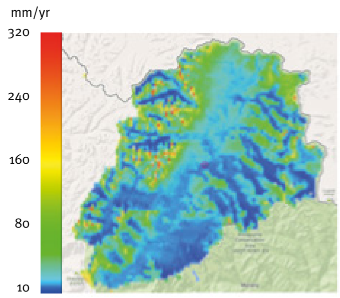

C


D

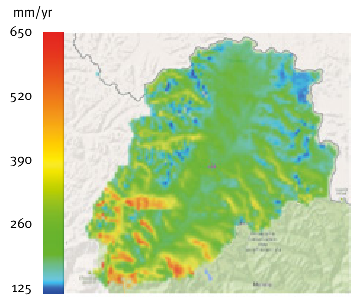
Figure 4: Water and cropland management practices in the Upper Kaligandaki Basin –
a) agricultural land
b) irrigation pond
c) apple farming
d) community discussion.



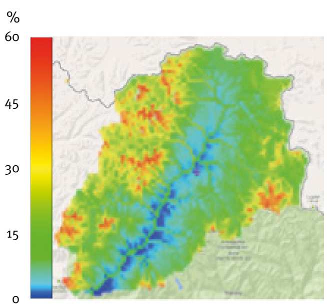
A: Annual rainfall



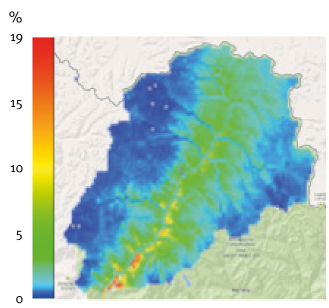
B: Annual actual evapotranspiration



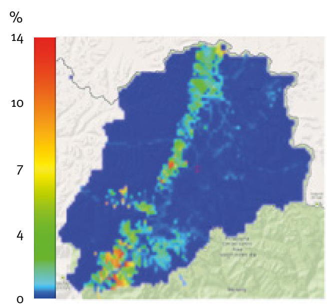
C: Annual water balance



D: Annual percentage of runoff generated by snowmelt



E: Annual percentage of runoff generated by fog input



F: Human footprint on water quality (percentage contamination)

Figure 5: Hydrological services generated by the Upper Kaligandaki Basin[13]

Lessons learned and opportunities for capacity building

There is an urgent need for evidence-based and locally relevant water resource management, especially in data scarce mountain regions.

With the recent development of user friendly and affordable technologies such as low-cost hydrological sensors, citizen science practices can now be used in remote and data-scarce Himalayan mountain regions. Our experience shows that the greater availability of data and simplified tools would eventually cascade down to the local scale, as has been the case with other technologies. Local stakeholders would be able to use such tools independently and integrate new data and knowledge into their decision making practices.

Accelerating the use of citizen science, and mapping and modelling tools requires enhanced capabilities among policy makers and practitioners to incorporate these practices. We foresee potential opportunities in collaboration with the Government of Nepal's Department of Hydrology and Meteorology (DHM), and the regional offices of WWF and Practical Action that can help ensure these methods are applied more widely, and in a lasting manner, at local level.

Acknowledgements

This study is funded by the UK Economic and Social Research Council – Impact Acceleration Account (grant number: ES/M500562.1), ESPA's Fellowship Grant (FELL-2014-105) and Mountain-EVO Project (NE-K010239-1). We also thank UNESCO-IHP, Society of Hydrologists and Meteorologists (SOHAM) and Department of Hydrology and Meteorology (DHM) for their valuable inputs in the paper. We are also grateful to Dr Mark Mulligan of King's College London for providing access to the WaterWorld hydrological model and SimTerra database.

About the authors

Dr Bhopal Pandeya

Bhopal Pandeya is a Postdoctoral Research Fellow at the Grantham Institute – Climate Change and the Environment. He has more than ten years of research experience at the science-policy interface and has expertise in natural capital and ecosystem services (especially freshwater and land resources management), citizen science, policy support systems, climate change and sustainable development agenda. He graduated with an MPhil degree in Environment, Society and Development from Cambridge University and completed his PhD in understanding the hydrological ecosystem services produced by the Indo-Gangetic Basins and selected mountain catchments in the Himalayas at King's College London. His research activities are funded by the UK Research Councils and DFID, and mainly focused in the Himalayas and the South Asian region. Email: b.pandeya@imperial.ac.uk

Dr Wouter Buytaert

Dr Buytaert is a Senior Lecturer in water resources and environmental change in the Department of Civil and Environmental Engineering at Imperial College London. He has more than 15 years of experience in hydrology and water resources management in different parts of the world including the Tropical Andes, the Himalayas, East Africa and Central Asia. He is an expert on the impact of land use changes and climate change on hydrological processes and water supply, but also works on the development of environmental models, prediction, decision support and sustainable development. Email: w.buytaert@imperial.ac.uk

References

1. Viviroli D., Dürr H. H., Messerli B., Meybeck M. and Weingartner R. (2007) 'Mountains of the world, water towers for humanity: Typology, mapping, and global significance', Water Resources Research, 43(7), W07447
2. Messerli B., Viviroli D. and Weingartner R. (2004) 'Mountains of the world: vulnerable water towers for the 21st Century', Ambio, 29-34
3. Xu, J., Grumbine, R.E., Shrestha, A., Eriksson, M., Yang, X., Wang, Y.U.N. and Wilkes, A. (2009) 'The melting Himalayas: cascading effects of climate change on water, biodiversity, and livelihoods', Conservation Biology, 23(3), 520-530
4. Grey, D. and Sadoff, C.W. (2007) Sink or swim? Water security for growth and development, Water Policy, 9(6), 545-571
5. Crossman, N. D., Burkhard, B., Nedkov, S., Willemen, L., Petz, K., Palomo, I., Drakou, E. G., Martín-Lopez, B., McPhearson, T., Boyanova, K., Alkemade, R., Egoh, B., Dunbar, M. B. and Maes, J. (2013) 'A blueprint for mapping and modelling ecosystem services', Ecosystem Services, 4: 4-14
6. Buytaert, W., Baez, S., Bustamante, M. and Dewulf, A., (2012) Web-based environmental simulation: bridging the gap between scientific modeling and decision-making, Environmental science & technology, 46(4), pp.1971-1976.
7. Mulligan, M. (2013) 'WaterWorld: a self-parameterising, physically-based model for application in data-poor but problem-rich environments globally', Hydrology Research, 44(5), 748-769, doi:10.2166/nh.2012.217
8. Jankowski, P., (2009) Towards participatory geographic information systems for community-based environmental decision making, Journal of Envt. Management, 90(6), 1966-1971
9. Buytaert W., Zulkafli Z., Grainger S., Acosta L., Bastiaensen J., Bhusal J., Chanie T., Clark, J., De Bièvre B., Dewulf A., Hannah, D.M., Hergarten C., Isaeva A., Karpouzoglou T., Pandeya B., Paudel D., Sharma K., Steenhuis T., Tilahun S., Van Hecken G., Zhumanova M. (2014) 'Citizen science for hydrology and water resources: opportunities for knowledge generation and sustainable ecosystem service management' Frontiers in Earth Science, Section Hydrosphere, pp. 1-21
10. Dickinson, J.L., Shirk, J., Bonter, D., Bonney, R., Crain, R.L., Martin, J., Phillips, T. and Purcell, K., (2012) The current state of citizen science as a tool for ecological research and public engagement. Frontiers in Ecology and the Environment, 10(6), pp.291-297.
11. Crain, R., Cooper, C. and Dickenson, J.L. (2014) Citizen science: a tool for integrating studies of human and natural systems, Annu. Rev. Environ. Resour., 39:641-65
12. Pandeya B., Buytaert W., Zulkafli Z., Karpouzoglou T., Mao F. and Hannah D.M. (2016) 'A comparative analysis of ecosystem services valuation approaches for application at the local scale and in data scarce regions' Ecosystem Services, (doi.org/10.1016/j.ecoser.2016.10.015)
13. WaterWorld v2, 2016, WaterWorld Version 2 Modules, King's College London, UK
14. Sharp, R., Tallis, H.T., Ricketts, T., Guerry, A.D. et al., 2016, InVEST version 3.3.1, User's Guide, The Natural Capital Project, Stanford University, University of Minnesota, The Nature Conservancy, and World Wildlife Fund

About the Grantham Institute

The Grantham Institute is committed to driving research on climate change and the environment, and translating it into real world impact. Established in February 2007 with a £12.8 million donation over ten years from the Grantham Foundation for the Protection of the Environment, the Institute's researchers are developing both the fundamental scientific understanding of climate and environmental change, and the mitigation and adaptation responses to it. The research, policy and outreach work that the Institute carries out is based on, and backed up by, the world-leading research by academic staff at Imperial.

www.imperial.ac.uk/grantham

Contact us

For more information about this subject, to discuss how the issues covered affect you and your work, or to contact the authors, please email us at: **grantham@imperial.ac.uk**

About Imperial College London

Consistently rated amongst the world's best universities, Imperial College London is a science-based institution with a reputation for excellence in teaching and research that attracts 13,000 students and 6,000 staff of the highest international quality.

Innovative research at the College explores the interface between science, medicine, engineering and business, delivering practical solutions that improve quality of life and the environment—underpinned by a dynamic enterprise culture. Since its foundation in 1907, Imperial's contributions to society have included the discovery of penicillin, the development of holography and the foundations of fibre optics.

This commitment to the application of research for the benefit of all continues today, with current focuses including interdisciplinary collaborations to improve health in the UK and globally, tackle climate change and develop clean and sustainable sources of energy.

www.imperial.ac.uk