Climate change effects on the livelihoods of Illimani glacier’s communities
Juan C. Alurralde¹, Edson Ramirez², Magaly Garcia¹, Elena Villarroel¹, Danitza Salazar⁴, Paula Pacheco⁴
KULeuven¹ Leuven, Belgium; Illimani Project: IHH², IIAREN³, Agua Sustentable⁴, La Paz, Bolivia

Abstract
Global warming is the most clear climate change effect and is occurring faster at higher altitudes where glaciers have been standing for centuries. Tropical glaciers are even more affected by climate change than their temperate counterparts due to larger sun exposure and summer-rainy season coincidence that reduces snow accumulation. Though, glaciers are their principal natural water regulators and the only domestic and productive water source during dry seasons, their retreat affects directly downstream communities’ livelihoods. Climate change is already affecting water right rules, crop patterns and upward expanding productive areas in the tropical Andes.

The Illimani project studies Illimani’s glacier dependent area in a physical and socio-productive context to generate socially and participative accepted adaptation strategies for climate change and climate variability effects. Multidisciplinary results are integrated in watershed management models to develop technically and socially validated descriptions of the dynamics between the glacier and the basin, for actual and future scenarios, resulting in proposals for adaptation actions. Different adaptations strategies between the upper and lower part of this small area and the need for dynamic research-action oriented programs are identified as essential. These studies seek to set decision support tools that will help to shape water use policies of the region, for an effective adaptation to a rapid shifting climate.

Keywords: adaptation strategies, climate change effects, Illimani glacier, irrigation, tropical Andean glaciers, water rights.

Introduction
The Illimani glacier, Bolivia’s second highest mountain, is a natural water reservoir that regulates the water provision for its downstream communities during the dry season when it is the only water source for their agricultural activities.

Climate change with rising temperatures, more erratic rainfall and higher water demand is causing the retreat of this and other Andean glaciers, it has been observed that global warming is occurring faster at higher altitudes (Engle, 2010). As a result, downstream communities’ livelihoods are affected, crop patterns are changing, productive areas are expanding upwards where before it was impossible to cultivate and water conflicts are rising.

General overview of the study area
The main course of the studied basin is the Sajhuaya (Illimani) River, a tributary of La Paz River (Fig. 1). This basin covers 59 km², rises at the east of the Cordillera Oriental and is part of the central western flank of the Illimani Mountain. The peak is located at 6350masl. and its lowest point at 2500masl. over the Palca river (Villarroel, Perez, Castel, & Torrez, 2010), approx. 66 km from La Paz city, Bolivia’s government city. The basin encloses Khapi, Cohoni, Jalancha, La Granja Challasirca, Cebollullo, Chañurani and Tahuapalca communities (Fig. 2).
The main ecological strata in the area are Highland Andean Puna, Pre-Puna and Upper valley. The main economic activities and water uses are agriculture and livestock farming. The upper basin has difficult access, harsh weather with several frosts days per year that limit their crops choices. The lower part has more agricultural potential thanks to better temperatures. The few livestock units feed upon the upper natural highland pastures and wetlands.

Agriculture uses mostly surface water from rivers and springs while human consumption sources are mainly springs. Springs have appreciable discharge the whole year that is reduced only during the dry season (June to October), these discharges can be larger than river discharges (direct from the glacier) (Villarroel, Perez, Castel, & Torrez, 2010).

Methods

Climate change evaluation

Given that no long climatic records are available in the area; climatic data from 5 near-highly-correlated stations (El Alto, Bolsa Negra, Patacamaya, Achachicala and Viacha) were used to statistically generate reconstructed series with the short data (3 yrs) from the basin stations (Montaño 2010).

Glacier’s retreat estimation

The change on the Illimani’s surfaces and thickness is performed using aerial photos of the studied area, 60% overposed, for the years: 1963, 1975 y 1983 with scales 1:30000, 1:60000 and 1:50000, respectively. Additionally, a present-day photogrammetric flight was carried out in July 2009. The DEMs of the Illimani Glacier are digitalized using a photogrammetric digital restitution with the stereoscopic model for each year. The snow extension of the whole glacier and the snow thickness along 5 longitudinal profiles over the most representative glacier fronts are measured for each year (Ramirez, Machaca, Garcia & Alurralde, 2011).

Water rights mapping

The information collected from field visits, surveys/interviews to local authorities/users and processed satellite images is analyzed and systematized with excel data bases and ArcGIS software (Villarroel, Perez, Castel, & Torrez, 2010). The resulting information is: the local management rules for water organizations, the identified formal and
informal water users and how they apply their water rights for irrigation or domestic purposes, areas under cultivation, cropping patterns and agricultural calendar.

Irrigation and agriculture changes
The productive structure, its water demand (García, M. 2010), and the biophysical, socioeconomic, productive and institutional vulnerability (García & Taboada, 2010) are evaluated in the Illimani area under an integrated approach. 3 representative communities in this area (Khapi, Cebollullo and Tahuapalca were detailed monitored since August 2009 to December 2010 to study their cultivated areas (crops types, distribution and seasonality), irrigation systems (canals and its operation), water use and rights for domestic and agricultural purposes (irrigation turns, amounts, efficiency and methods). Because of their observed similarities, the information from Khapi is extrapolated to Challasirca and the upper part of Cohoni; the information from Cebollullo to Chañurani, Cachapaya and the lower part of Cohoni; and the information from Tahuapalca to La Granja.

Results
Climate change evaluation
The resulting historic reconstructed series (Montaño, 2010. Fig. 3 and ¡Error! No se encuentra el origen de la referencia.) show a clear upward tendency for temperature (high significance in Mann-Kendall test) while a less clear reducing trend is appreciated for rainfall (no significance).

Thus, farmers’ perception on temperatures increase is confirmed, but their perception concerning a reduction in the precipitations is not clearly verified. Related studies (Seth et al, 2010) indicate that between latitudes 10 to 20ºS, the total precipitation amount is generally maintained but its temporal distribution is changing. In these areas it is expected: less precipitation during the spring (Sept-Nov), more often delays on the beginning of the rainy season, more precipitation from December until April and a faster reduction at the end of the rainy season. This explanation fits better the increasing drought perception of farmers.
Most common climate risks in this area are snowfalls, frosts and hail storms (especially in the upper basin), unusual distribution of rainfalls (generally delay), droughts (high risk) or flooding (low risk). Sporadical frosts between April and September might damage the production. Hailstorms between December and February and snowfalls in winter (July-August, max. 3 times) increase the soil water storage (PDM-Palca, Palca's Development Municipal Plan, 2007-2011) and (Emergency Operations Center, COE).

There are no historical available records of extreme events in this area, but 80% of the inhabitants remind some important climatic event in the past 25 years. The 1983’s El Niño event is the most clearly reminded (recorded as the driest year in Bolivian West), it affected strongly these families’ livelihoods causing that more families felt the need of periodical irrigation. To face past extreme events, most families (33, 62, 70%) used their savings (Tahuapalca, Cebollullo and Khapi respectively) since government aid only reached 19% of the population in the lower communities (Cebollullo and Tahuapalca). 17% Khapi’s farmers migrated to compensate their economic damage.

**Glacier’s retreat estimation**

The most direct, notorious and perturbing climate change effect in the area is the Illimani’s glacier retraction. The glacier’s extension for 1963, 1975, 1983 and 2009, estimated using photogrammetric restitutions and the longitudinal profiles’ axes (A, B, C, D, E and F), used to estimate the snow thickness lost between each period are shown in Fig. 5 (2009’s photo).

Fig. show the estimated surfaces evolution of Illimani Glacier between 1963 and 2009. According to morphological similarities, the glacier is divided in 3 sectors. Sector I corresponds to glacier close to profiles A, B and C; Sector II to profiles D and E, and Sector III to profile F and the continuous main glacier. During 1963-2009 (46 years), the glacier lost approximately 21.3% of its 1963’s surface. Glacier surface loss is not uniform, some parts maintained a similar extension between 1963-1983 (A, B, D and E) while others suffered more appreciable losses for the same period (C and F). During 1983-2009, the glacier mass loss is larger and more uniformly in all studied profiles.

The snow thickness lost is evaluated along the profiles shown in Fig. (profiles A, B, C, D, E and F). The estimated loss per studied period and profile, relative to 1963, is shown in ¡Error! No se encuentra el origen de la referencia. Fig. 7. In average, this glacier lost 22m between 1963 and 2009 which gives a rate of 47 cm/year. The thickness loss occurred faster on profiles A, B, C since 1980 but slower on profiles D, E, F.
Glacier mass losses (surface and thickness) depend on the extension, orientation, altitude and slope of the studied glacier front.

**Fig. 5.** Illimani’s Glacier extension for 1963 (blue), 1975 (green), 1983 (yellow) y 2009 (red). Longitudinal profiles (dashed lines).

**Fig. 6.** Illimani Glacier’s surface evolution, 1963-2009.

**Fig. 7.** Lost thickness per Illimani Glacier’s front for 1963, 1963-2009.

**Water rights mapping**

There are 15 irrigation systems in the basin (Fig. 8). Most systems present water use overlapping, the excess of irrigated water or the remaining water in a canal is used by downstream areas/canals, even if they belong to other communities or systems. The identified water rights in this basin are summarized in Table2.

<table>
<thead>
<tr>
<th>Type</th>
<th>Subject</th>
<th>Expression</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collective</td>
<td>Irrigation System</td>
<td>Discharge available in the river uptake. Remaining discharge after upstream systems took their part.</td>
</tr>
<tr>
<td>Individual</td>
<td>Family or person</td>
<td>Period with available water in the individual user’s canal. Turns only during dry period. Free access on rainy season.</td>
</tr>
<tr>
<td>Community</td>
<td></td>
<td>Period with available water in the community canal. Rainy period: available every day. Dry period: only few days per week.</td>
</tr>
</tbody>
</table>

Table 2: Type, subject and expression of water rights in the Sajhuaya basin (Villarroel, Perez, Castel, & Torrez, 2010).
At Collective level, the irrigation period for each irrigation system can strongly vary yearly. The upper systems (Khapi, Llujo and Challasirca) do not need to irrigate strictly between Dec-Apr, the lower systems between Jan-Feb, while Tahuapalca and La Granja depend always on irrigation turns.

At individual right level, the flexibility of the rules for shifts assignment also depends on the water availability: in La Granja (low altitude with highest water deficit), the shifts rules are very strict nowadays, they have fixed turns schedules for every year and all users, without considering crops size or type. In communities with less water stress, shifts are given according user’s daily arrival order without water restrictions during each turn. In general, the area has enough water availability for present requirements during most of the year. However, water conflicts are increasing due to a higher water competition, but also to the change in water rights priorities after the 1952 Bolivian Agrarian Reform (haciendas’ owners had water rights priority for their lower lands; nowadays, the priority is for upper communities because they are closer to the canals’ intakes). Identified conflict cases: La Granja vs. Pusquiri, Cohoni vs. Khapi, La Granja water rights loss in Canal Camapo’s System, La Granja and Khapi water rights losses in Canal Llujo’s System (Villarroel, Perez, Castel, & Torrez, 2010).

**Irrigation and agriculture changes**

The increase in temperatures observed since the 80’s caused increasing crop diversity at altitudes were previously it was impossible to produce with a profitable gain and intensively during a year (lettuce, gladiolus flower). The changes in crops production are summarized in Table 3.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Khapi</th>
<th>Tahuapalca</th>
<th>Cebollullo</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
<td>I</td>
<td>I</td>
</tr>
<tr>
<td>Potato</td>
<td>100</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>Maize</td>
<td>80</td>
<td>95</td>
<td>15</td>
</tr>
<tr>
<td>G. bean</td>
<td>60</td>
<td>50</td>
<td>0</td>
</tr>
</tbody>
</table>
Table 3: Crops production (%farmers). I:2010. II:1990 (Garcia & Taboada, 2010).

<table>
<thead>
<tr>
<th>Crop</th>
<th>2010</th>
<th>2000</th>
<th>0 87</th>
<th>0</th>
<th>87</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lettuce</td>
<td>30</td>
<td>-</td>
<td>95</td>
<td>0</td>
<td>87</td>
<td>0</td>
</tr>
<tr>
<td>Tomato</td>
<td>0</td>
<td>0</td>
<td>25</td>
<td>6</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td>Gladiolus</td>
<td>0</td>
<td>0</td>
<td>15</td>
<td>0</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Parsley</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>68</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fruits</td>
<td>15</td>
<td>0</td>
<td>2</td>
<td>70</td>
<td>0</td>
<td>70</td>
</tr>
</tbody>
</table>

The access improvement since 1985 is promoting the commercialization of their products to the cities of La Paz and El Alto.

The usually small properties (from 250m² to 1ha in Tahuapalca, to max. 4ha in Khapi, Garcia & Taboada, 2010) are inherited and divided every generation, causing every time smaller properties and a impassable subsistence economy (farmers’ difficulty to try bigger inversions or get productive credits) which beside climate change, promotes the migration to big cities.

The historical irrigation requirements of Khapi, Cebollullo and Tahuapalca during 1975-2009, estimated according FAO guidelines (Allen, Pereira, Raes, & Smith, 2006) are presented in (García, 2010). Water irrigation needs are increasing in all communities. Tahuapalca’s requirement increased 500%, while Khapi doubled its requirement. Tahuapalca is now producing lettuce in bigger surfaces and in a more intensive way (3-4 times/year) with higher water requirements. Besides, the irrigation efficiency is very low because farmers still irrigate in function of their water rights and not the crops’ requirements: applied water to lettuce is approx. 800mm when it should be approx. 350mm, applied water to maize is approx. 970mm, it should be approx 550mm.

The changes in agricultural practices are increasing production losses’ risk. During 2008-2009, more than 80% of the population reported important agricultural losses; the most frequent causes were plagues and diseases (80% interviewed families). Besides, climatic events affected all interviewed families in Khapi, while low market prices affected 27-44% of the interviewed families in the lower communities.

Andean systems have developed their own traditional adaptations strategies to prevent climate variability (Garcia & Taboada,
Vertical spatial occupation at communal and family level (communal or family land over more than one ecological stratum) ensures food security with wide crops diversity and crops survival at least at one ecological stratum under extreme weather conditions, this structure has been broken after the Haciendas’ period resulting in relatively small altitudinal range communities. At each ecological stratum, crop plots dispersion decreases plagues and illness propagation. Soil conservation is improved by having small plots in very steep hills, while bigger plots in less steep hills. Terraces cultivation improves water retention and absorption. The “aynoqas” system, based on crop rotation, prevents productivity reduction by monocropping but its application is reducing nowadays.

**Discussion and Conclusions**

This area shows an intermediate water conflict level: the systems are starting to need more complex rules due to an increase in water demand or water deficit. Their application and acceptation of customary management rules show these communities’ high flexibility and potential adaptability to changes in their ecosystem. However, their adaptability should be enforced to respond as fast as impacts of climate change occur.

The Illimani Glacier is still on relative balance compared to other studied tropical glaciers that show evident changes in melting tendencies since the 70’s. Illimani’s homogeneous retreat tendency can be attributed to its high altitude (6300m.a.s.l.) and its remaining recharge area (principally the Amazonas’s basin). However, if the Glacier continues retracting, the downstream population will lose their water regulator and they will need to implement artificial water saving and storage structures to regulate irrigation and drinking water.

In the upper communities, production systems are very exposed to climatic extreme events due to their higher altitude (more frequent and stronger hails). Besides, climatic constraints are not so significant for lower communities because most farmers are connected to the irrigation system and frosts are not frequent, while market prices impact harder, showing higher market dependence.

At the upper communities, the increasing temperatures are promoting the upward expansion of productive plots and the diversity of crops. While, at the lower communities, small size of land, more market integration and higher temperatures are changing their agricultural systems to more intensive and profitable crops like lettuce and flowers, promoting the monocropping and the shift from agro-forestry to a completely agricultural system. These changes are improving the economical condition of farmers at short term, but their sustainability should be analyzed at long term because they are already increasing production losses’ risk and water demands, reducing soils fertility and turning the system more vulnerable to plagues, external supplies provision, external market prices of few products and the contamination by using irresponsibly fertilizers and pesticides.

**References**


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Disclosures
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