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GIS/Technologies and Socio-Natural Vulnerability: A call for geographical research on the South America Andes

SIG/Tecnologías y vulnerabilidad socio-natural: Un llamado a la investigación geográfica sobre los Andes Sudamericanos

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ABSTRACT

From a selected body of publications in English, this essay explores the GIS/technologies-vulnerability relationship in order to contribute to geographical research focused on the Andes. After a brief description of the space and climatic problematic that is related to it, the articulation of these with a concept of vulnerability that has been developed throughout the current century and the analysis of case studies that research the Andean geographical system are presented. The article concludes that, within the frame of the impacts that climate change has been generating, these advances pay the way and call for the execution of comprehensive studies on vulnerability on the Andes that consider simultaneously the social, the natural and the specific space of study being investigated. Resources in terms of geospatial, conceptual, of scales and outcomes here presented can help to guide and serve as inputs in research related with the treated topic.

Keywords: Andes, geographical information systems, vulnerability, human geography, physical geography, mountain research, climate change, geospatial technologies, GIS

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RESUMEN

Desde un cuerpo seleccionado de publicaciones en inglés, este ensayo explora la relación SIG tecnologías y vulnerabilidad con el fin de contribuir a la investigación geográfica enfocada en los Andes. Tras una breve descripción del espacio y problemática climática que se le relaciona, se presentan algunas tecnologías geoespaciales, la articulación de éstas con un concepto de vulnerabilidad que se ha venido desarrollando a lo largo del presente siglo y el análisis de estudios de caso que investigan el sistema geográfico andino. El documento concluye que, en el marco de los impactos que viene generando el cambio climático, estos avances allanan el camino y convocan a la ejecución de estudios integrales sobre vulnerabilidad en los Andes que consideren simultáneamente lo social, lo natural y el espacio específico de estudio que se investiga. Los recursos en términos de herramientas geoespaciales, conceptuales, de escalas, y de resultados aquí presentados pueden contribuir a orientar y servir como insumos en investigaciones relacionadas con el tópico tratado.

Palabras clave: Andes, Sistemas de información geográfica, vulnerabilidad, geografía humana, geografía física, investigación de la montaña, cambio climático, tecnologías geoespaciales, SIG

Introduction

Between the latitude -32.6520 and the longitude -70.0110 (Getty Thesaurus of Geographic Names) there are more than surface's 8000 km that cross Venezuela, Colombia, Ecuador, Peru, Bolivia, Chile and Argentina. It is about the mountain system that constitutes the Andes, which flanks the western of South America in its totality. Meanwhile the southern Andes is characterized by having the highest elevation and be a coastal cordillera, the central Andes is a mountain chains that houses extended plateaus. For its part, the northern Andes is configured by three mountain regions and diverse geological characteristics. Meanwhile just a small percentage of the Argentina's area belong to the Andes, almost all of Chile surface is located on this mountain system. Large parts of Colombia, Ecuador, Peru and Bolivia have a considerable part of its territory and population in the sierras. Nonetheless, the majesty of Andean landscapes, that concentrates capital cities, navigable lake, international airports and mine highest, contrasts with poverty, marginality, modest dwellings of peasant communities that are found among its population (Borsdorf, 2017).

According to the IPCC (2022), climate change exposure of Andes' people, as well as regional infrastructure, has increased meanwhile location, frequency and magnitude of natural hazards have been modified because of mass glacier reduction in the last decades. Since the 1980s, more than 50% of the Andean glacier areas has been lost due to global warming. Because of this, as well as the precipitation variability and land use changes, livelihoods, water resources and ecosystems have been affected. The increasing temperature has caused variations in the distribution of terrestrial species, including crops and diseases' vectors. All of this phenomena occurs in the Central and South America's regional context of vulnerability and impacts.

> Central and South America (CSA) are highly exposed, vulnerable and strongly impacted by climate change, a situation amplified by inequality, poverty, population growth and high population density, land use change particularly deforestation with the consequent biodiversity loss, soil degradation, and high dependence of national and local economies on natural resources for the production of commodities. (Castellanos et al. 2022: 1691)

To the extent that geography, from different needs, interests and perspectives, can continue contributing to spatial analysis and description of vulnerability focused in the Andes, this document is aimed at generating a contribution to the issue from GIS/Technologies-vulnerability perspective. Although not exclusively for the vulnerability in the Andes topic, Pinos y Quesada-Román (2022) have made use of English literature in order to review the research related to flood risk in Latin America and Caribbean. The authors' analysis conclude that GIS/remote sensing methods and vulnerability/resilience count among the research trends in the area of its study. In a similar order of ideas, this essay is based on selected English literature to explore the relationship GIS/technologies, vulnerability and the Andes in order to generate inputs for the geographical research. The work, based on secondary sources, also suggests horizons for the inherent disciplinary work of the geographer, as well as for the multidisciplary and multifactorial articulation. Under such a course, this essay presents the description of a GIS and technologies tools' set (1), the articulation of these with a vulnerability concept

that has been developed throughout the current century (2) and an analysis of case studies that research the Andean geographical system (3).

1. GIS and Technologies

Geographic Information systems and technologies such as Web GIS, Spatial Data Infrastructure, and Remote Sensing, increasingly play a crucial role in the geographic research. Its recent developments provides the users a better way of access, store, integrate, and analyze spatiotemporal data, as well as graph and project, particularly with Internet advances. This wide margin of maneuver has made it possible to explore processes and changes that occurred in the interaction between the natural and the social. Given the proliferation and recent developments of geospatial technologies, schemes of its organization have been proposed so that they can be useful in the current juncture.

From a broad sense, GIS, including systems and technologies, can be defined as "an information system designed to handle geographic, spatial or geospatial data for spatiotemporal use and geographic research" (Lü at al., 2019). From its functionality, GIS can be seen both as a supporting technology which stores and allows access to data and information, and as a way to solving problems through functions like analyzing/displaying georeferenced information and the integration of geographical technologies like a Remote Sensing (RS) and Global Positioning System (GPS) (Peggion¸ Bernardini, and Marcelo Masera, 2008). Between the different geographic information systems, can be considered the Web GIS Technologies and the Spatial Data Infrastructures (SDI) and Remote Sensing (RS). The first of them puts its data and functionality over Internet, implies low costs and easy operation. Web GIS have developed to the point of integrating GIS and Relational Database Management System (RDMS), which allows spatial data attributes to be manipulated efficiently. Virtual globes (as Google Earth, NASA World Wind) and mapping websites (such as Google Maps, Windows Live Local) are expressions of development of Geowebs. An SDI, in turns, refers to "the relevant base collection of technologies, policies and institutional arrangements that facilitate the availability of and access to spatial data" (20). It hosts data, attributes, metadata, catalogues, Web mapping, and access method to data,

organizational agreements. RS can be seen as a science and technology aimed to obtaining information from vehicles, like satellites sensors, “that capture images of the earth surface across a variety of spectra including visible light, heat, and radar” (Manson, Bonsal, Kernik, 2015, 64).

According to Lü at al. (2019), GIS has become popular in the extent that it provides users with digital images through its basic functions, as computer mapping. Combined with statistics and spatial analysis, it also allows the study and understanding of geo-objects and spatiotemporal relationships. GIS has been used in the exploration of the interaction of geographic physical and social phenomena, emphasizing in process and changes through analysis models that provides prediction and decision support. To the authors, the fundamental idea of GIS’ use is to enable the conditions to understand the world.

> Thus, the core of GIS should be its geographic features, and the development of GIS should follow the mission of ‘exploring the laws of nature and revealing the essence of humanity’, which cannot be achieved through information technologies alone. We are motivated to do this by the necessity of bridging spatial information technologies with geographic perspective and knowledge. By doing so, GIS can provide more powerful geographic problem-solving ability. (Lü et al. 2019, 360)

Given the growing dynamics of development and proliferation of different type of GIS and technologies, the need has been generated to organize them so that they can provide a more efficient and timely service.From this perspective, Manfré et al. (2012) present a panorama of the use of geospatial technologies that offer a suggestive organization’s perspectives of information management. According to the authors, the use of technologies and tools like remote-sensing (RS), geographic information system (GIS), global navigation satellite system (GNSS), spatial data infrastructures (SDI), and volunteered geographic information (VGI), will continue to increase to the extent that they grow and there is greater availability to access them. The authors propose an organization’s scheme of geospatial technologies whose structure is made up of 1) data source, 2) spatial data infrastructure, and 3) remote sensing and GIS techniques that 4) allows to

risk and disaster managers to have relevant information. In the scheme, data source like global navigation satellite system and satellite images provide the components that serve as inputs to produce the metadata with which the data catalog that form the spatial data infrastructures is configured. The remote-sensing information that is analyzed with GIS would allow governments to take action in terms of preventive plans and emergency.

2. Social and natural vulnerability

Support that GIS can give to the data collection, modelling, organization, analysis, representation and prediction allows, and calls upon, geographers to explore new dimensions, like social-natural interaction on the surface.In fact, possibility that geography can bridging the two dimensions in vulnerability's studies has been raised due to the volume of research that have been incorporating them, as well as the availability of geo-technologies and literature related. It is in this area in which GIS finds a point of articulation with the concept of vulnerability, that have an antecedent and starting point at the end of the 20th century, when the IPCC makes visible the negative impacts that climate change was causing. This concept is headed to the assessment of natural and social systems in terms of sensibility and to ability to adapt to climate change. From an applied optics, the case studies constitutes illustrative referents of integration of those dimensions and GIS for research on the Andes, as the analysis of vulnerability in South Carolina, early this century, in which computerized model, index, flood map and statistics were used.

At the end of the 20th century, the IPCC assessment of the regional impacts of climate showed the vulnerability degree in which natural and social systems have been affected. According to the IPCC, changes in climate were affecting the regions in socioeconomic, ecological, loss of human life, health and capital terms. The greenhouse gases concentrations were increasing by effect of human activities, impacting in a negative way the soil moisture, sea level, and temperatures. The studies that the IPCC assessment collect in its report show that mentioned sectors were sensitive to changes in climate and its variability. Even though climate change can exercise both adverse as beneficial effects, it represented an additional stress on those systems already affected by human

activity and a reducer of the ability to provide sustained development, although some groups or countries may be less vulnerable to it due to its economic development. Underlies this IPCC diagnosis a vulnerability's concept expressed in terms of sensitivity, adaptation ability, and susceptibility to damage that different social or human systems could experience because of climate change. It is about a definition that, with different nuances, has made a career since then and has gained ground by permeating a whole myriad of research done from different disciplines focused directly or indirectly on vulnerability's analysis. According to IPCC:

> Vulnerability is defined as the extent to which a natural or social system is susceptible to sustaining damage from climate change. Vulnerability is a function of the sensitivity of a system to changes in climate […] and the ability to adapt the system to changes in climate […] Under this framework, a highly vulnerable system would be one that is highly sensitive to modest changes in climate, where the sensitivity includes the potential for substantial harmful effects, and one for which the ability to adapt is severely constrained.(IPCC 1998, 3)

If the review of Paul makes of the vulnerability's concept (2013) is taken into account, it can stated that in 21th century, the support provided by technologies and geo-information induces geographers to think research from the point of view both theoretical as applied. According to the author, geography counts with a growing volume of literature in areas such as the use and measurement of data, as well as vulnerability measurement and assessment. In this context, appears the use of vulnerability maps by different experts, as well as the need to adopt a multi-scalar perspective that makes it possible to understand the vulnerability's differential. The addition to the above of the staging of studies such as those that focus on the understanding of networks exposed to harm and on outlining the socio-economic effects of vulnerability, leads to the author to maintain that "geography can work as a bridge between bio-physical and socio-ecological dimensions of vulnerability research" (13).

To the extent that it assesses vulnerability under a methodical proposal that takes into consideration biophysical and social indicators and the particular context, the study of Cutter, Mitchell and Scott in South Carolina (2000), early this century, represents a valuable input and an important referent for research that relevantly involves the use of GIS. In this research, layers of social and biophysical vulnerability were combined within GIS in order to get the specific place of vulnerability. To identify biophysical vulnerability, was used information related to identification of hazards, its frequency and zone delineation from sources data such as Palmer Drought Severity Index, FEMA's Q3, the National Hurricane Center's SLOSH model, at the time that the authors built its earthquake hazard zone into a GIS. For the data integration more than 25 created in GIS data layers were combined into a unity of intersected polygons. Characteristics of vulnerable populations such as differential access to resources, wealth or poverty, and structure, were based in 1990 U. S. Census block statistics.

3. GIS and vulnerability in Andean Region: case studies

The studies case set out below are presented with the purpose of providing support and empirical body to developed theme at the same time that they serve as background of its research proceeding on different scales. The four studies were carried out between 2003 and 2017 and they are identified in its purpose to evaluate, direct or indirect, explicit or not, vulnerability that Andes experience in the climate change's context. All these analysis use GIS or some geographic information platform with which they also do its geographical representations, as well as computerized models. The database or data layers are more common in studies on a global scale, in which also is made use of data sets and maps, and in sub-regional studies. The referred local research is supplied with information through remote sensing, sensors, photographs, satellite images and head/geochemical tracing. In the first three cases, FAO makes a presence, either as research entity or as a generator of environments, data or geospatial tools. In terms of social and natural vulnerability, outcomes of the studies evidence in the Andes farming ranges that shows levels which are in decreasing degree below the optimal, which coincides with food insecurity, poverty and out-migration

phenomena. The crops that make up the food security base are losing suitability because of the climate change impact in almost all of the countries that are part of the Andean Cordillera. The case focused on the glacial melt in Peru, evidence at local level the climate change impact on water sources that Andean region has been experiencing.

The first findings of the study in progress of Huddleston at al. carried out for the FAO (2003) is based on GIS techniques and available geo-referenced data in order to understand the underlying conditions of poverty and hunger in the mountain environments and populations at global level. Vulnerability of mountain people is understood in terms of environmental constraints, isolation and lack of access to infrastructure, malnutrition and poor health. The research found that "around 245 million rural mountain people in developing and transition countries are estimated to be vulnerable to food insecurity" (iv).

The analysis GIS database produced by FAO's Environment and Natural Resources Service used in the research was elaborated from different sources like Land Scan 2000 Global Population Database that allowed to estimate parameters that contributed to consider the number of mountain vulnerable people. Other sources were the UNEP-WCMC map, the world cities population database (WCPD), Pilot analysis of global eco-systems (PAGE) agricultural extent, the Global map of irrigated areas version 2.1. Regarding main farming systems in mountain areas of the Andean range, the research found in the North Andes an agricultural farming system that is still viable, although out-migration is widespread and poverty is severe in higher elevations. In the Central Andes, although farming is feasible, there is endemic poverty and growing out-migration, as well as extensive and very severe. The Southern Andes allows sub-marginal cultivation, but it remains low to moderate levels of poverty and food insecurity.

Metternicht et al. (2014) describes a methodological framework for conducting vulnerability, impact and adaptation (VIAs) assesments. The VIA assessment of this framework considers the vulnerability to climate change as a component that integrates and correlates the other components of this stage, namely, local climate and climate change scenarios, sensitive of the sector(s), sensitive of the

ecosystem services and adaptive capacity. The framework was implemented in the Gran Chaco Americano and Colombia, Ecuador and Peru as Andeans countries. In the case of the Andes, data and information based on results from the exposure, sensitivity and adaptive capacity analysis were used to estimate the cropping areas that could experience greatest loss in suitability. At the same time that these elements were taken from sources such as national statistics, Food and Agriculture Organization (FAO) parameters for crops and Worldclim, methods and tools such as Hydrological model SWAT, agromodelecocrop, Human Development Index and Index of Social Fragility were used. Because of factors like cost, availability of data input and use experience, the research team of the Andes used the Ecocrop FAO model like analysis method of changes for crop suitability, calibrating it from local data and area knowledge.

The Zapata's study (2014) aims to generate projections of the impact of climate change on the most important food security crops of Venezuela, Colombia, Ecuador, Peru and Bolivia, as Andean countries, using parameters of uncertainty, current/ future and change in climatic suitability. The information were obtained from the database Worldclim and Global Circulation Models (SRES-A2 and SRES-A1B). GIS tools contained in ArcGIS 10.1 was used to manipulate the selected Ecological Niche Model, namely, EcoCrop as methodology the study is based and that allows generate projections of selected crops. The author concludes that negative impact of climate change is larger than the positive particularly for the scenario A1B (2020) in coffee, bean, and wheat crops, whose suitability will decrease in percentages greater than 76.3 and that is projected until 2050 (scenario A2).

From the biophysical and social determinants, Mark et al. (2017) develop a conceptual framework to assess the way in which glacier change, social risks and vulnerability intertwine through sectors and water uses in tropical Andes. The research shows a nourished use of GIS and technological tools on each of the identified interacting variables. So, to evaluate pro-glacial hydrologic transformation the study used equipment in situ, multiple sensors, remote sensing, historical photographs of glacier termini, as wells as a combination of continuous automated, near-surface geophysics high-resolution multispectral

remote sensing with UAV, kite-borne aerial photography (KAP), terrestrial time-lapse photography, and heat and geochemical tracing. In the case of land cover change analysis were used TM images from the USGS Global Visualization Viewer¸ ERDAS Imagine 2014, Hexagon Geospatial AL, ArcGIS Version 10.2, ESRI. In social processes analysis, high-resolution satellite imagery was used to develop spatially-based, stratified random sampling frame, as well as an expanded set of methods that includes analyses drawing upon laws and regulatory frameworks, among others. The application of the conceptual framework to the Santa River watershed draining the Cordillera Blanca to the Pacific, shows that in the context of climate change "interacting biophysical processes and social dynamics at diverse scales shape environmental risks and resource entitlements for different water users in multi-level hydrosocial systems." (74)

Conclusion

A vertiginous evolution and proliferous development of GIS and technologies, of its utility on geographical studies and related, of the utility's expansion that they provide, of its organization with a view to providing a better contribution to the descriptive and applied research, as well as of a greater execution of geographical research and availability of vulnerability literature were given in the last decades. Within the frame of the impacts that climate change has been generating, these advances pay the way and call for the execution of comprehensive studies on vulnerability on the Andes that consider simultaneously the social, the natural and the specific space of study being researched. The task finds a foothold in the vulnerability concept development, which has an influential background in the connotation that is given to the definition in terms of sensitivity and ability to adapt to the climate effects that could experience a social or natural system. The existence of empirical material, as those analyzed in this essay, provides support to the previously formulated proposition and it serves as background of its research proceeding. It deploy in its research scaffolding, to a greater or lesser extent, a set of geographical information systems and technologies that are applied and interrelated with such dimensions. In addition to using computerized models, between the spectrum of components that configure its geographical information platforms, the databases or data layers are the more common in the

large scale studies, meanwhile remote sensing are used at local level. The diagnoses provided by these empirical works shows signs of vulnerability in Andes' water resources and crops, as well as in sectors of its population in terms of poverty and food security that leads to migratory movements. A complementary call to this research challenge would be to generate the opportunities to create interdisciplinary and interinstitutional teams as well as the opening doors to access financial and technological resources that contribute to produce the equilibrium necessary among the research actors of different latitudes to facing a common work of assessing the Andean Cordillera in multiscalar and multifactorial ways. In this prospective stage, the expertise and institutional capacity of supranational entities can to play a protagonist role, such as FAO, already committed on several fronts in the study of the topic treated in this document.

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