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VULNERABILITY AND ADAPTATION TO CLIMATE CHANGE IN THE PERUVIAN CENTRAL ANDES: RESULTS OF A PILOT STUDY

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1. INTRODUCTION

The Geophysical Institute of Peru, in coordination with the National Council of Environment, CONAM, through the Program of National Capacities Building for Impact of Climate Change and Air Pollution Management, PROCLIM, developed the pilot study "Integrated Local Assessment of the Mantaro River Basin", as part of the activities related to the study of vulnerability and adaptation to climate change.

Figure 01: Localization and administrative map of Mantaro river basin.

The main objective of the study was to systematize and to extend the knowledge about climate change in the Mantaro river basin, and to evaluate the climatic, physical and social aspects of its vulnerability, as well as to identify viable adaptation options for the agriculture, hydroelectric energy and health sectors, to be incorporated into local and regional development planning.

The Mantaro river basin is located in the central Andes of Peru, and includes territories of Junin, Pasco, Huancavelica and Ayacucho regions (Figure 01). The Mantaro river depends on the precipitations throughout the basin, and on the level of Junin Lake, and the lagoons located below the glaciers in the western and eastern mountain ranges.

The Mantaro river basin is very important, because its hydroelectric plants produce nearly 35% of the electrical energy of the country, the agricultural production of its valley is the main source of food for the capital city, Lima, and its population surpasses the 700,000 inhabitants.

2. METHODOLOGY

This research was done within the framework of an integrated local evaluation of the river basin, which is an interdisciplinary process that combines, interprets and communicates knowledge of diverse scientific disciplines so that the chain of cause-effect of a problem can be evaluated with a synoptic perspective (Rotmans and Dowlatabadi, 1998). Thus, in the development of the study in the Mantaro river basin, two parallel interdisciplinary working groups were formed.

The first group (Group A) made the analysis of the climatic characteristics of the river basin, mainly referred to rainy and dry periods, their relation with the El Niño phenomenon, teleconnection mechanisms and the relation be-

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tween the physical processes on the meso and local scales with the monthly, seasonal and/or interannual variability of the main meteorological variables (rain and air temperature). The results were used to identify the meteorological phenomena that have historically affected the population of the river basin. Fundamental part was the development of future climate scenarios, information that later was used for the analysis of the future vulnerability of the population.

The second group (Group B), analyzed the present and future vulnerability to climate variability and/or change in the river basin, considering three socioeconomic sectors that were prioritized in this study, and using the information generated by Group A. In a series of workshops, the high-priority sectors were selected, and after the analysis of present and future vulnerability, the adaptation measures to climate change for each one of these sectors were elaborated.

The sectors prioritized were: agriculture-forest-cattle, generation of hydroelectric energy and health, and were chosen by their sensitivity against changes in the climate. Due to the absence of data and information in the agriculture-forest-cattle sector, it was replaced by the agricultural sector. Figure 02 shows the methodological flow chart followed in the study.

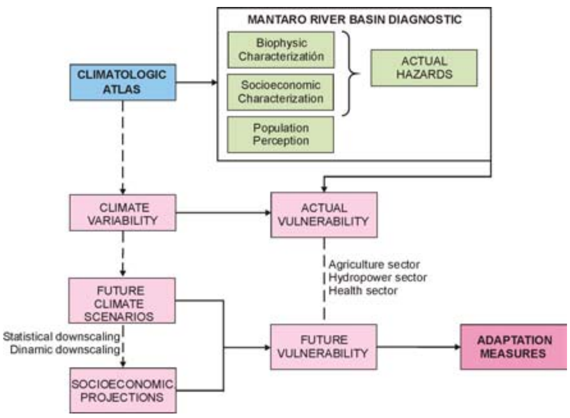

Figure 02: Methodological flow chart (From Instituto Geofísico del Perú, 2005a)

The research was of an interdisciplinary and interinstitutional nature, and its fundamental tool consisted in participative workshops with the collaborating institutions and the local population, which made numerous and useful contributions not only to the recollection of information, but to the analysis, data modeling and application of results.

An important goal of the study was to incorporate climate change as a prioritized subject in the regional agenda, at institutional and grassroots organization levels, and the population in general. Thus, the population of the river basin had to be not only subject of study, but an acting part in the development of the research.

The first step for the development of the study, was the design and development of a diagnosis that served as baseline for the study of the river basin, and provided the "big picture" of the reality of the basin as perceived by the population, not only from a biophysical and socioeconomic perspective, but also cultural and of ancestral knowledge.

The diagnosis allowed the identification of the main natural hazards in the river basin - droughts, frosts and superficial geology phenomena- and their incorporation into the elaboration of the adaptation proposals, considering water resources as the transversal factor of the study. Also, it was vital to take into account that the capacity of the human systems to adapt and to face the probable consequences of climate change depends on factors not necessarily dependant of climate, like technology, education, information, creativity, innovation, access to financial resources and institutional capacities.

The results of this diagnosis became both a source of information and a tool for the validation of the study. With this information, the river basin was divided in three zones of analysis: northern, central and southern zone (Figure 01), based on climatical, physiographical, hydrological, socioeconomic and institutional differences.

The northern zone is the less populated in the basin. It contains the National Reserve of Junin and most of its territory is occupied by Junin Lake, also called Chinchaycocha, the second largest lake of Peru after Titicaca. Around the reserve, an interesting experience has developed with the cultivation of maca for export. Nevertheless, this zone faces serious problems related to contamination from mining, mainly by heavy metals settling in the lake waters, problem that has not been studied in the present research.

The central zone – in which the so-called "Mantaro valley" is located – is the most populated, and is where the main cities of the basin are located. Most of the agriculture of the basin takes place in this zone - mainly oriented to supply the coastal cities with products like potato, artichoke, carrot, barley, etc. It is the commercial axis of the Mantaro, and agglutinates the largest amount of goods and services offered in the river basin.

The southern zone, which has the greatest poverty indices in the basin, has the largest amount of agricultural land, and crops like potato, barley, olluco, oca and tuna are cultivated. The population has little access to services like potable water and electricity, even though this zone is where the main hydro-energetic infrastructure is located.

3. CURRENT VULNERABILITY IN MANTARO RIVER BASIN

The vulnerability of the population is strongly associated to poverty, since poor people have little resources to be able to overcome adversities of different types. Frequently, the poor population is located in ecologically fragile areas, including areas of low agricultural potential and, in many cases, they are "intruders" in urban areas (Ekbom and Bojö, 1999).

The socioeconomic vulnerability is amplified by factors that we have called critical vulnerability amplifiers in the Mantaro river basin: structural land crisis, characterized by low rural income, degradation of traditional production systems, rural depopulation, etc.; increasing and disordered urbanization, characterized by deficient habitational infrastructure, lack of basic services, etc.; and population displacement, migration and conflicts over use of resources, characterized by land and water conflicts, environmental risks (like contamination), etc. (Figure 03).

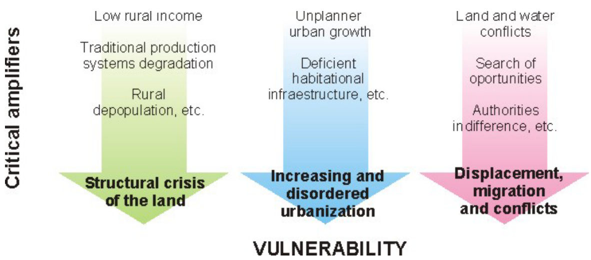

Figure 03: Critical vulnerability amplifiers in Mantaro river basin

These factors are associated with a generalization of poverty, which is a decisive factor for the lack of resilience of the population. Additionally, the population of the Mantaro river basin is vulnerable to numerous meteorological and geodynamic phenomena, that constantly act against the security and well-being of the population, and these hazards would possibly be exacerbated by climate change, increasing even more the risks for the population.

3.1 Current vulnerability in agricultural sector

Agriculture constitutes the most important economic sector in the Mantaro river basin (Figure 04) according to the fraction of the economically active population (EAP) dedicated to it, which is 54.6%. There are approximately 339,065 has of agricultural land, 29% of which are under an irrigation system, and 71% are dependent on rains.

Figure 04: Agriculture constitutes the most important economic sector in the Mantaro river basin

One of the main characteristics of agriculture in the Mantaro river basin is the existence of the “minifundio” (private ownership of less than 0,5 hectares), and small property (0.5 hectares – 4.9 hectares), both representing the 85.7% of the producers.

Climatic variations have direct and indirect influences in food production, since variations in temperature, irregularity of precipitations and the presence of extreme climatic events like frosts and droughts increase the pressure on the agrarian resources and reduce the quality of the land dedicated to the agricultural production, affecting their yield.

For the analysis of current vulnerability in this sector, two representative crops were chosen: maca, for the analysis in the northern zone of the river basin; and potato, for the analysis in the central and southern zones.

Records of precipitation accumulated during the agricultural year (September-April), mean temperatures and frequencies of frosts (also between September-April) were used in representation of the climatic variations; and production, harvested surface and yield in representation of the socioeconomic variables. A recurrent problem in the analysis was the short duration of the used time series.

In the northern zone, maca is of particular interest, due to its good yield in the zone and its potential for exportation. The correlation analysis between maca and the mean temperature, indicates a significant negative relation. This result would reflect the relation between the temperature and the incidence of plagues and diseases, as mentioned previously. Also it could be due to the preference of this crop by low temperatures, reason why warmer temperatures could reduce the yield of the crop.

For potato, in the Central and South zones of the river basin, we have found that reduced production, cultivated surface and yield are expected, when the temperatures are warmer - due to the greater incidence of plagues -, when the frequency of frosts is greater - since the frosts can kill the crops -, and when the precipitations are smaller - since it is more difficult to fulfill the plant hydric requirement.

3.2 Current vulnerability in hydroelectric power sector

Although the Mantaro river basin produces nearly 35% of the electrical energy of the country, the electrical energy coverage in the homes in the basin is very low, for example, the southern zone produces 96% of the hydroelectric energy generated in the river basin, and only 17.7% of the homes count with this service.

The Mantaro Hydroenergetic Complex is the most important center of hydroelectric generation of the country (Figure 05), and it is located in the southern zone, in the province of Tayacaja, department of Huancavelica, and belongs to the ElectroPeru company. It is conformed by the Tablachaca hydroelectric dam, and central power stations Santiago Antúnez de Mayolo and Restitución (Figure 01).

The energy generated in both central power stations is transmitted towards Campo Armiño Substation from the transmission lines goes to the transformation and distribution centers of all the country, including Lima (the capital city), mining centers and main industrial companies. For that reason, any factor that affects the energy generation, affects not only the Mantaro river basin, but also a great part of cities, mining centers and main industrial companies of the country.

The data of hydroelectric energy generated in the hydroelectric power stations of Mantaro and Restitución have been correlated with precipitation data in the stations of Upamayo, Huayao and Mejorada, located in the North, Central and South part of the Mantaro river basin, respectively. Also the correlations between the useful volume of the Junin lake and natural volumes in the La Mejorada station, were calculated.

Figure 05: Partial view of the Mantaro Hydroenergetic Complex

Significant positive correlation exists between the useful volume of the Junin lake, the main reservoir, and the energy generated in the Mantaro and Restitución hydroelectric central. Similarly, good correlations are observed between the energy produced in the Mantaro and the volume of the Mantaro river in La Mejorada station.

These results confirm that there is a dependency between the amount of energy that is generated in the Mantaro river basin and the availability of water, indicated by the volume of Lake Junin, as well as by the volume of the

Mantaro river measured in La Mejorada station.

3.3 Current vulnerability in health sector

The occurrence of extreme climate events in the basin often becomes leading factor of changes in the health of the population. In the Mantaro river basin, these changes are indirectly related to variations in the precipitation and air temperature, which affect main economic activities, agriculture and cattle, placing the population in a situation of high vulnerability. This situation is aggravated by the lack of basic services, as potable water and sewerage.

In the case of the gastrointestinal diseases, its occurrence is independent of the air temperature and precipitation levels, as indicated by the negligible correlation factor for both parameters. Nevertheless, the main cause of its presence in the basin would be the restricted access to potable water and sewerage services, which might become worse with climate change.

For infectious diseases as the malaria, numerous studies made in tropical countries indicate that the seasonal changes in the climate of a region, rather than high annual temperatures or rain, play the main role in the appearance of epidemics. Thus, for a breakout of a malaria epidemic, it is not necessary an increase of air temperatures throughout the year, but an increase of air temperature and greater precipitations in the season in which the mosquitoes that spread the disease reproduce.
In the Mantaro river basin, the reported cases of malaria are imported from the tropical forest zone of Oxapampa and Satipo mainly, by reasons for work and/or tourism, and most of the registered cases appeared during June and July, where the factors of raised air temperatures due to the strong insolation and lack of cloudiness in this period, and the presence of precipitation in the tropical forest, are factors that promote the reproduction of the malaria vector mosquito.

The diseases related with respiratory infections, appears with much greater incidence during the dry season, between May and August, when the minimum air temperatures are lowest. Thus, these diseases are inversely correlated with the minimum air temperatures, so an increase in the minimum air temperatures would produce a diminution of the morbidity and mortality related to these diseases. On the contrary, an increase in the occurrence of frosts or low air temperatures in the river basin would elevate the number of cases.

During the last few years, an increasing preoccupation to analyze the level of ultraviolet radiation of the Mantaro river basin has been developed by numerous groups of investigators.

Figure 06: The high ultraviolet radiation presented in the Mantaro river basin is caused by a series of factors, like small zenith angles in the region, the cloudless sky during the months from May to September, its location above 3,000 masl, etc.

These researchers concluded that the ultraviolet radiation in the basin is very high due to reduced concentrations in the ozone layer, the small zenith angles in the region, the cloudless sky during the months from May to September, as well as its location above 3,000 masl. Although the data are still limited, it is known that the cases of skin cancer, cataracts (clouding of the crystalline lens) and pterignon (conjunctive hypertrophy characterized by a vascular weave appearance) have increased considerably in the basin.

4. FUTURE VULNERABILITY IN MANTARO RIVER BASIN

The future climate scenarios estimated for the river basin for the year 2050 using statistical downscaling, indicate an increase of 1.3°C and 1 g/kg in air temperature and specific humidity, respectively, and a diminution of 6% in relative humidity in the Mantaro river basin during the peak of the rainy season, of December to February. Also, the precipitations would diminish by 10%, 19% and 14% in the northern, central and southern zones of the basin, respectively. These results are consistent with the trends estimated from historical climate information for the period 1950-2002.

These results were crossed with the socio-economic information projected to 2050, in order to estimate the future vulnerability in the prioritized sectors.
The main hazard to the environment is related to the lack of water, which would affect the existing ecosystems in the basin, and also the increase of air temperature in more of a degree, which, due to the glacier melting, could cause increased landslides, mainly at the feet of the glaciated mountains, erosion, and surface run-off.

The impact on the population, however, will be dominated by urban expansion and the increasing demand of water and land resources. Thus, it is the socioeconomic aspects that would determine the future vulnerability in the basin.

4.1 Future vulnerability in agriculture sector

Projections indicate that agriculture would pass to a second level of economic importance after the activity of commerce and services, in terms of the economically active population participation, which would only be 31.5% (INEI, 1993). Nevertheless the agrarian structures, the main crops and cattle, will be maintained.

An average decrease in precipitations between 10 to 20%, like that projected for year 2050, would have the effect of a prolonged drought that could not be lessened by the management of dams and reservoirs, since evidently these cannot provide water indefinitely. Therefore, the effects will be felt by both irrigation agriculture and by rain depending systems.

The agriculture land dependent of rain would be specially harmed. However, lands under irrigation would also be affected, mainly by the social conflicts between the users of potable water, water for irrigation and water for the generation of hydroelectric energy, which would alter the already fragile social panorama of the river basin.

The raise of air temperatures could allow the cultivation of some products at higher altitudes, although always with the limitation of smaller water availability. On the other hand, the maca cultivation, which requires low air temperatures, could be been seriously affected by the disappearance of areas with this range of temperatures.

An indirect effect of the rise of air temperature could be an increase in the incidence of plagues and diseases in the crops. If the observed positive trend in the frost frequency persists, the vulnerability of the crops would be increased even more.

4.2 Future vulnerability in hydroelectric power sector

As previously mentioned, although the Mantaro river basin generates a large fraction of the electricity energy of the country, the coverage of the energy service for homes in the river basin is insufficient. The future estimates indicate that the situation will improve for year 2050. Nevertheless, the deficit will still be considerable, from an actual deficit of 56.8% to a future deficit of 38.7% for the river basin (MEM, 1998; INEI, 1993),

The rain estimations for year 2050 indicate that the rain deficit in the northern zone of the river basin would be of 10%. Due to the dependency of the amount of energy that is generated in the Mantaro river basin on the amount of accumulated water in the Junin lake, this indicates that in a next future the amount of hydroelectric energy generated in the river basin it will be negatively affected.

The national population projections indicate that the population would have an increase of approximate 50% for year 2050 (INEI, 2001), which indicates that the necessities of electrical energy would be increased, at least in the same proportion. This situation, combined with the precipitation deficit, and therefore, of energy in the river basin will be serious.

4.3 Future vulnerability in health sector

The potable water deficit in the homes and the unacceptable hygienic conditions will continue being the main causes of diseases, that will put in risk the well-being of the population, with women being those more exposed to water related diseases, due to their traditional tasks of washing, agricultural irrigation and water recollection.

The lack of public sewerage systems in the Mantaro river basin will continue being still greater than the potable water deficit. According to projections, in the southern zone of the basin, more than 50% of the homes will continue without potable water, and 60% without sewerage, negligibly less than in the present.

The increase of air temperatures would favor the appearance of infectious focus by the expose of excretes and sewer water and the more prolonged drought periods would affect the potable water availability for the population.

On the other hand, the river basin receives high levels of UV radiation through the year, and is reasonable to expect a greater amount of days with cloudless skies in drier conditions, which will produce greater intensity of radiation in some years, with negative effects on the population, mainly in skin and eyes.

5. ADAPTATION MEASURES IN MANTARO RIVER BASIN

The formulation of the adaptation measures for the Mantaro river basin took place in numerous workshops and work meetings with the participation of the main actors of the basin – representatives of the regional governments, public and private institutions, NGOs, etc. - and water (use, distribution and management) was identified as the cross-sectional factor that connects the three prioritized sectors (Figure 07). For that reason, its integral management with the support of all the involved stakeholders is vital in the adoption of the adaptation measures proposed.

Figure 07: Partial view of Huaytapallana glacier. Water resources (use, distribution and management) were identified as the cross-sectional factor that connects the three prioritized sectors in the Mantaro river basin.

The human systems capacity to adapt and to face the probable consequences of the climate change, depends on factors not necessarily related to climate, but related to technology, education, information, creativity, innovation, access to resources and institutional capacities.

Actions such as the territorial ordering of the basin and the redistribution of the increasing population, are part of the baseline of necessary management that must be taken into account to appropriately incorporate adaptation measures into the local and regional development plans, which must go accompanied by institutional strengthening and the support and action of the involved actors in the basin.

For the elaboration of the proposals of the adaptation measures, in addition to the future climate scenarios and the socioeconomic projections, the identified risk factors in the river basin - droughts, frosts and superficial geologic phenomena - were considered. For each prioritized sector - agriculture, hydroelectric power and health - structural and nonstructural measures were proposed.

The structural measures are referred to the physical intervention by the development or reinforcement of works of engineering, which seek to minimize material damages. In the three prioritized sectors we found one common structural adaptation measure: the reinforcement, extension and modernization of the hydrometeorological observation systems, for the generation of baseline information for the study and forecast of adverse meteorological phenomena.

The nonstructural measures are referred to actions based on an efficient use of resources, related to educative actions or of legislative application of management and organization, that are complemented with the structural measures, and that promote the organization, the institutional fortification and the public information of the actors involved.

In Mantaro river basin, six groups (Figure 08) were identified: those related with capacitation, training and sensibilization; institutional reinforcement; recognition and recovery of native knowledge; scientific research; quantification and monitoring of biophysical resources and those related with application of climate information.

This last group of adaptation measures is, clearly, the complement of the structural measure of reinforcement, extension and modernization of the hydrometeorological observation systems, and was also proposed for each of the three prioritized sectors.

The amplitude of the river basin, and the coexistence of very diverse economic and social systems was an obstacle for a more detailed development of the adaptation measures.

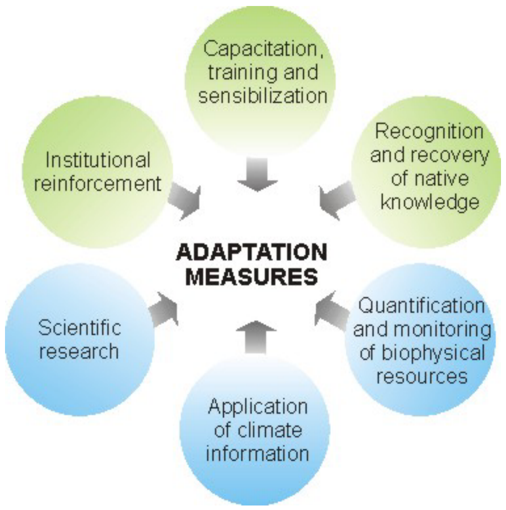

Figure 08: Non structural adaptation measures in the Mantaro river basin. The green ones are related to cultural, political and socioeconomic aspects, and the blue one are related to technological and scientific improvements.

The agricultural sector involves the largest number of economically active population in the Mantaro river basin, and its reality is broad and complex. Thus, the structural and non-structural measures are numerous and general, and, nevertheless vital for the development of the basin. The stakeholders that should be involved in the implementation of these measures are not limited to the Ministry of Agriculture, and local and regional governments, but include pedagogical institutions, universities, farming institutes, professional unions and schools, farmers communities, etc.

The structural adaptation measures are mainly referred to improving the capacity of water storage, and the construction and improvement of irrigation systems. Related to the non-structural measures, we can mentioned regulation of migratory agriculture; the rescue of traditional technologies better suited for the zone, like an update of the Andean technology in diversification, crop rotation and land rest periods, etc.

The hydroelectric energy generation is affected by the lack of rain. Therefore with a decrease in rain, the cost of its generation increases, with the consequent increase of the cost to the consumers. This situation would affect not only the basin, but a great part of the country, including important cities and industrial companies supplied by the Mantaro hydroenergetic system.

The main actors in the implementation of adaptation measures are: Ministry of Energy and Mines, hydroelectric energy generating companies like ElectroPeru and ElectroAndes, regional and local governments, education sector, and the main users of the generated energy.

The structural adaptation measures are mainly referred to the use of alternative systems of energy generation, and the improvement of the electric network in the river basin.

The main nonstructural adaptation measures, are those referred to enhance capacities in the efficient use of the electrical energy, the development of research programs for the generation of electrical energy using alternative power sources, etc.

The adaptation proposals for the health sector are directly related to the subject of sanitation (water and sewerage networks). Thus, the quality of potable water, its correct use and suitable planning and management, are subjects that cannot be separated from a suitable management of the health sector in the basin. The main actors in the implementation of adaptation measures are the Ministry of Health with their attention centers: hospitals, basic health units, the regional and local governments, etc., Ministry of Education, etc.

The structural adaptation measures of adaptation for the health sector are mainly referred to improve the infrastructure of public health, and the health services, the increase of shaded areas in schools and recreation zones for children, etc.

The nonstructural adaptation measures are mainly directed towards the implementation of services such as early cancer detection, early detection of ocular diseases (cataracts and pterinon), development of capacitating programs oriented to the medical personnel, etc.

6. GLOSARY

Maca *(Lepidium meyenii walp)*..- The only brasicaceas domesticated in the Andes. It is adapted to very cold ecological conditions, characterized by average temperatures between 4 and 7° C, high solar irradiation, frequent frosts, strong winds and acid grounds. It has high nutritional and medicinal value, and is consumed in flour form and prepared in soups, desserts, breads, cakes, etc.

Oca *(Oxalis tuberosa Moll)*.- Andean tuber. In fresh it is consumed cooked, generally previously exposed to sun, and dehydrates like "ccaya" or "uma ccaya". Also candies and jams are made. Its stem constitutes excellent forage for cattle.

Olluco *(Ullucus tuberosus Caldas)*.- Andean tuber. It is the most spread specie, after the potato, among the consumers of the coast of Peru. It is consumed in two forms: fresh and dehydrated

Tuna *(Opuntia Ficus)*.- Cactaceous, in Peru their fruits are destined to the human consumption in fresh form, and for the elaboration of regional products (sweeties, boiled must). Pencas are used like forage, being a very valuable resource at times of drought and low forage availability for the cattle.

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REFERENCES

Ekbom, A. and J. Bojö, 1999: Poverty and environment: evidence of links and integration with the country assistance strategy process, Discussion Paper 4. Environmental Group, Africa Region, World Bank, Washington DC.

Instituto Nacional de Estadística e Informática, 1993. Perfil Sociodemógráfico de Junín, Pasco, Huanuco, Pasco y Huancavelica. INEI. Lima, Perú

Instituto Nacional de Estadística e Informática, 2001. Perú: Estimaciones y proyecciones de población, 1950-2050. Boletín de Análisis Demográfico INEI. Lima, Perú

Instituto Geofísico del Perú, 2005a. Diagnóstico de la cuenca del río Mantaro bajo la visión de cambio climático. Fondo Editorial CONAM. Lima, Perú.

Instituto Geofísico del Perú, 2005b. Vulnerabilidad y adaptación al cambio climático en la cuenca del río Mantaro. Fondo Editorial CONAM. Lima, Perú.

Ministerio de Energía y Minas, 1998. Altas de Minería y Energía en el Perú. MEM. Lima, Perú

Rotmans, J and H. Dowlatabadi, 1998: Integrated assessment modelling. In: Human Choice and Climate Change. Volume 3: The tools for Policy Analysis (Rayneer, S. and E. L. Malone Editors). Batelle Press, Columbus, OH, USA.