International Environmental Modelling and Software Society (iEMSs)
2012 International Congress on Environmental Modelling and Software
Managing Resources of a Limited Planet, Sixth Biennial Meeting, Leipzig, Germany
R. Seppelt, A.A. Voinov, S. Lange, D. Bankamp (Eds.)
http://www.iemss.org/society/index.php/iemss-2012-proceedings

Modelling and Simulating Social Vulnerability under the Influence of Climate Change in the Cordillera Blanca (Peru)

Thaís López-Inojosa, Geography Institute, Faculty of Geosciences and Atmospheric Science, Leopold-Franzens University, Innsbruck, Austria.
thais.lopez-inojosa@student.uibk.ac.at

Martina Neuburger, Geography Institute, Faculty of Mathematics, Informatics and Natural Sciences, Hamburg University, Hamburg, Germany.
neuburger@geowiss.uni-hamburg.de

Sebastian Medina-Plascencia, Department of System Engineering, School of Engineering, University of Los Andes, Mérida, Venezuela. isebas@ula.ve

Abstract: The objective of this research is to develop and simulate a model of the ecosocial concept of populations' *vulnerability* under the impact of environmental change in the Peruvian Cordillera Blanca, through a social vulnerability indicator. Numerous studies provide evidence for the impact of climate change on nature, water scarcity, and social problems; people living near glaciers are particularly affected by these natural hazards. The Peruvian Cordillera Blanca, an area with one fourth of the world's tropical glaciers and its population are highly at risk. The applications of fuzzy algorithms to research works in this area, and even more to social and ecological aspects, is a new approach to this field of research. It can be used to model the behavior of any population in a specified area under similar circumstances. In this paper, we use the ecosocial concept of *Vulnerability* to analyze the process of man-environment relationship in a comprehensive multidimensional model. Regarding the social dimension we aim to improve the quality of life for peasant populations close to glaciers. At the same time, with respect to an environmental scope, the work with and the relationships between all the actors in this human-environmental system is of great importance in order to achieve massive participation in finding the most shared solution. Finally, our scientific contribution is the use of system theory, fuzzy dynamics system and data mining to build a social vulnerability indicator and its development in a climate change process.

***Keywords**:* Social Vulnerability, Climate Change, Fuzzy Dynamic Systems.

1 INTRODUCTION TO THE PROBLEM

Among the numerous impacts that climate change brings about is recession of glaciers. There is a system of coexistence, highly structured and related with the social setting of the populations close to glaciers that can be characterized as a human-environmental system. This study focuses on an area where climate change and its consequences on the adjacent populations are prominent: the Quebrada Shallap, which covers parts of the districts of Independencia and Huaráz of the Department Ancash in the Peruvian Cordillera Blanca.

Even though the problem of climate change is considered a global phenomenon, human beings have to cope with its consequences on a local level: "y la triste realidad en Latinoamérica es, que la población, en las inmediaciones del glaciar, no tiene nada que ver con el aumento de la emision de gases a la atmosfera…" ("and the pitiful reality in Latin America is that the population in the vicinity of the glacier does not have anything to do with the increase of the gas emissions to the atmosphere") (Chehbouni, cited by [Ovando, N. 2008, own translation]).
Peru is most likely to suffer from these changes, as the vast majority of all tropical glaciers (77%) are found on its territory and they provide about 60% of the country's population with water.
The consequences are numerous. The shifting in altitude of the snow line and therefore also of the altitudinal zonation is producing in the first instance higher and more frequent precipitations: "In the degree in which glaciers melt off, the runoff in the rivers rises and it can happen that people think 'We have got more water because runoff is higher', but in the end this is a snap-shot because what is left of the glacier is less and less." [Urrutia, R. 2012, own translation].
The reality is that in Peru and other Andean countries "…*glaciers are melting and that this process is connected to a rise in global temperature. The consequences will not only be noticeable for the residents of immediately adjacent areas but also for persons that are living many kilometers away from the glacier*" [Young, K. 2006].
Meanwhile, the variation in these regions is not recent. The vital question is the degree of disturbance which is caused by its impact regarding the natural and/or social environment.

2 SETTING

Climate change could be described as a large subsystem, as an umbrella which covers and exerts pressure on the area where the actions, activities and man-environment relations take place. This big umbrella is represented in this study by climatic variables measured from the point of view of local experts - engineers, sociologists, glaciologist, NGOs' activists - and local citizens represented by presidents of irrigations committees and local mayors in the surroundings of the Shallap Glacier.
The selected area of investigation is east of the city of Huaráz, the capital of the mountain region called Callejón de Huaylas, between 3091 m and 5843 m of altitude, topped by the mountain Nevado San Juan and Shallap Glacier. It comprises the settlements Jancu, Paquishca, Llupa, Coyllur, Ichoca and los Pinos, located in the administrative districts of Huaráz and Independencia. The poverty incidence in the Huaraz district is of 30.6% (gini coefficient: 0.34) of a total population of 57499 and 36.4% (gini coefficient: 0.33) in the Independencia district with a population of 64322. Illiteracy amounts to 12.4 %,for the whole Department of Ancash, according to the National Statistics and Informatics Institute of Peru (Instituto Nacional de Estadísticas e Informática – INEI).
Various authors (Carey, Kaser, Mark) have described the area as particularly vulnerable. Its evolution as part of a water-dependent society leads the authors to the necessity of developing a Social Vulnerability Index. This index is structured by local indicators comprised of multidimensional variables such as large-scale mining, tourism, and change in income sources, loss of social recognition, level of community conflicts, political power and changes in agricultural production systems. The multivariability of these indicators will be expressed by the use of natural resources, generated economic income and its effects as social phenomenon. In order to understand the climate management of socio-ecological systems, it is not only necessary that scientists, engineers, politicians, economic actors, civil society and all those who contribute their view of the object of research. Rather, there is also a specific need for the development of holistic analyses. It is thus important to examine human-environmental systems react to changes in climate. This question could be contemplated in the light of the principle "Culture often matters more than science". Deriving often from power structures and the economic situation, the reaction of the population to changes in climate, is based on their ideology and on

their social relations and not on scientific findings about environmental processes. [Carey, M. 2010], [Law, T. - Zhang, W. 2009], [Ulanowicz, R. 2009].
The complexity of the natural environment and its sensitivity to human interference is a topic that, although by no means being new, is of growing importance as it comes along with human action. The loss of biodiversity and natural resources on our planet is taking place with breathtaking velocity. The reasons for this waste and the approaches to detain it are however still not fully understood and difficult to explain due to the pronounced complexity of the relations [Carrere, J.1998].
The ongoing reaction of ecosystems in the light of climate change – as far as investigated by the respective scientific disciplines – is a predictable response of nature. Paradoxically, the human influence, in spite of constantly being criticized, is largely absent in the stakeholder analyses on the interdependency of environmental damage and only limited research exists that accounts for this influence in their analyses. The exclusion of human factors in the examination and modeling of environmental systems is a shortsighted interpretation of the problem.
This exclusion is also evident in the analysis and modeling of the deglaciation problem and it is sustained also for the interpretation of the results. Limiting the observation of the human being and its actions to an external and non-system variable has fragmented the information from the modeling of ecosocial dynamics [Gunderson, L. 2005]. In order to avoid this kind of disjunction, a proposal to this matter is the formulation of projects that include research about the impacts on human-environmental systems, vulnerability, exposure, resistance and resilience. Research and corresponding data generation are aimed at orientating a well-founded and reasonable decision making.
In the year 2008 the World Bank invited experts from all over the world to contribute to the project *Adaptation to the Impact of Rapid Glacier Retreat in the Tropical Andes*, "Recognizing both the likelihood of future glacier and the vulnerability of Andean economies, energy supplies, and human populations […] . *The success of the World Bank´s Andean project and other climate adaptation programs worldwide will depend as much on understanding social relations and power dynamics as on deciphering how many cubic meters of water per second will flow out of the Mantaro valley´s Huaytapallana Glacier in 2005"* . [Carey, M. 2010].
There are good models and model simulations that can capture and predict precipitation in millimeters per square meter with high precision but most of them do not contemplate the measuring of the impacts on the human level. Fortunately, there already exist research works of a group of people like Carey, Kaser, Mark, to mention only some of them, who consider social vulnerability to be important and put it at the same level as the physical parameters.
The present model is more comprehensive. Even though it is not intended to give a final answer on the modeling and evaluations of aspects like vulnerability, resilience and survival strategies of social groups.

3 AREA OF INVESTIGATION

The Cordillera Blanca in the Department of Ancash is a region with a great natural potential and the incidence of glaciers. It comprises about one fourth of the world's tropical glaciers and it is highly endangered by Environmental Change. As shown by the predictions for climatic change in the tropical Andes, the inhabitants of this region have experienced a tragic process of change in the past years, characterized by more frequent natural disasters and water crisis.
There exist already numerous scientific publications with different focus about this area, exemplified by Carey, Kaser, Mark and Young. The region has been chosen as a case study for this research work because of this situation and favorable starting position.

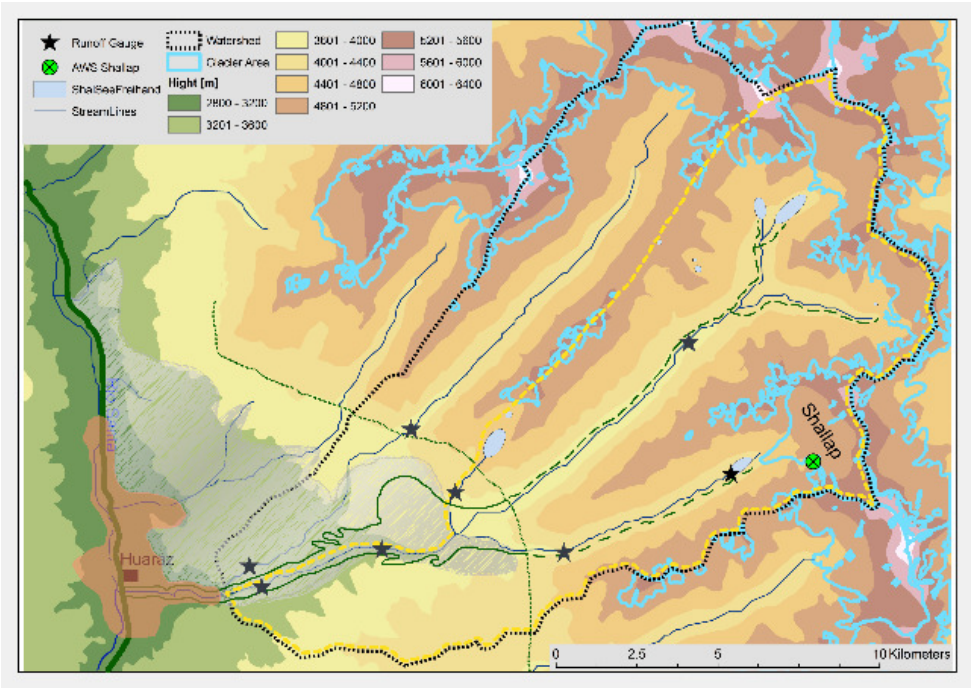

Figure 1. Area of Investigation Province Ancash

Source: Gurgiser, Kaser, Neuburger, Bregulla 2011

The development of the situation in the Peruvian Cordillera Blanca is not an exception and its analysis and comprehension can serve as a case study for comparison and contrast with other parts of the world [Young, K. 2006].

4 MODELING THE SITUATION

The studies on diverse topics of deglaciation are being developed; the data, maps, satellite images and forecasts on ecological vulnerability in the affected areas are also available; but of what is known, only very little is available on the populations and settlements in the vicinity of glaciers. Which significance does water have in their culture? How do they experience the change of the glaciers? What are their strategies for prevention or compensation? How are the power structures in the affected region? All these are questions that remain still open.
This research work offers a possibility to develop a computer-based model that includes for the first time eco-social aspects, vulnerability and the environmental analysis in the context of Fuzzy Dynamic Systems.

5 METHODOLOGY

In order to understand and describe the peculiar structure of actors and relationships of an eco-social system, this research is making use of the methods of system analysis and simulation thus allowing a comprehensive examination of the research problem.
The data basis for this model is compiled from the analysis and systematization of the literature and through empirical field research (interviews) in the area of investigation. In this context, methods such as guided interviews, fuzzy inference systems and its application by system dynamics as well as structured and participative observations are applied.
Fuzzy logic is a methodology that allows obtaining a solution for problems and the processing of vague, ambiguous or imprecise information. *"Fuzzy theory holds that all things are matters of degree. It mechanizes much of our "folk psychology". Fuzzy theory also reduces black-white logic and mathematics to special limiting cases of gray relationships."* Lofti Zadeh in the 1960s "[…] *developed the multivalued set*

theory, introduced the term fuzzy into the technical literature, and inaugurated a second wave of interest in multivalued mathematical structure, from systems to topologies" [Kosko, B. 1992]. It offers similar characteristics and methods as the probabilistic method but it differs from the latter in its level of information.
The use of fuzzy sets and its application does not require a profound knowledge of the systems, the handling of exact equations and precise numeric values; it allows the use of the knowledge and experience of whom is trying to obtain information of subjective concepts or linguistic variables such as: very little, quite close or light brown, which can be located within precise numeric intervals. It has to be emphasized that fuzzy sets depend on the context in which they are developed.
Finally, system identification, data mining and principles of fuzzy theory are the basis for the development of a model that pretends to represent the impact of climate change on the social vulnerability of the populations in the adjacency to a glacier of the Peruvian Cordillera Blanca.

6 EXPECTED RESULTS

The identification, definition and modeling of the locally perceived environmental change with regard to social vulnerability is a project that has just started. Nevertheless, its expected results can be defined in a general manner and broadly be described by the following sequence: the model will result in a collection of relevant indicators, the relation between the variables will be investigated with a fuzzy base, given the imprecise nature and the linguistic definition of the variables, and an index of social vulnerability (SVI) will be constituted. The weight of each of the indicators will be obtained by interviews with experts and local residents. Given this weighting scheme, the specific past and present values of the SVI indicators will be obtained by means of data mining of the National Statistics and Informatics Institute of Peru (Instituto Nacional de Estadísticas e Informática – INEI).
Climate change definitions that are considered to be of great impact for the local vulnerability, will be modeled through the perspective of local experts in the calculations. The effect of each of its factors will be examined in detail by the application of fuzzy inference systems.
As a result of this way of analyzing the role of climate change and its effects on the social vulnerability for the selected area of Shallap Valley, this research can be considered an important new contribution to take into account within the huge human-environmental relationship system.

ACKNOWLEDGMENTS

This research is conducted with financial support from the Science Fund of the Land Tirol (Tiroler Wissenschaftsfonds, TWF).

REFERENCES

Carey, M. 2004. Living and dying with glaciers: people´s historical vulnerability to avalanches and outburst floods in Peru. Global and Planetary Change 47 (2005), P. 122-134.

Carey, M. 2010. In the Shadow of Melting Glaciers. Climate Change and Andean Society. Oxford University Press, USA. P190-192.

Carrere, J. 1998. Los verdaderos responsables de la deforestación. http://www.revistadelsur.org.uy/revista.085/WRM.htm (last review: April 2010).

Craig A. 2006. Sprawl and the resilience of humans and nature: an introduction to the special feature. Ecology & society 11 (1), P. 36.

Forrester, J. 1968. Principles of systems. MIT Press, Cambridge-Massachussetts.

Gunderson, L. 2005. Resilience - Now more than ever. Ecology&Society 10 (2), P. 22.

Kaser, G. 2001. The Impact of glaciers on the runoff and the construction of mass balance history from hydrological data in the tropical Cordillera Blanca, Peru. Glacier & Hydrology Peru. IAHS Maastricht.

Kasperson,R. and J., 2005. The Social Contours of risk, Volume I: Publics, Risk Communication & the Social Amplification of Risk. EARTHSCAN, London, VA.

Kasperson,R. and J.,2005. The Social Contours of risk, Volume II: Risk Analysis, Corporations & the Globalization of Risk. EARTHSCAN, London, VA.

Kosko, B. 1992. Neural Networks and Fuzzy Systems, a dynamical System Approach to Machine Intelligence. Prentice Hall, 1992, P 3,6.

Larsen, K. 2008. Climate change scenarios and citizen-participation: Mitigation and adaptation perspectives in constructing sustainable futures. Habitat International 33 (2009), P. 260-266.

Law, T. – Zhang, W.2009. Structural changes in lake functioning induced from nutrient loading and climate variability. Ecological Modelling 220(7), P. 979-997.

Neuburger, M. 2002. Pionierfrontenentwicklung im Hinterland von Cáceres (Mato Grosso, Brasilien). Ökologische Degradierung, Verwundbarkeit und kleinbäuerliche Überlebensstrategien. Tübinger Geographische Studien 135 / Tübinger Beiträge zur Geographischen Lateinamerika-Forschung 23 (Hrsg. G. Kohlhepp).

Mark et al. 2010. Climate Change and Tropical Andean Glacier Recession: Evaluating Hydrologic Changes and Livelihood Vulnerability in the Cordillera Blanca, Peru. Annals of the Association of American Geographers, 100(4)2010,P. 794-805.

Ovando, N. 2008. Impactos del cambio climático en áreas protegidas y glaciares: Foco América Latina. http://www.medioambienteonline.com/site/root/resources/analysis/6823.html (last review: August 2010).

Turner,B.L. 2003. A Framework for vulnerability analysis in sustainability science. www.pnas.org/cdi/doi/10.1073/pnas.1231335100 (last review: January 2012)

Ulanowicz, R. 2009. The dual nature of ecosystem dynamics. Ecological Modelling (2009), doi: 10.1016/j.ecolmodel.2009.04.015.

Urrutia, R. 2010. Glaciares en peligro por cambio climatico.

http://www.terram.cl/index.php?option=com_content&task=view&id=3440. (last review: April 2010).

Vuille, M. – Kaser, G. 2008. Climate change and tropical Andean glaciers: past, present and future. Earth-Science Reviews 89 (2008) P. 79-96.

Walker, B. et al. 2006. Exploring resilience in social-ecological systems through comparative studies and theory development: introduction to the special issue. Ecology & Society, 11 (1), P. 12.

Young, K. 2006. Adaptive governance and climate change in the tropical highlands of western South America. Climatic Change 78 (2006), P. 63-102.

Youssefi,H.2011]. A New Method for Modelling System Dynamics by Fuzzy Logic: Modelling of Research and Development in the National System of Innovation. http://www.tjmcs.com/includes/files/articles/Vol2_Iss1_88%20-%2099_A_New_Method_for_Modeling_System_Dynamics_by_Fuzzy_Logic_Modeling_of_Research_and_Development_in_the_National_System_of_Innovation.pdf (last review: December 2011)