MAPPING VEGETATION CHANGE AFFECTING STREAM YIELD IN THE CENTRAL ANDES OF COLOMBIA

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Abstract

This paper presents the efforts of producing cartographic products as a component of a study analyzing the spatio temporal variation of landuse/land cover (LULC) and vegetation structure affecting stream yield at different altitudinal gradients in the Chinchina watershed of the Colombian Andes. Maps, 3D visualizations and animation will serve as communication tools to inform decision makers and the public to propose policy that addresses water related issues for local communities in this mountain landscape. In the tropical Andes of Colombia little research has been conducted at the sub-basin level to understand the spatio-temporal variations of climate, land use/land cover LULC and stream yield. Under climate change condition, glacier depletion on the snow mountain and increasing population growth, suggest that human settlements are at risk of facing fresh water supply shortages under cycles of intense drought caused by ENSO (El Nino South Pacific Oscillation) years. At the upper Chinchina watershed, in the Colombian Central cordillera hydrologic and climatic historical records are available from a network of stations administrated by the municipality of Manizales and AGUAS, a local water utility company. Geo visualization tools have been critical in assessing the relationship between landscape patterns and processes in mountain landscapes. In this research, I use techniques from Cartography, GIScience, and remote sensing to map the spatial variation of landuse/land cover and its relationships between precipitation and stream yield. In this project 2D and 3D landscape representations are used to visualize spatial variation of vegetation cover, and vegetation composition and to assess their relationship with stream yield. This project is a first step towards understanding question regarding LULC, water yield, watershed behavior, and human-environment interactions in this mountain landscape.

Introduction

Recent studies show that 69% of Colombia’s population is expected to face severe water related problems threatening human life and economic activities by the year 2025 (Villalba, 2008, Semana, edition 1357, 05-05-08). The threat is common to mountain communities world wide where lack of damns and glacier retreat makes them vulnerable to stream yield variations caused by landuse/land cover (LULC) change and disruptions in the precipitation cycles (Buytaert, et al. 2004). Although scientific efforts have been successful in understanding macro scale phenomena such as the annual distribution of rainfall and alterations caused by climatic anomalies such as ENSO events in the hydrological cycle at the country scale (Carvajal et al. 1998, Gutierrez and Dracup, 2001), little attention has been given to the study of the spatial and temporal variation of stream yield influenced by anthropogenic impacts such as LULC change. Such studies are of paramount importance since the lack of dams makes year around precipitation the only water supply for mountain communities under active population growth.

In the tropical Andes, human settlements strategically located in the mid range of the mountain (1000- 2000 m.a.s.l) exert strong pressure over surrounding natural conservation areas to satisfy the needs for urban and infrastructure growth, decreasing suitable areas for water catchment. In the rural areas, a long tradition of mountain colonization and LULC change creates a competition between land preservation for water catchment purposes and human activities, especially agriculture (Guhl, 2002, Garcia and Ramirez, 2002). Intense competition for water resources unfolds, since local catchments, mostly under agriculture cover, decrease the amount of water supplied to the stream network, and therefore to the local human settlements, mostly middle and small-size cities. Under a current scenario of mountain glacier retreat (Coudrain et al. 2005, Jordan et al. 2005), assessing catchments' ability to harvest rainfall water above 2000 m.a.s.l. becomes of great importance for the sustainability of mountain communities, as well as for understanding the dynamics of human intervention and changes inflected into the landscape that may affect long term water security. Neither of these investigations has yet been conducted for the study area.

At the Chinchina watershed more than 2 million people from 3 municipalities including the state capital, as well as agriculture and industrial activities, may be negatively impacted by the local effects of climatic variations (El Tiempo, print edition 04-06-08, Villalba, 2008). Downstream water flow from melted glaciers becomes relevant during periods of intense drought or ENSO years (Guzman and Baldion, 1997); however, under climate change conditions (Jordan et al. 2005), glacier depletion on the snow mountains and increasing population growth suggest that human settlements are at risk of facing fresh water supply shortages under cycles of intense drought caused by ENSO (Poveda et al. 2001). In fact, previous El Nino events have shown that at the upper Chinchina, important annual agriculture activities such the coffee harvest—with about 8000 farms in one municipality (Manizales) representing 10% of the country's production (Federacion Nal de Cafeteros, 1998, Garcia, 2002) can be severely impacted by drought and low flows on local streams (Jaramillo, 2006). In the opposite scenario of extreme rainy conditions during La Nina events, above average precipitation and increasing rainy days interfere with the water stress required for the coffee plant to activate normal blooming

(Camayo and Arcila, 1997) while decreasing the amount of solar radiation reaching the ground, which also affects the normal development of the plant (Guzman and Gomez, 1997).

This research uses techniques from Cartography, GIScience, and remote sensing to map the spatial variation of landuse/land cover and its relationships between precipitation and stream yield. 2D and 3D landscape representations are used to visualize spatial variation of vegetation cover, and vegetation composition and to assess their relationship with stream yield. The final products of this research such as maps and visualizations will be used as educative tools to inform public servers and government agents as well as the general public in the effects of landuse transformation and water resources.

Objectives

The objectives of this research are to create map and 3D visualizations of the spatial and temporal variation of vegetation cover and composition as a way to understand the effects of landuse/land cover in stream yield for this part of the tropical Andes.

Methodology

Study area: The study area (figure 1) is located at the upper Chinchina watershed in the municipality of Manizales in the western slope of the Colombian (South America) central cordillera in the altitudinal belt between 2200 and 4000 meters above sea level (m.a.s.l). At its upper portion the tree line mixes with *paramo* vegetation in the protected area of the Los Nevados National Park, while its lower portion includes a mix of agriculture and urban landscapes. The water cycle at the upper Chinchina watershed is regulated by the interactions between local events linked to orographic precipitation and by regional and global phenomena such El Nino South Pacific Oscillation (ENSO), mid Atlantic storms and glacier melting on El Ruiz Snow Mountain (Jaramillo and Chavez, 2000). These characteristics are shared in varying degrees with tropical mountain watersheds worldwide, making the study site ideal for the analysis of climatic variations and watershed behavior that serve as reference for similar landscapes

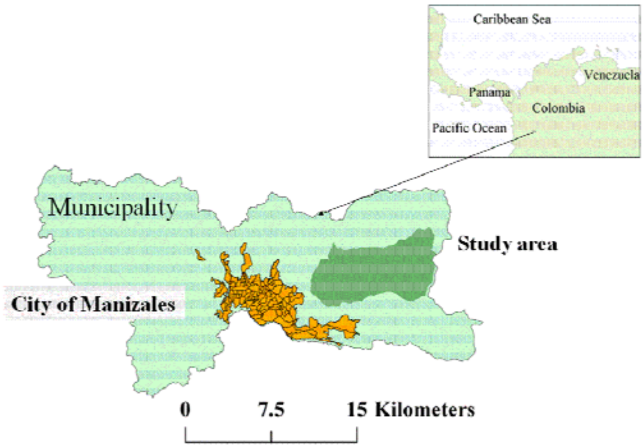

Figure 1. Study area and municipality of Manizales

Data collection

During two summers field works in Colombia on 2007 and 2008 I assembled a geographic and hydro-climatic database including 10+ years of hydrologic data as well as vector data for three sub-watersheds of the upper Chinchina watershed. Primary data included ground control points (GCP), land use/land cover (LULC) training sets, and elevation points (EP) from the nine different sub-watersheds serving the upper Chinchina river. Three sets of aerial photos, 1987, 1996 and 2007 in scale 1:40000 from the National Geographic Institute and the local water utility company are used as source for LULC data. Satellite images such as NASA-EOS Landsat TM serve as ancillary data for the vegetation analysis. GCP were collected to geometrically correct and rectify remote sensing data in the form of aerial photos and satellite images necessary to build the GIS database. Elevation points (EP) were collected to correct a digital elevation model (DEM) used to delineate the watershed and the hydrological network. ArcGIS 9.2 and ERDAS imagine 9.2 software and equipment from the GIS-Cartography lab at Kennesaw State University was used to analyze the spatial and temporal composition of the landscape and to map the spatial variation of precipitation and yield throughout the time period.

Maps and cartographic visualizations were produced to visually inspect the temporal variation of the two variables and their spatial association within particular critical periods (Dent, et al. 2009; Slocum et al., 2009.) A geodatabase is used to generate maps and 3D landscape representations to visualize spatial variation of vegetation cover, and vegetation composition and to assess their relationship with stream yield (Harvey, 2008; Lo and Yeung, 2008). Maps and visualizations as final products of this research will be print as educative tools to inform government agents and the general public in the effects of landuse transformation and water resources.

Results

During the 1997-1998 ENSO event, in the rural areas under agricultural use (below 1800 m.a.s.l) the upper Chinchina watershed decreased the volume of water drained towards the stream network and therefore affected the water availability for rural communities and households. Communities with access to the local water pipe network had to rely on water provided by the utility company, from upstream the upper Chinchina watershed (above 2200 m.a.s.l) and delivered by kilometers of pipelines (Figure 2).

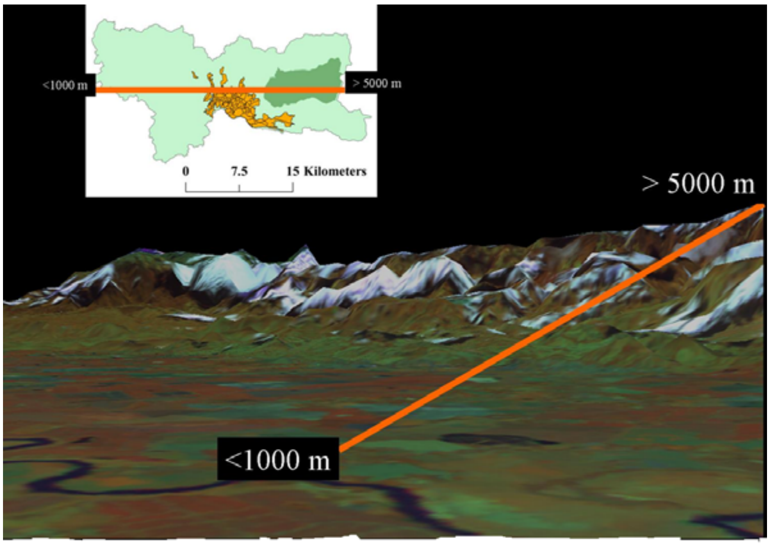

Figure 2. Mountain profile of the area served by the Pipeline system of the water utility company

Field observations showed how coffee plants were affected differently according to the characteristics of the land cover: in areas where the highest canopy interception (fully grown high populated plantations and those under tree shadows) limited precipitation, the amount of water reaching the ground and the root system was decreased, affecting coffee yield. These observations agreed with previous research showing that 17-23% highest interception of vegetation were in areas with high canopy such as forest and shadow coffee (Jaramillo and Chavez, 1997).

Analysis of ENSO events since 1953 shows that the amount of precipitation in the area can decrease by 24% with maximum values up to 60% (Guzman and Baldion, 1997). When high interception is combined with low precipitation, agricultural production may experience important losses. On the other hand, in watersheds covered mostly by agricultural areas, high precipitation interception and low precipitation creates competition between water for agriculture and water for human needs. During the 1997-1998 ENSO event in the rural areas under agricultural use (below 1800 m.a.s.l) the watersheds decreased the volume of water drained towards the stream network and therefore affected the water availability for rural communities and households. During this event communities with access to the local water pipe network had to rely on water provided by the utility company, from upstream the upper Chinchina watershed (above 2200 m.a.s.l) and delivered by kilometers of pipelines.

The temporal analysis of the 10+ years of hydro-climatic data (figure 3.) suggested that it is possible to identify climatic cycles that serve to anticipate the strength and length of extreme precipitation and drought events in this part of the tropical Andes caused by inter decadal anomalies such as ENSO and La Nina. In the analysis of a sample of three watersheds I found that precipitation does not distribute uniformly within the Chinchina watershed and that variations can be found among subwatersheds located at the same elevation.

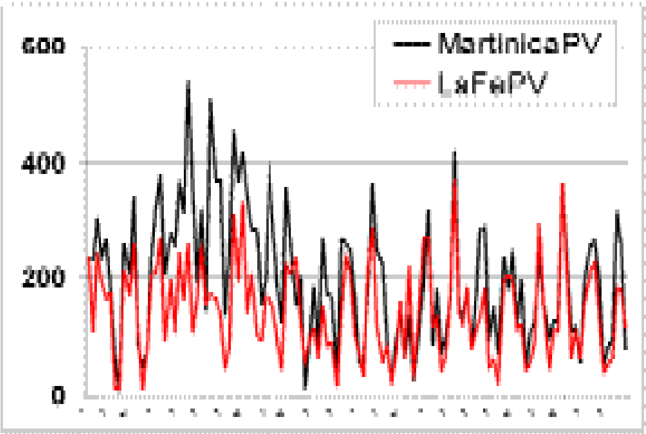

Figure 3. Ten years of monthly precipitation at the 3500 m.a.s.l altitudinal level for two sub-watersheds

A preliminary data analysis also showed that spatio-temporal variations in the streamflow regimen may exist between the watersheds despite their relative geographic proximity that may be associated with LULC changes (figure 4).

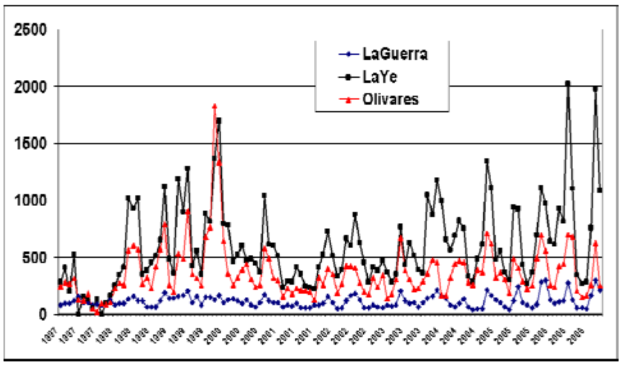

Figure 4. Ten years of stream flow distribution of three sub-watersheds at the upper Chinchina watershed

Conclusion

The diversity in LULC and vegetation types of the sub-watersheds and the long tradition of human intervention and colonization in this part of the Andes (Guhl, 2004) make this research the first opportunity to produce much needed knowledge about the water resources and the human actions affecting them under scenarios of climate change in mountain landscapes.

Thanks to GIS, cartographic and statistical tools was possible to visualize spatial and temporal variations in landuse/land cover change and vegetation structure affecting hydroclimatic variables in the study area (figure 5). The results allow us to observe the spatio temporal variation of vegetation cover affecting stream yield at different altitudinal gradients. Maps and 3D visualization (figure 6 and 7) will serve as communication tools to inform the public and enhance general understanding of the spatial variation of LULC and vegetation structure in this mountain landscape. Future elements of this research will explore the effects of landuse/land cover changes in the dynamics of hydroclimatic variables and processes affecting the water cycle where maps and 3D visualization are expected to contribute to inform decision makers and guide policy in addressing water related issues for local communities.

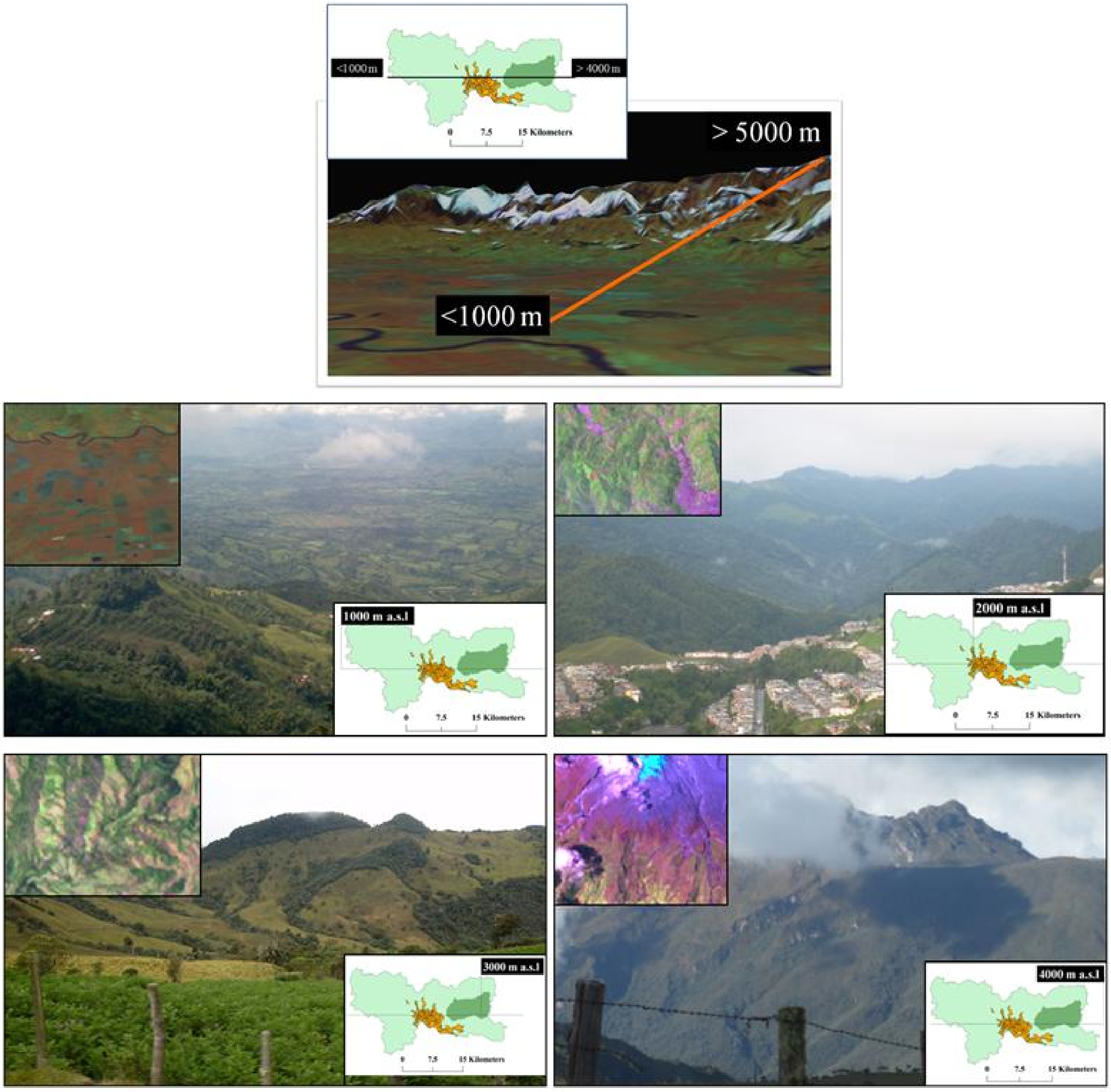

Figure 5. Mapping landuse change across altitudinal transects

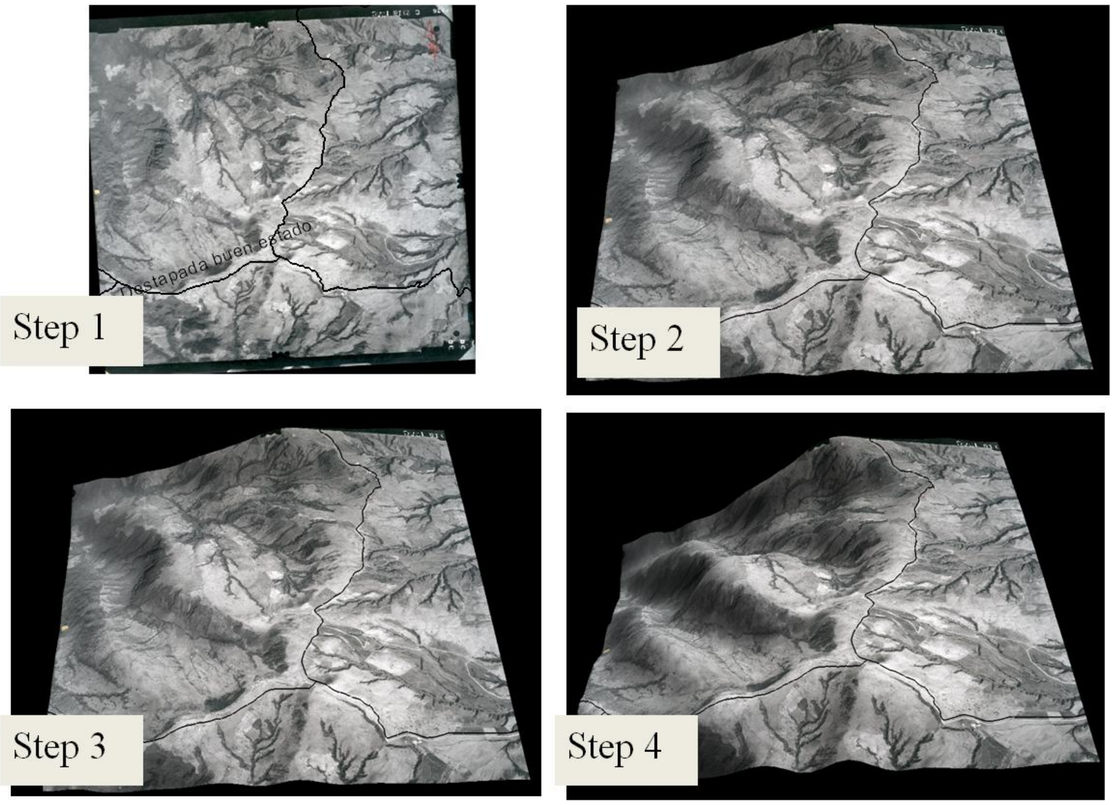

Figure 6. Time steps in a 3D map animation

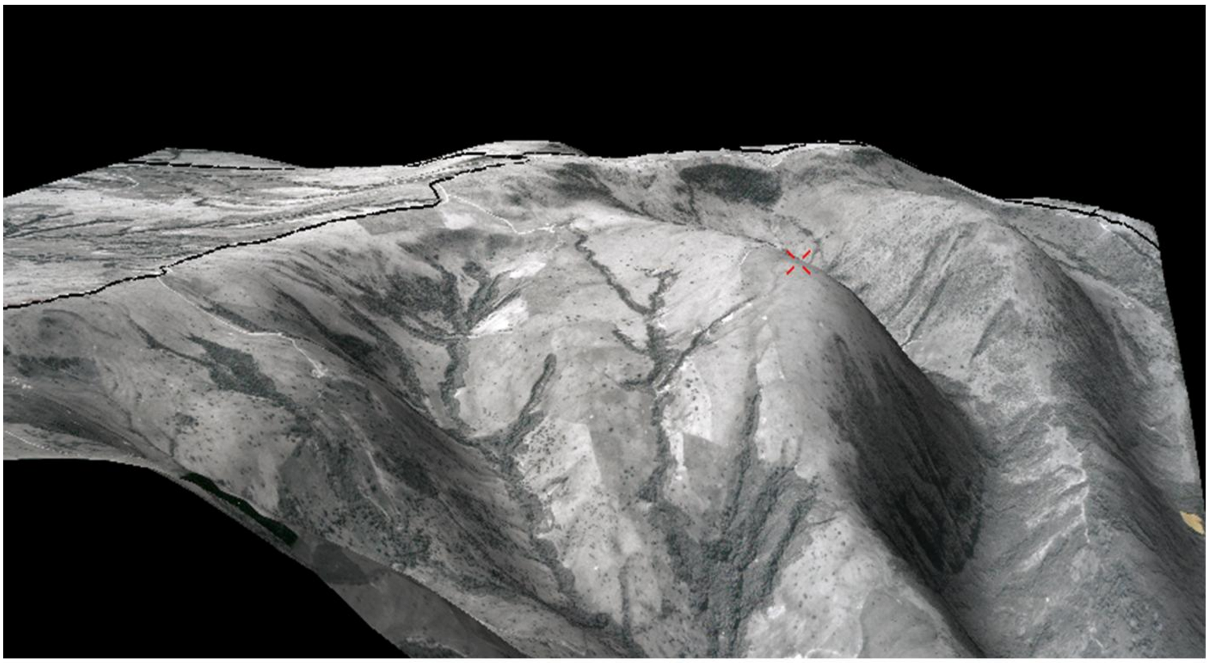

Figure 7. 3D visualization of study area at 3500 m.a.s.l

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