C. A. Gibson[1], J. M. Smith[1], K. Smits[2], J. Lucena[1], O. J. Restrepo Baena[3]

[1] Dept. of Engineering, Design, & Society, Colorado School of Mines.

[2] Dept. of Civil and Environmental Engineering, Southern Methodist University.

[3] Dept. of Materials & Minerals, Universidad Nacional de Colombia.

Corresponding author: Casey Gibson (cagibson@mines.edu)

Key Points:

- Established social science tools can help socio-hydrologists better characterize complex human-water systems.
- Rapid ethnography illuminated the main threats to water resources in a site reliant on agriculture and small-scale mining.
- Hydrological risk perceptions influenced livelihood decisions that, in turn, threatened water resource sustainability.

Abstract

The burgeoning field of socio-hydrology aims to understand the dynamics of coupled human–water systems in order to inform sustainable water management. However, socio-hydrological methods have traditionally relied on the quantification of qualitative social data, which runs into significant epistemological challenges between the positivist paradigm of hydrology and the interpretivist paradigm of much of social science. This article builds on recent literature that advocates for a pluralistic approach, retaining the methodological and epistemological differences inherent to social sciences and hydrology, and thereby revealing a more complete understanding of situated human-water relationships. In this vein, we propose rapid ethnography as a tool to complement hydrological modeling. We demonstrate the utility of this technique with a case study on hydrological entanglements of rural livelihoods in Andes, Antioquia, Colombia–a region dominated by agriculture, but with the presence of artisanal and small-scale gold mining (ASGM). Our ethnographic study builds on previous hydrological models and quantitative social studies of the region by exploring a myriad of local risk perceptions of hydrological systems, in particular, 1) climate change, 2) water contamination, and 3) hydrological erosion and landslides. We explore how these risk perceptions informed livelihood decisions that paradoxically threatened the very hydrological resources that the livelihoods depended on; yet, this cycle was difficult to interrupt given prevailing economic and political constraints. Ultimately, we seek to advocate for pluralistic approaches in socio-hydrology to help understand complex human-water relationships and ultimately identify critical points of intervention for sustainable water resource management, model-based or otherwise.

Plain Language Summary

The field of socio-hydrology recognizes that water systems cannot be understood properly without simultaneously understanding the ways they impact, and are impacted by, human society. However, the tools and philosophies developed to study hydrological systems often fall short when it comes to understanding social systems. Recent advances have advocated drawing upon techniques from qualitative social sciences that are often better suited to characterizing the complex ways that humans behave. However, tensions between qualitative social science research and quantitative hydrological research need to be acknowledged in order to create robust pluralistic socio-hydrological studies. This study proposes rapid ethnography as a helpful tool for socio-hydrology and demonstrates the effectiveness of this approach with a case study on the hydrological risks facing farming/mining communities in rural Colombia. Through rapid ethnography, we identified how human perceptions of hydrological risk were informing decisions and actions that in turn amplified these risks. This approach ultimately allowed us to identify key points of intervention for water resource sustainability.

1 Introduction

In the age of the Anthropocene, human activity is recognized as the greatest driver of environmental change. Natural science fields are increasingly considering social factors as integral drivers of environmental systems. From this line of thought the field of socio-hydrology (Sivapalan et al., 2012) has emerged, which aims to "endogenize human agency" (Pande & Sivapalan, 2017, p. 9) in hydrological models for improved predictive capability and informed sustainable water management. This is often done by integrating hydrological and social data to form generalizable hypotheses about human-water interactions over temporal and spatial scales (Rusca & Di Baldassarre, 2019). Take, for example, the approximation of human migration using Fick's Law of Diffusion, "i.e., migration flux is proportional to the negative gradient of unemployment" (Di Baldassarre et al., 2019, p. 6337), which helps predict changing water demand. The "community sensitivity" theory (Elshafei et al., 2014, p. 2141) quantifies "a community's social and environmental values" (p. 2145) to predict the anthropogenic degradation of water resources. Though theories such as these have advanced our understanding of coupled human-water systems, other critical data for understanding human-water interactions are not amenable to quantitative models, necessitating new ways of thinking about socio-hydrological integration.

Practically speaking, there is a paucity of social data that is compatible with the resolution and spatial/temporal scales of most hydrological data. Moreover, social scientists and socio-hydrologists alike recognize the limits of using homogenizing social hypotheses (Lane, 2014; Massuel et al., 2018; Wesselink et al., 2017) to model human behavior, which can be irrational and not conform with predictions (Sivapalan & Blöschl, 2015). The quantification of complex social data "raise[s] numerous concerns, such as limited representativeness and their unavoidable inability to describe the heterogeneity of human society" Di Baldassarre et al. (2019) (p. 6344). Too narrow of a focus on quantifiable human behavior may cause socio-hydrologists to overlook the more interesting, qualitative ways that people depend on, utilize, modify, make decisions about, and respond to changes in hydrological systems. These ongoing theoretical discussions on the fundamental epistemological differences between hydrology and qualitative social sciences (Savelli et al., 2022; Wesselink et al., 2017) have given rise to pluralistic "negotiated approach[es]" (Massuel et al., 2018, p. 2510) that allow different disciplines to investigate human-water systems with their own methods, analyses, and epistemologies (Di Baldassarre et al., 2021; Rusca & Di Baldassarre, 2019). In other words, hydrological models and qualitative analysis can serve as discrete pieces of a larger understanding of human-water relationships. "Between infinite complexity on the one hand and extreme simplification on the other, there is an intermediate area in which it is possible to produce models that are both sufficiently simple and robust to represent reality with a degree of reliability and scientifically and/or operationally 'useful' " (Rusca & Di Baldassarre, 2019, p. 2515).

To build on previous work advocating for pluralistic methodologies in socio-hydrology, we propose the Rapid Assessment Procedure (RAP) framework from anthropology as a complement to hydrological models. And in response to calls for more empirical studies that "cross the natural-social science divide" (Rusca & Di Baldassarre, 2019, p. 2) we support our argument through a case study on a rural Colombian community that is highly dependent on hydrological resources for agro-mining livelihoods. The objectives of this study were two-fold: 1) contribute to the larger discussion on how socio-hydrologists can better understand intertwined socio-hydrological systems by drawing from established social science frameworks, and 2) ground our theoretical arguments with a case study in which we applied an anthropological RAP technique. Our research questions were: 1) what barriers and opportunities exist for integrating transdisciplinary, qualitative tools in socio-hydrological studies? 2) What can the application of RAP reveal about coupled human-water systems in our study site? And 3) how can these qualitative findings complement traditional modeling approaches?

The following section explores the ongoing challenges and successes around transdisciplinary integration of social science and hydrological fields. We then outline the anthropological RAP methods used in our own pluralistic approach, followed by a socio-hydrological description of the study site. Next, the ethnographic findings section from our case study highlights key aspects of human-water systems in Andes, principally: community members' risk perceptions around water resources and livelihood activities, and a resulting paradox regarding risk-based livelihood decisions and water resource sustainability. The final discussion & conclusion section summarizes our argument for the adoption of pluralistic, social science-based approaches to socio-hydrology, and distills the insights we gained through ethnography that were concealed by purely quantitative methodologies.

2 Pluralistic Approaches to Socio-Hydrology

All research is grounded in a particular epistemological framework, whether it is explicitly recognized or not. Given that natural and social sciences often adhere to distinct epistemological frameworks, socio-hydrology could benefit from considering epistemologies that have evolved to understand *social* systems, not just hydrological ones. Socio-hydrology, like most natural science fields, is largely based on a positivist paradigm (Savelli et al., 2022) in which the scientific method and empirical research are used to generate “objective” data that can explain, predict, and generalize the behavior of natural (and in this case, social) systems. A positivist mindset is often accompanied by a “reductionist” perspective (Riley, 2005) that conceptualizes complex systems as functions of their foundational parts. For example, human decisions about whether to raise or lower the level of a reservoir have been modeled as direct functions of rational revenue maximization (Giudici et al., 2021). Positivism has facilitated the advancement of natural science fields for hundreds of years. Moreover, certain social sciences like psychology and economics can also be based on positivist epistemologies.

On the other hand, other valuable social science research is based on an interpretivist epistemology. An interpretivist perspective posits that there is no innate and singular truth about reality to be discovered and modeled through the scientific method; rather, truths are partial, multiple, and situated. For interpretivists, “knowledge about social life (or any other knowledge about anything, for that matter) involves understanding the meaning that interaction has for the participants, and realizing that any analysis of society is made from some standpoint or perspective” (Warren & Karner, 2009, p. 4). Interpretivists also rely on empirical data, but of a qualitative nature. This data often describes the different ways that people experience and make meaning of the world, for example, by investigating the multiple ontologies of water held by diverse actors, such as indigenous agriculturalists and mining company engineers (Li, 2015). Since context is paramount, strict interpretivists would argue against quantifying social data for integration with a model or extrapolation across distinct times and locations, because people in different contexts will think and behave in different ways.

The positivist bias of socio-hydrology also contributes to critiques of the field as “hydrocentric” (Massuel et al., 2018, p. 2510), leading to calls for more symmetrical integration of social and hydrological theory (Lane, 2014; Massuel et al., 2018; Rusca & Di Baldassarre, 2019; Wesselink et al., 2017). A recent review of socio-hydrological literature found that “quantitative approaches were used more often (65.9%) in comparison to mixed (22.7%) and qualitative (11.4%) approaches; monodisciplinary studies prevailed (61.4%) over multi or interdisciplinary (9.1%) ones, and only 15 (34.1%) of the articles involved stakeholder participation” (Vanelli et al., 2021, p. 1). These findings may reflect the “unspoken assumption of the ‘superiority’ of quantitative natural sciences” (Rusca & Di Baldassarre, 2019, p. 2), consistent with engineers and scientists’ general proclivity to consider qualitative social data as context for their technical work (Kleine et al., 2021) rather than as intellectual contributions in their own right. There are ongoing discussions about how to establish “equally rigorous (though not necessarily identical) standards for judging both quantitative and qualitative research" (Ragin et al., 2004, p. 9), in particular, in studies where non-social scientists are implementing social science methods (Forsythe, 1999). To achieve a more symmetrical and robust integration of the social and hydrological sciences, socio-hydrology should strive to "[treat] the understanding of social dynamics as comprehensively as the way hydrological dynamics are generally studied and represented" (Massuel et al., 2018, p. 2512). To this end, we argue that qualitative data should be analyzed from an interpretivist framework, and not oversimplified into generalizable, quantifiable theories.

Researchers have begun to put these principles to practice with pluralistic case studies that implement qualitative, interpretivist approaches alongside quantitative, positivist approaches. For example, in order to understand water consumption rates in parts of Morocco and Tunisia, Massuel et al. (2018) used qualitative surveys to deconstruct the correlation between the number of wells and groundwater abstraction. Cultural factors like "prestige" in North Africa were found to influence how many wells one owns, regardless of whether they are in use. Their qualitative investigation also revealed how the Tunisian revolution of 2011 affected customary rules involving land inheritance, leading to long disputes and abandonment of wells, further accounting for discrepancies in groundwater consumption estimations. In Ethiopia, Teweldebrihan et al. (2021) analyzed qualitative household surveys and interviews along with Landsat crop coverage data and time series hydrological data to understand smallholder farmers' choices to plant certain crops and the subsequent water demands. They found that these decisions were "endogenous to the smallholder sociohydrology of the basin" (p. 1), and thus could not be extrapolated to different contexts. 81% of their subjects decided which crops to grow based on indigenous knowledge that is not effectively quantifiable. Nüsser et al. (2012) combined qualitative interviews with multi-temporal remote sensing to understand the drivers of land-use change in Northern India and the impacts on agricultural irrigation, concluding that water availability was inextricable from the sociopolitical interventions in the community. Similarly, Parveen et al. (2015) used field observation and interviews along with remote sensing and mapping to analyze the dynamics of land-use change and irrigation systems in Pakistan, finding that "modifications in the hydrological pattern can only be fully understood by taking social change and local political economy into account" (p. 60). From these examples, it is clear that it is sometimes "necessary to leave part of the analysis outside the modeling platform" (Massuel et al., 2018, p. 2515).

3 Rapid Ethnography

Ethnography is a foundational anthropological tool that can provide "detailed insight into the concepts and premises that underlie what people do – but that they are often unaware of" (Forsythe, 1999, p. 129). This includes how people utilize and impact water resources. Ethnography usually consists of extended periods immersed in a specific cultural context, conducting interviews, observation, and iterative generation and interpretation of data in accordance with ethnographic theories (Reeves et al., 2008). However, much of the rigorous work that goes into ethnographic analysis remains “invisible to the untrained eye” (Forsythe, 1999, p. 127), as it requires deep knowledge of social theories and the ability to “detect consistent patterns of thought and practice and to investigate the relationship between them…since what people do is not always the same as what they say they do” (p. 128). Relevant to socio-hydrology, ethnography has been used to understand political opinions on water re-use in Kenya (Wakhungu, 2019), to identify the technological barriers to eliminating aquatic mercury pollution from the Colombian mining sector (Robertson & Farrelly, 2020), and to analyze permaculture practices in Amazonian regions aerially fumigated with herbicides (Lyons, 2020). Although traditional ethnography requires extensive time immersed in the field, anthropologists have developed modified ethnographic procedures, e.g. the Rapid Assessment Procedure (RAP), that allow for quicker, yet robust analysis of complex sociotechnical contexts (Beebe, 1995), thus aligning better with the timelines of scientific studies. RAP, for instance, has been widely applied in time-sensitive public health interventions such as disease control programs (Vlassoff & Tanner, 1992).

One main difference between traditional ethnography and modified, rapid ethnographic research is the scope (Manderson & Aaby, 1992). Traditional ethnography is primarily inductive, meaning that the direction of the research arises out of the data itself during extensive field immersion, and “where to look next depends on what was just uncovered” (Ragin et al., 2004, p. 12). While modified ethnography is also inductive in its execution, it usually has a clearer initial research aim such as to “evaluate and improve the design of a novel water treatment technology” (Burleson et al., 2019, p. 68); “[investigate] the role of social, economic, and related systematic factors on recently completed water source interventions in [Timor-Leste]” (Troeger et al., 2015, p. 164); reveal “what socio-cultural factors influenced the adoption of rejection of Clean Water in Homes programs” at the northern border of Mexico (Cifuentes et al., 2006, p. 24); or in the case of the present study, analyze risk perceptions informing livelihood decisions that impact water resources in Andes, Colombia. In order for modified ethnographies to be time-effective and “operationally useful” (Massuel et al., 2018, p. 2515), the research scope must be limited to those qualitative findings that are most crucial to understanding the coupled dynamics between people and water.

Additionally, while conventional ethnography usually relies on a single ethnographer, modified ethnographies prioritize collaboration amongst a research team to allow for a quicker turnaround time without compromising the integrity of the findings. It is recommended to form a research team that includes members of the target community as well as professionals from diverse disciplines who all partake in iterative research triangulation, generating and validating qualitative findings from their unique perspectives (Lewis & Russell, 2011).

4 Methodology

Our research followed best practices for rapid ethnography (Pepall et al., 2006; Scrimshaw & Hurtado, 1987; Utarini et al., 2001). Our field research team was assembled based on pre-existing local contacts in the region developed during our project's multi-year presence in the same community. This continued presence facilitated trust and rapport building (Spradley, 1979) with the local team and community members. Participant involvement, trust, and rapport are essential in ethnography, and have long been recognized as paramount for the sustainability of development interventions (e.g. Parsons, 1996) not only because of increased "buy-in" but also because community members possess local knowledge about their own unique sociotechnical context which outsiders cannot fully understand in a short time (J. Lucena, Schneider, & Leydens, 2010; Ongley & Booty, 1999; Schwartz, Smits, Smith J., et al., 2021). Our field team included two community members: women from Andes in their 30's engaged in artisanal small-scale gold mining (ASGM) and farming. The field team also consisted of researchers from distinct academic disciplines: two American researchers from humanitarian engineering and environmental engineering trained in community-based research, and two Colombian researchers from mining engineering. Other research collaborators included environmental engineers and anthropologists.

The two local collaborators were instrumental in arranging contact with other community stakeholders of interest. We sought out participants with first-hand experience in farming, mining, and/or relevant knowledge about the impacts of these activities on the environment. From there, we used the snowball sampling method (Parker et al., 2019) to identify more participants. We made contact with both "individual respondents" and "key informants" (Beebe, 1995). The former can reveal the variability of individual experiences, while the latter can describe "the broader system beyond their own direct participation" (p. 45). In our case, "individual respondents" included coffee farmers, artisanal and small-scale gold (ASG) miners, organic polyculture farmers, apiarists, trout farmers, and people engaged in multiple rural livelihoods. However, most of our participants were rural small-holder farmers and/or ASG miners (79%). These stakeholders relayed the individual challenges they faced regarding their livelihoods and water. Some "key informants" included a historian, librarian, aqueduct technician, and professors in mining and agricultural engineering who were able to provide wider context about the economic, political, historical, and environmental trends that influenced local water-related challenges. We spoke with both men (62%) and women (38%). In total, we interviewed 77 participants over the course of four weeks, with all the individual respondent interviews/focus groups taking place in Andes, and most of the key informant interviews taking place in Medellín, the capital of Antioquia.

We conducted four focus groups and 32 semi-structured interviews in Spanish. Semi-structured interviewing incorporates guided lines of questioning along with the flexibility to allow interviewees to speak more in-depth about the topics that are of greatest interest/relevance to them. Our focus groups were also semi-structured and consisted of 6-13 participants each in order to elicit group discussions that illuminated points of contention and agreement, power dynamics, and common narratives amongst stakeholders. Descriptive and non-leading questions for interviews and focus groups were based on ethnographic interview methods described in Spradley (1979) and Warren & Karner (2009). Like Massuel et al. (2018), we used "sociological [and anthropological] knowledge to guide the discussions and hydrological skills to interpret their answers" (p. 2517). Common lines of questioning included: *How do you earn a living? How long have you been doing it? Where did you learn your skills? What has changed over time? Have you noticed any environmental changes? Have these affected your work, and if so, how? How is the environment/water here in Andes? Has it changed over time, if so, how and why?*

We combined interviews with site visits to subjects' homes, farms, and mine processing plants which allowed us to observe water sources, coffee and gold processing methods, treatment of water used in these processes, location of farms and mines with respect to streams and rivers, and so on. After the first week of interviews, we began hearing recurring themes and opinions, indicating we were reaching saturation in our qualitative data collection (Saunders et al., 2018). With written and verbal informed consent, we made audio recordings of each interview and focus group, took photos, and wrote field observation notes. The recordings of the interviews and focus groups were analyzed via thematic analysis (for a deeper explanation of thematic analysis, see Guest et al., 2011) and data triangulation (see Carter et al., 2014) in collaboration with the research team, select individual respondents, and key informants.

5 Site Description of Andes, Antioquia, Colombia

Andes is a municipality in the southwestern department of Antioquia, Colombia. Hydrological resources are fundamental to this region's cultural heritage, ecology, and livelihoods (Zapata Restrepo & Mejía Aramburo, 2019). Andes is located within the intertropical convergence zone (ITCZ), and thus receives significant amounts of rainfall year-round (over 82 inches per year on average) (Alcaldía de Andes, n.d.) and has a bimodal climate with alternating rainy and "dry" seasons. Weather patterns in the ITCZ are closely linked to global environmental variables like sea surface temperatures (SSTs) and sea level pressures (SLPs); so despite a scarcity of in situ hydrological data from Andes, local rainfall and streamflow can be modeled as functions of these global variables. For instance, Roberts (2022) used different combinations of remotely-sensed environmental variables (SSTs, SLPs, temperature, precipitation, and soil moisture) to model empirical streamflow in the San Juan River in Andes between 1972 and 2015. Roberts' models predicted maximum streamflow in the rainy seasons using global variables from the previous dry seasons (max $r^2 = 0.77$). Though these models were calibrated and validated with historical data, they could be modified to make predictions about future rainfall and streamflow, giving Andes' residents advanced notice on probable hydrological conditions that will affect their livelihoods. One of Roberts' key findings was the negative correlation between average SSTs in the El Niño 3.4 region and rainfall/streamflow in Andes (Figure 1), indicating that future increases in sea temperatures due to global warming could result in decreases in rainfall in Andes. However, to understand how the information from these models will actually affect local livelihoods, it is necessary to understand the livelihood practices themselves and the myriad ways that these activities are intertwined with hydrological systems.

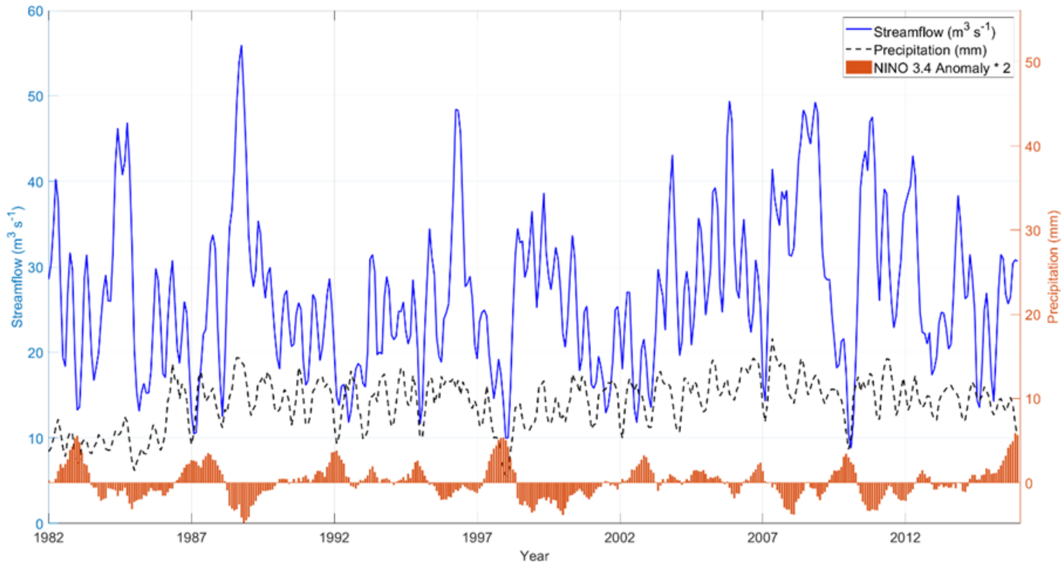

Figure 1. Graph from Roberts (2022). Peaks and dips in empirical streamflow and precipitation in Andes are negatively correlated with sea surface temperatures from the El Niño 3.4 region.

According to the 2005 Colombian census, the majority of Andes' population (54%) lived outside of the urban center in rural districts known as *corregimientos* [sub-regions of a municipality] (Alcaldía de Andes, n.d.) where the primary livelihood has been Arabica coffee farming since the 1890's (Zapata Restrepo & Mejía Aramburo, 2019). Coffee farms in Andes cover about 40 square miles and generate nearly 14,000 tons of dried coffee beans per year. Andes' climatic and hydrological conditions allow for two to three annual coffee harvests (Octavio Cardona, 2018), along with year-round production of other crops and fruits, pisciculture, apiculture, and more. However, temperature and rainfall have become increasingly erratic and extreme due to climate change (Barrucand et al., 2017), a phenomenon also observed by Roberts (2022), causing variations in agricultural yields. For instance, extended rainy seasons in 2020-2021 led to a 5% decrease in production during peak harvest from 2019-2020, and a 13% decrease from 2020-2021 (F. A. Jiménez, 2021).

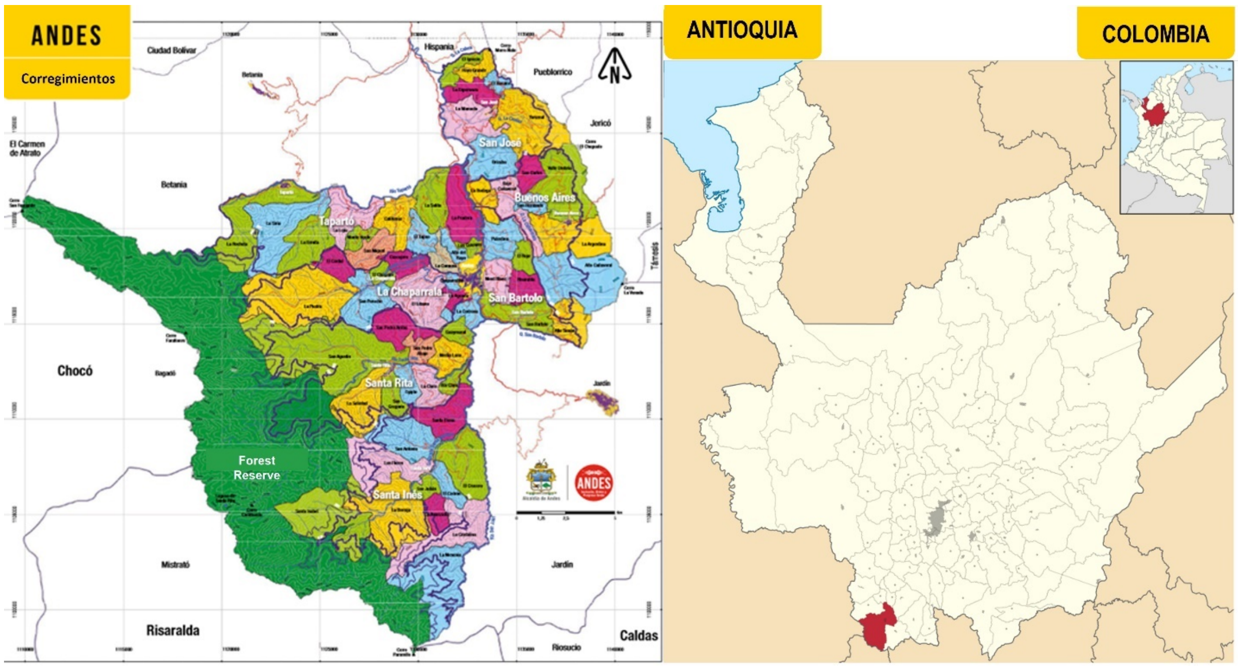

Figure 2. Map of Andes and its *corregimientos*. Adapted from Zapata Restrepo & Mejía Aramburo (2019) and Milenioscuro (2010).

Another livelihood closely linked to hydrological systems is gold mining. Gold panning in rivers and streams has been practiced since pre-Hispanic times in Colombia (Ferry & Ferry, 2017), but increasing gold prices in the 21st century led to a boom of mechanized artisanal and small-scale gold mining (ASGM) in Andes and throughout the country/world. ASGM broadly refers to the largely informal practice (Veiga & Marshall, 2019) of using rudimentary mining and processing techniques to extract gold from ore. An estimated 400-600 people rely on ASGM as their main livelihood in Andes (M. P. F. Jiménez et al., 2021), though this value is difficult to ascertain given ASGM's informality, seasonality, and the often sparse distribution of gold that leads to booms and busts in this region. In Andes, ASGM contaminates water through gold extraction methods–historically a two-phase aqueous mercury-cyanide process (Esdaile & Chalker, 2018). This extraction method has been prohibited since 2018 after Colombia's ratification of the Minimata Convention, yet mercury elimination has proven complicated nationwide (Diaz et al., 2020; Robertson & Farrelly, 2020). Soluble mercury compounds can enter surface water systems via direct runoff from processing plants or through the weathering of historic tailings that were treated with mercury (O. Restrepo et al., 2020; Velásquez et al., 2022), causing devastating ecological and human health effects (Basu et al., 2015; Rajaee et al., 2015). That said, agriculture is also responsible for contaminating water with pesticides and coffee mucilage in Andes. And although ASGM is most commonly associated with the degradation of water resources, it also relies on water for processing ore, and is thus intertwined with the seasonality of hydrological cycles. Extreme precipitation in the rainy seasons can make accessing subterranean mines and transporting ore impractical and dangerous. Moreover, the ASGM workforce expands and declines as a function of the timing of the coffee harvests, which directly depend on precipitation cycles.

In Andes, it is also critical to consider the links between human activities, hydrological conditions, and landslides. Mountainous terrain and steep elevations (4,300-12,800 ft above sea level; Zapata Restrepo & Mejía Aramburo, 2019) make Andes and its surrounding regions high-risk zones for denudation processes, especially rain-triggered landslides (Giraldo et al., 2022; Muñoz et al., 2014). These risks have been exacerbated due to anthropogenic activity such as road development and deforestation due to the expansion of agriculture and mining (Marin, 2020; Muñoz et al., 2014). Coupled with the risk of subsidence from subterranean ASGM activities (Ojeda & Donnelly, 2006), and increasingly extreme precipitation events (Giraldo et al., 2022), Andes' residents are vulnerable to life-threatening landslide disasters.

Previous research has investigated social perceptions of and responses to these hydrological threats in Andes. For instance, O'Brien et al. (2021) conducted 100 structured surveys in Andes in 2019 amongst stakeholders from mining and agricultural sectors in order to identify and quantify residents' environmental concerns, with the goal of informing local-knowledge based conceptual site models for environmental remediation. On a scale of 1-5, respondents rated "mercury amalgamation" (5) and "pesticide application" (4) as the two most dangerous (peligroso) activities in the region, while "soil erosion" (2) and "suspended sediment deposition" (2) ranked lower on the list (p. 10). Schwartz et al. (2021) explored local perceptions of environmental risks in Andes by identifying environmental remediation initiatives started by miners. This study found that water and air quality, as well as contaminant leaching from mercury-process mine tailings, were concerns that locals had begun to address themselves. Jiménez et al. (2021) conducted qualitative participatory mapping of the principal ASGM corregimiento in Andes (Santa Rita) through which locals also identified environmental problems and brainstormed "idealized solutions," finding that the protection of water resources was a primary concern for residents, and moreover, that "decisions made about [environmental problems] cannot be based on a linear understanding of the situation, but they should consider the relationships and causalities of all variables" (p. 679).

Given the large rural population in Andes, the prevalence of livelihoods that directly depend on hydrological resources, and the diverse concerns around and experiences of subsequent hydrological risks to human health and safety, a transdisciplinary, pluralistic, socio-hydrological perspective is warranted to help illuminate the mechanisms underlying these complex coupled human-water systems so that these water resources can be managed sustainably.

6 Ethnographic Findings: Risk perceptions and Livelihood Decisions

Our ethnographic study found that analyzing perceptions (and/or expressions) of hydrological risks was critical in understanding the impacts that humans and water had on one another. Generally speaking, whether or not risk perceptions correspond with empirical evidence, they shape human behavior and therefore have real impacts on hydrological systems. Though this risk-perspective lens is convergent with previous social-environmental research in Andes (M. P. F. Jiménez et al., 2021; O'Brien et al., 2021; Schwartz, Smits, Smith J., et al., 2021; Schwartz, Smits, Smith N., et al., 2021), it was not pre-conceived, but rather a result of the inductive data collection and analysis process. We found that people divulged their hydrological risk perceptions in order to describe their understandings of hydrological systems, convey their priorities and concerns around water resources, demonstrate how they had been affected by hydrological changes, explain why they made particular livelihood decisions, and justify why they believed future actions needed to be taken regarding water management. To illustrate, one of our subjects expressed the perception that a particular mountain stream was uncontaminated, despite its close proximity to an informal ASGM processing center. Although this stream may have been contaminated with mercury, cyanide, pesticides, etc., the perception of safety led this subject to construct a trout farm on that stream, resulting in implications for water use, contamination, and human health. What follows is a summary of the multiple local risk perceptions that surround and affect hydrological systems, focusing on 1) climate change, 2) water contamination, and 3) hydrological erosion and landslides. We then show how risk-informed livelihood decisions have imperiled the very hydrological resources on which both agriculture and mining livelihoods depend, but are difficult to interrupt given prevailing economic and political constraints.

6.1 Risk Perceptions

A ubiquitous hydrological risk perceived by our subjects concerned climate change, chiefly increasingly irregular precipitation cycles. Many respondents explained how in the past (within one to two generations), their ancestors knew precisely which months were summer and winter (the dry and rainy seasons, respectively), and could readily predict the best times to plant and harvest a wide variety of crops. Now, this is not the case. An elderly farmer echoed the community-wide concern that in 2021, "we did not have a summer season because the weather is crazy now…water fell the entire year." This corresponds with data from different Colombian coffee-growing regions in which farmers ubiquitously perceived significant changes in precipitation and temperature that impacted their livelihoods (Barrucand et al., 2017; Eitzinger et al., 2018). Climate change is rendering void the ancestral environmental knowledge passed down through generations, necessitating farmers to re-invent ways of co-existing with hydrological systems. In Andes, some farmers opted to change locations. Farmers explained how warming temperatures have made coffee farming possible at elevations that were historically too cold; yet, they are still cold enough to prevent pest infestations like coffee borer beetles [*la broca*] that thrive in hotter, more humid conditions. Other farmers adapted by building infrastructure. One subject, Davíd, proudly showed us the makeshift rain shields he built for his cilantro plots with wooden poles and sheets of semi-transparent plastic. Others, however, turned to agrochemicals to help save their yields. María, for example, was taught by her father to fumigate her tomatoes first thing in the morning after it rains with *trivia* [fluopicolide-propineb] or *ridomil* [mefenoxam] to prevent *la gotera* [*Omphalia flavida* fungus], which could quickly destroy an entire field.

While most of our research subjects learned to farm from their parents, grandparents, and even great-grandparents, they admitted that their ancestors did not use pesticides until recent decades. They learned how to apply pesticides from their friends, neighbors, relatives, agrochemical distributors, or sometimes in trainings from the National Coffee Federation or the local coffee co-op. A common perception by those who used pesticides was that "stronger" equated to "more effective," and "more expensive," resulting in a correlation between agrarian prosperity and the use of increasingly toxic agrochemicals. This narrative suggests that farmers may be over-applying agrochemicals, which was corroborated by a volunteer who would collect and discard pesticide containers from rural farms. She reported how she regularly recycled large quantities of highly toxic pesticide containers from several large farms in Andes, and asserted that larger farms were more likely to use harsher, prohibited chemicals than smaller farms because they could afford more the expensive pesticides, had more land to cover, and could thus save time and labor spent weeding, re-fumigating, etc.

Because of the ubiquity of farming in this region, water contamination from farming was seen as an immediate and widespread threat. Most people in Andes reportedly used to "trust their eye" when it came to water quality; however, our interview with a local aqueduct technician suggested that peoples' trust in water quality had declined in recent years, leading to a rapid expansion in the aqueduct network supplying sanitized and filtered water for household use. Multiple subjects corroborated this growing awareness amongst community members of the detrimental health effects of ingesting water contaminated with pesticides, metals, and/or pathogens undetectable to the human eye, a finding also noted by Jiménez et al. (2021). Troublingly, Valbuena et al. (2021) found that "63% of the pesticides sold with slightly acute toxicity [in Colombia] are actually considered highly hazardous pesticides (HHP) for humans or the environment," (p. 1) which raises greater concerns about the health of humans ingesting these chemicals through water or during their application. María told us that she only used "smooth" [*suave*] pesticides because she lacked the capital for stronger ones, but even these *suave* chemicals could "make [her] vomit" while fumigating. Another subject explained how *thiodan* [endosulfan], a prohibited pesticide in Colombia, "destroys the birds, snakes, everything...I had to wait one month to re-enter my farm that had been fumigated [with thiodan]." In Andes, the use of prohibited chemicals like thiodan has led to mass human exposure and hospitalization (Caracol Radio, 2014). Many participants were leery of eating food grown with pesticides, especially crops like cabbage where the chemicals were thought to become trapped between the leaves. Some blamed consumption of agrochemicals for increasing rates of disease and shorter lifespans as compared to previous generations. And in addition to contamination by pesticides, stakeholders were concerned about runoff from farms in Andes containing nutrients from fertilizers and organic matter such as coffee mucilage, which not only generated foul odors, but also could result in the eutrophication of aquatic ecosystems.

Concerns over environmental transport of agricultural contaminants have contributed to a burgeoning organic farming movement in Andes. Davíd, an organic farmer, explained that when his neighbors would fumigate, he would wait a few days to plant because the pesticides would drift to his farm, get "washed" into the soil when it rained, and the "plants would come up weak." Another organic farmer, Héctor, credited the "beautiful [uncontaminated] waters" in his *corregimiento* Santa Inés for allowing him to grow world-class, organic, Fair Trade coffee that fetched a higher market price. Nonetheless, it was widely recognized that organic farming generated lower yields and was more labor-intensive in terms of making the fertilizer, weeding, combating pests, and so on. And in some cases, farmers could not farm organically even if they wanted to because of their geographic proximity to other farms that utilized synthetic agrochemicals. As a compromise, many farming families we spoke with used agrochemicals to maximize production of coffee and plantain to be sold, and used organic methods to cultivate gardens for household consumption.

Like O'Brien et al. (2021), we found that participants were divided in their perceptions of which activities were most dangerous to hydrological systems. Despite ASGM's relative isolation and smaller presence compared to farming, ASGM was largely considered to be a more severe, longer-term threat to water because of deforestation, land upheaval, and mercury contamination. There was a common narrative borrowed from national anti-large-scale mining movements (Sierra Musse, 2019) about the mutual exclusivity of water and gold mining. Phrases like "we want water not gold" and "you can't eat gold" were common, the latter referring to the perceived threats that mining presented to agriculture regarding water, land, and labor. Subjects told us that "where the sands with mercury are deposited, it will take more than 200 years for a plant to grow there again," and that "before, the fish were overflowing...but now you won't find a single fish" in the San Juan River. The overarching cultural stereotype was that ASG miners were irresponsible, sinful, greedy, and unconcerned about the environment. Many participants were adamant that "a mining town is a town lost in vice," and "what [miners] want is money. They don't care about nature, they don't love the planet." When we asked miners themselves whether other miners cared about protecting the environment, one miner responded that about 30% of them cared, but the other 70% saw contaminating activities as "normal." Despite these perceptions, a counter-narrative existed among ASG miners that developed grassroots projects in Andes to protect water resources (Schwartz, Smits, Smith J., et al., 2021), including banding together to form an association to help miners decrease their environmental impacts and increase their political power.

Nevertheless, contamination from *both* agriculture and ASGM had compromised the historic regional identity and cultural activities associated with Andes' pristine and abundant water resources. In the past, it was common for locals to go down to the San Juan River to pan for gold, fish, and spend time with family. "We would go to the river to make *sancocho* [traditional Colombian stew] using the same water from the river. We would swim. Now you cannot do that." However, residents' understandings of how water moved in this steep landscape created a perceived surface water quality gradient along the mountain slopes from high (clean) to low (dirty). Stakeholders largely trusted the water quality from *arriba* [above], originating in the protected forest reserves and *paramos* [rare, protected alpine meadow ecosystems] at the highest elevations of Andes (despite allegations by other subjects of ASGM activity in the reserve areas), especially the water from mountainside springs that passes through hundreds of feet of natural rock and gravel filters. This was the justification for the subject who established a trout farm directly next to an ASGM processing plant. She assured us that the contaminated runoff from the processing plant went *that way*, pursing her lips toward the steep slope leading down to the river, and that the water that they drank, bathed, cooked, and farmed with came from *arriba*, gesturing upward. Another farmer explained how "for me at this moment, mining doesn't threaten me at all," because his water came from a spring originating in the forest reserve, while ASGM was practiced on a completely different mountain. Approval or disapproval of ASGM was thus influenced (partially) by one's geographical proximity, including vertical proximity, to ASGM operations.

In addition to contamination from agro-mining chemicals and waste, water quality was perceived to have diminished due to increased erosion and sedimentation associated with excess rainfall, land-use change, and deforestation. This had caused problems for the trout industry. A manager of a trout farm and restaurant in neighboring Jardín explained how "the enemy of trout farming is rainwater…it's the raw material, it's the principal product for trout production, but it's the principal enemy" due to high rates of sedimentation that can cause fish kill, along with increased transportation of trash. More critically, storms of increased duration and frequency had increased the probability of rain-triggered landslides and floods in the region (Giraldo et al., 2022; Muñoz et al., 2014), phenomena which were perceived by our subjects to be more common now than in years past. One resident of Santa Inés expressed his belief that "from one moment to the next, a landslide will appear that will take the whole town." The zones which were most vulnerable to landslides in Andes according to Zapata Restrepo & Mejía Aramburo, (2019) were the high elevation, ASGM zones in the *corrigimientos* of Santa Rita and Santa Inés. These same regions were purportedly prime for the upward expansion of specialty coffee farms, along with ASGM, resulting in compounding deforestation, subsidence, and destabilization of precarious hillsides. Some common mitigation efforts throughout the municipality included the interspersing of banana and plantain trees with coffee shrubs, as well as the planting of larger, native tree species throughout the farms.

6.2 Livelihood Decision Paradox

A common tactic for residents to protect themselves against hydrological risks (e.g. landslides, floods, droughts, contamination) was livelihood diversification, which is simply the cultivation of multiple income streams. Yet paradoxically, while diversification could protect rural residents against some challenges arising from variable hydrology, this diversification appeared to have exacerbated other hydrological risks. For example, if excess precipitation reduced a farmer's coffee yield, they could diversify in ASGM to supplement their income. This is precisely what many local and migrant workers did in Andes. Daniel, a local farmer/miner, explained how "when things go badly in the mine, the land gives me food. When the land isn't producing, because it's by seasons, I go to the mine." These agro-mining "livelihood complements" have also been observed in other parts of the world (Cartier & Bürge, 2011, p. 1080). But in turn, water and air contamination from ASGM may have compromised the quality of the coffee grown in the area. Coffee beans were described like sponges that absorb everything around them–for this reason, the local coffee co-op did not allow their workers to smoke cigarettes while loading coffee sacks. A co-op employee stated that coffee connoisseurs "can taste everything in the cup."

Similarly, if coffee farmers tried to increase their yields by increasing the application of synthetic agrochemicals, especially strong pesticides, they may have threatened the ecological health of the surrounding farms and the wider hydrological system that feeds their own farm. The expanding use of agrochemicals was deeply entwined with an agrarian debt cycle common in rural Colombia (Arango Vásquez, 2020), which further intensified the need for farmers to seek additional income streams. In another tragic example, one family we spoke to had their entire house and farm buried by a landslide in 2015. Their strategy for economic recovery was to diversify their incomes as much as possible, expanding from mono-culture coffee farming (pre-landslide) into the production of diverse fruits and vegetables year-round, trout pisciculture, ASGM, and tourism. Yet once again, the expansion of these livelihood activities and the subsequent development and deforestation could have increased landslide risks. This livelihood diversification-hydrological risk paradox is summarized in Figure 3.

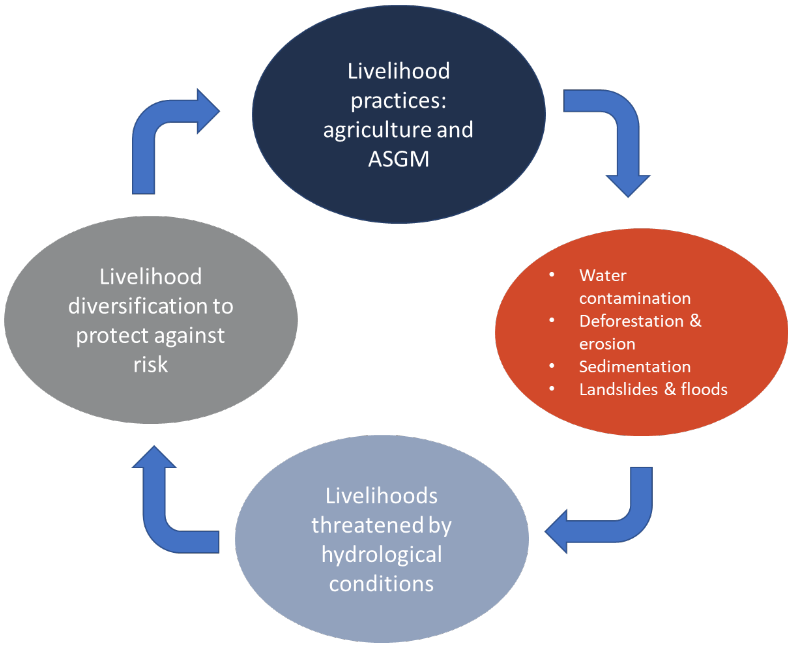

Figure 3. Livelihood diversification-hydrological degradation paradox in which subjects diversified livelihoods to mitigate hydrological risk, but in turn, exacerbated those risks. Our ethnographic analysis revealed additional factors contributing to unsustainable livelihood practices, chiefly a lack of profitable alternative livelihood options and a sense of abandonment by local and federal institutions. In Andes, there was a widespread distrust of government officials and institutions, multinational mining companies, and even the local coffee co-op, which was liquidated in early 2022 after an investigation of a high profile corruption scandal (Mercado, 2020). CORANTIOQUIA, Antioquia's environmental regulation agency, was perceived as corrupt by some subjects who believed that they accepted bribes in exchange for granting environmental permits. One respondent with particular animosity towards CORANTIOQUIA stated that all they do is "sit in an office and sanction the people…they charge a fine for anything." Our interview subjects lamented over development and rural assistance programs promised by politicians to gain votes, yet never came to fruition. Even the projects that seemed well-designed, such as CORANTIOQUIA's implementation of rural septic tanks for coffee mucilage diversion (CORANTIOQUIAOFICIAL, 2015), proved to be unsustainable after the outside experts left. A couple of respondents admitted that they had sold their septic tanks due to the amount of extra labor required for their upkeep. There were common feelings of resignation regarding whether rural conditions, including hydrological ones, would ever improve.

Many stakeholders emphasized that they survived "by their fingernails," meaning that they leveraged whatever resources were available to them to make a living without relying on outside help. Residents told us how they built their own roads and parks with their neighbors after they became tired of waiting for assistance from the mayor's office. People in the San Augustín neighborhood burned all of the trash they could not compost because they received no municipal trash collection services. This lack of support meant that locals had to do whatever was necessary to make ends meet, including making environmental and economic tradeoffs. Agrochemicals for instance, allowed farmers to produce greater yields faster, with less labor than organic methods. And despite the fears over ASGM contamination, miners were reported to sometimes earn "in 15 days what takes me [a coffee farmer] two to three months of work." These economic incentives, along with agricultural challenges due to climate change could contribute to deagrarianization and expansion of ASGM in Andes, a fear expressed by many farmers. Though our data revealed environmental concerns amongst some ASG miners, as long as the economic incentives are high and legal barriers to formalization remain insurmountable (Veiga & Marshall, 2019), ASG miners will likely continue to operate informally, with little environmental regulation, remaining socially marginalized and stigmatized.

7 Discussion & Conclusions

In this article, we contributed to ongoing discussions on how socio-hydrologists can enhance their understandings of social phenomena. We outlined how the epistemological foundation of socio-hydrology differs from that of many social science fields (positivism vs. interpretivism, respectively), leading to an often asymmetrical integration of social and hydrological theory. We critiqued socio-hydrologists' prioritization of quantifiable social data, which can homogenize and oversimplify complex human thought and behavior. Instead, we built on recent literature advocating for the adoption of pluralistic approaches that complement conventional hydrological modeling with qualitative, interpretivist frameworks from social science. We grounded this argument with a concrete, well-established anthropological tool (RAP) and an analysis of how we applied it in the field to qualitatively characterize the coupled human-water systems in our study site. This process allowed us to identify several *socio*-hydrological threats to water resource sustainability in Andes, Colombia, which we found to be related to risk-based livelihood decisions in agricultural and mining sectors.

This investigation built upon previous quantitative research done in Andes. Roberts (2022) developed models to predict how precipitation and streamflow in the San Juan River changed as a function of remotely-sensed environmental variables (like sea surface temperature, pressure, temperature, etc.), potentially providing locals with advanced notice about next-season hydrological conditions. To complement this promising tool, our qualitative study revealed how changes in precipitation and streamflow could and *have* actually affected local farming and mining livelihoods, as well as subsequent livelihood adaptations that have had tangible impacts on hydrological systems. O'Brien et al. (2021) used a ranked survey to quantify local contamination concerns, finding that residents were most concerned about mercury amalgamation and pesticides (similar to our own findings); however, this preformulated questionnaire could not provide deep insight into *why* people held those perceptions, nor why these activities persisted despite the acknowledged environmental risks.

Through ethnographic RAP, we were able to characterize hydrological risk perceptions related to not only contamination, but also climate change, erosion, and landslides. These risk perceptions were dependent upon factors like local knowledge of past and present hydrological systems, geographic (including vertical) location, cultural stereotypes, and regional political movements, to name a few. We identified responses to these risks, changes in farming and mining practices, and the paradoxical expansion and perpetuation of specific livelihood activities that exacerbated these risks. While some subjects were able to disrupt this cycle of water resource degradation through alternative practices like organic farming and reforestation, prevailing social, political, and economic constraints, such as a lack of institutional support and viable livelihood options, forced most residents to make difficult environmental-economic tradeoffs. That said, identifying the explicit, qualitative mechanisms underlying these human-water feedback cycles is critical for interrupting them, highlighting areas of effective future research, and fostering sustainable water resource management.

Some opportunities to support future sustainable water resource management in Andes include leveraging the growing awareness of hydrological risks and the importance of restoring and conserving water resources, as well as the identification of locals, like Davíd and Héctor, who had already begun to interrupt the cycles of agro-mining water contamination and deforestation. Future interventions for sustainable water resource management could elevate the local knowledge of these community members through peer-to-peer capacity building programs, for instance. Some key focus areas for fruitful quantitative hydrological analysis could be modeling the vertical transport of agro-mining contamination and measuring empirical contamination levels of water sources considered "safe" by locals. Technical assistance could also help locals understand which areas are relatively safe or unsafe to develop in terms of landslide risks. Importantly, outside "experts" should recognize the widespread distrust of institutional programs for rural development in Andes, and ensure that future interventions respond to expressed community-based needs, dedicate time to building trust, and prioritize follow-through. Moreover, this study illuminated how most points of critical intervention exist beyond hydrological models, such as creating more viable livelihood opportunities, addressing agrarian debt cycles, facilitating the formalization of ASGM, and reducing political corruption. Certainly, no single research team, project, or discipline can address all of these issues, which reiterates the importance of transdisciplinary, holistic, pluralistic approaches that move incrementally toward appropriate solutions that take these multi-faceted contexts into account. This more inclusive approach to socio-hydrology indeed challenges the field's identity as a purely quantitative science and blurs the lines between socio-hydrology and informed water resource management.

Acknowledgments

The authors would like to thank the U.S. National Science Foundation Parnership for International Research and Education (PIRE) Grant No. 1743749 which funded the "Responsible Mining, Resilient Communities" project in partnership with the Colorado School of Mines, Universidad Nacional de Colombia (Medellín, Colombia), the University of Texas at Arlington, and the U.S. Air Force Academy. Thank you to our Colombian research team, as well as to all of the stakeholders from Andes and Medellín who generously participated in this study. The authors have no conflicts of interest to declare.

Open Research

Due to IRB conditions from the University of Texas at Arlington and privacy and ethical concerns, neither the data nor the source of the data can be made available.

References

Alcaldía de Andes. (n.d.). Información del Municipio. Retrieved March 14, 2022, from https://www.andes-antioquia.gov.co/MiMunicipio/Paginas/Informacion-del-Municipio.aspx

Arango Vásquez, L. (2020). If you don't owe, you don't own: Debt, discipline and growth in rural Colombia. Journal of Rural Studies, 78, 271–281. https://doi.org/10.1016/j.jrurstud.2020.06.025

Barrucand, M. G., Giraldo Vieira, C., & Canziani, P. O. (2017). Climate change and its impacts: Perception and adaptation in rural areas of Manizales, Colombia. Climate and Development, 9(5), 415–427. https://doi.org/10.1080/17565529.2016.1167661

Basu, N., Clarke, E., Green, A., Calys-Tagoe, B., Chan, L., Dzodzomenyo, M., Fobil, J., Long, R. N., Neitzel, R. L., Obiri, S., Odei, E., Ovadje, L., Quansah, R., Rajaee, M., & Wilson, M. L. (2015). Integrated Assessment of Artisanal and Small-Scale Gold Mining in Ghana—Part 1: Human Health Review. International Journal of Environmental Research and Public Health, 12(5), 5143–5176. https://doi.org/10.3390/ijerph120505143

Beebe, J. (1995). Basic Concepts and Techniques of Rapid Appraisal. Human Organization, 54(1), 42–51. https://doi.org/10.17730/humo.54.1.k84tv883mr2756l3

Burleson, G., Tilt, B., Sharp, K., & MacCarty, N. (2019). Reinventing boiling: A rapid ethnographic and engineering evaluation of a high-efficiency thermal water treatment technology in Uganda. Energy Research & Social Science, 52, 68–77. https://doi.org/10.1016/j.erss.2019.02.009

Caracol Radio. (2014, March 21). Intoxicados con plaguicidas 46 niños y 6 adultos en Andes, Antioquia. https://caracol.com.co/radio/2014/03/21/regional/1395411840_140358.html

Carter, N., Bryant-Lukosius, D., DiCenso, A., Blythe, J., & Neville, A. (2014). The Use of Triangulation in Qualitative Research. Oncology Nursing Forum, 41(5).

Cartier, L. E., & Bürge, M. (2011). Agriculture and Artisanal Gold Mining in Sierra Leone: Alternatives or Complements? Journal of International Development, 23(8), 1080–1099. https://doi.org/10.1002/jid.1833

Cifuentes, E., Alamo, U., Kendall, T., Brunkard, J., & Scrimshaw, S. (2006). Rapid Assessment Procedures in Environmental Sanitation Research: A Case Study from the Northern Border of Mexico. Canadian Journal of Public Health, 97(1), 24–28.

CORANTIOQUIAOFICIAL. (2015, September 10). Saneamiento Hídrico Rural e Implementación de Pozos Sépticos. https://www.youtube.com/watch?v=f8KyOq7gGSs

Di Baldassarre, G., Cloke, H., Lindersson, S., Mazzoleni, M., Mondino, E., Mård, J., Odongo, V., Raffetti, E., Ridolfi, E., Rusca, M., Savelli, E., & Tootoonchi, F. (2021). Integrating Multiple Research Methods to Unravel the Complexity of Human-Water Systems. AGU Advances, 2. https://doi.org/10.1029/2021AV000473

Di Baldassarre, G., Sivapalan, M., Rusca, M., Cudennec, C., Garcia, M., Kreibich, H., Konar, M., Mondino, E., Mård, J., Pande, S., Sanderson, M. R., Tian, F., Viglione, A., Wei, J., Wei, Y., Yu, D. J., Srinivasan, V., & Blöschl, G. (2019). Sociohydrology: Scientific Challenges in Addressing the Sustainable Development Goals. Water Resources Research, 55(8), 6327–6355. https://doi.org/10.1029/2018WR023901

Diaz, F. A., Katz, L. E., & Lawler, D. F. (2020). Mercury pollution in Colombia: Challenges to reduce the use of mercury in artisanal and small-scale gold mining in the light of the Minamata Convention. Water International, 45(7–8), 730–745. https://doi.org/10.1080/02508060.2020.1845936

Eitzinger, A., Binder, C. R., & Meyer, M. A. (2018). Risk perception and decision-making: Do farmers consider risks from climate change? Climatic Change, 151(3), 507–524. https://doi.org/10.1007/s10584-018-2320-1

Elshafei, Y., Sivapalan, M., Tonts, M., & Hipsey, M. R. (2014). A prototype framework for models of socio-hydrology: Identification of key feedback loops and parameterisation approach. Hydrology and Earth System Sciences, 18(6), 2141–2166. https://doi.org/10.5194/hess-18-2141-2014

Esdaile, L. J., & Chalker, J. M. (2018). The Mercury Problem in Artisanal and Small-Scale Gold Mining. Chemistry : A European Journal, 24(27), 6905–6916. https://doi.org/10.1002/chem.201704840

Ferry, E., & Ferry, S. (2017). La Batea. Red Hook Editions.

Forsythe, D. E. (1999). "It's Just a Matter of Common Sense": Ethnography as Invisible Work. Computer Supported Cooperative Work (CSCW), 8(1), 127–145. https://doi.org/10.1023/A:1008692231284

Giraldo, E. V. A., Aristizábal, E. G., Sánchez, R. M., Cardona, F. G., & Martínez, J. C. G. (2022). Rainfall-intensity effect on landslide hazard assessment due to climate change in north-western Colombian Andes. Revista Facultad de Ingeniería Universidad de Antioquia, 103, 51–66. https://doi.org/10.17533/udea.redin.20201215

Giudici, F., Anghileri, D., Castelletti, A., & Burlando, P. (2021). Descriptive or normative: How does reservoir operations modeling influence hydrological simulations under climate change? Journal of Hydrology, 595, 125996. https://doi.org/10.1016/j.jhydrol.2021.125996

Guest, G., MacQueen, K. M., & Namey, E. E. (2011). Applied Thematic Analysis. SAGE Publications.

Jiménez, F. A. (2021, November 9). Cambio climático amenaza producción cafetera en Colombia. www.elcolombiano.com. https://www.elcolombiano.com/negocios/precio-del-cafe-en-colombia-es-alto-pero-preocupa-la-produccion-IE15999717

Jiménez, M. P. F., Plata, Á. M., Acero, A., Gaona, L. S., Araque, Á. S., & Sierra, D. (2021). Participatory Analysis of Small-Scale Artisanal Gold Mining in the Santa Rita District, Municipality of Andes, Antioquia, Based on the PAIIO Methodology. Systemic Practice and Action Research, 34(6), 669–681. https://doi.org/10.1007/s11213-020-09551-8

Kleine, M. S., Zacharias, K., & Ozkan, D. S. (2021, July 26). Contextualization as Virtue in Engineering Education. 2021 ASEE Virtual Annual Conference Content Access. https://peer.asee.org/contextualization-as-virtue-in-engineering-education

Lane, S. N. (2014). Acting, predicting and intervening in a socio-hydrological world. Hydrology and Earth System Sciences, 18(3), 927–952. https://doi.org/10.5194/hess-18-927-2014

Lewis, S., & Russell, A. (2011). Being embedded: A way forward for ethnographic research. Ethnography, 12(3), 398–416. https://doi.org/10.1177/1466138110393786

Li, F. (2015). Unearthing Conflict: Corporate Mining, Activism, and Expertise in Peru. Duke University Press Books.

Lucena, J., Schneider, J., & Leydens, J. (2010). Engineering And Sustainable Community Development: Critical Pedagogy In Education For “Engineering To Help.” 15.475.1-15.475.16. https://peer.asee.org/engineering-and-sustainable-community-development-critical-pedagogy-in-education-for-engineering-to-help

Lyons, K. M. (2020). Vital Decomposition: Soil Practitioners and Life Politics. Duke University Press Books.

Manderson, L., & Aaby, P. (1992). An epidemic in the field? Rapid assessment procedures and health research. Social Science & Medicine (1982), 35(7), 839–850. https://doi.org/10.1016/0277-9536(92)90098-B

Marin, R. J. (2020). Physically based and distributed rainfall intensity and duration thresholds for shallow landslides. Landslides, 17(12), 2907–2917. https://doi.org/10.1007/s10346-020-01481-9

Massuel, S., Riaux, J., Molle, F., Kuper, M., Ogilvie, A., Collard, A.-L., Leduc, C., & Barreteau, O. (2018). Inspiring a Broader Socio-Hydrological Negotiation Approach With Interdisciplinary Field-Based Experience. Water Resources Research, 54(4), 2510–2522. https://doi.org/10.1002/2017WR021691

Mercado, D. A. (2020, February 1). Caficultores del Suroeste esperan soluciones a su amarga situación. El Tiempo. https://www.eltiempo.com/colombia/medellin/caficultores-en-el-suroeste-de-antioquia-esperan-soluciones-a-su-aituacion-457636

Muñoz, E., Martínez-Carvajal, H., Arévalo, J., & Alvira, D. (2014). Quantification of the effect of precipitation as a triggering factor for landslides on the surroundings of Medellín—Colombia. DYNA, 81(187), 115–121. https://doi.org/10.15446/dyna.v81n186.40640

Nüsser, M., Schmidt, S., & Dame, J. (2012). Irrigation and Development in the Upper Indus Basin. Mountain Research & Development, 32(1), 51–61. https://doi.org/10.1659/MRD-JOURNAL-D-11-00091.1

O'Brien, R. M., Smits, K. M., Smith, N. M., Schwartz, M. R., Crouse, D. R., & Phelan, T. J. (2021). Integrating scientific and local knowledge into pollution remediation planning: An iterative conceptual site model framework. Environmental Development, 100675. https://doi.org/10.1016/j.envdev.2021.100675

Octavio Cardona, A. (2018). En Antioquia, 70% de la producción de café se da en el último cuatrimeste del año. https://www.agronegocios.co/agricultura/antioquia-requiere-cerca-de-80-000-recolectores-para-la-cosecha-cafetera-de-fin-de-ano-2773239

Ojeda, J., & Donnelly, L. (2006). Landslides in Colombia and their impact on towns and cities. International Association for Engineering Geology and the Environment.

Ongley, E. D., & Booty, W. G. (1999). Pollution Remediation Planning In Developing Countries. Water International, 24(1), 31–38. https://doi.org/10.1080/02508069908692131

Pande, S., & Sivapalan, M. (2017). Progress in socio-hydrology: A meta-analysis of challenges and opportunities. WIREs Water, 4(4), e1193. https://doi.org/10.1002/wat2.1193

Parker, C., Scott, S., & Geddes, A. (2019). Snowball Sampling. SAGE Research Methods Foundations. http://methods.sagepub.com/foundations/snowball-sampling

Parsons, L. B. (1996). Engineering in Context: Engineering in Developing Countries. Journal of Professional Issues in Engineering Education and Practice, 122(4), 170–176. https://doi.org/10.1061/(ASCE)1052-3928(1996)122:4(170)

Parveen, S., Winiger, M., Schmidt, S., & Nüsser, M. (2015). Irrigation in Upper Hunza: Evolution of Socio-Hydrological Interactions in the Karakoram, Northern Pakistan. Erdkunde, 69(1), 69–85.

Pepall, E., James, R. W., & Earnest, J. (2006). Guidelines for Conducting Rapid Participatory Appraisals of Community Health Needs in Developing Countries: Experience from Tulikup, Bali. Asia Pacific Journal of Public Health, 18(3), 42–48. https://doi.org/10.1177/10105395060180030801

Ragin, C., Nagel, J., & White, P. (2004). Workshop on Scientific Foundations of Qualitative Research. National Science Foundation.

Rajaee, M., Obiri, S., Green, A., Long, R., Cobbina, S. J., Nartey, V., Buck, D., Antwi, E., & Basu, N. (2015). Integrated Assessment of Artisanal and Small-Scale Gold Mining in Ghana-Part 2: Natural Sciences Review. International Journal of Environmental Research and Public Health, 12(8), 8971–9011. https://doi.org/10.3390/ijerph120808971

Reeves, S., Kuper, A., & Hodges, B. D. (2008). Qualitative research methodologies: Ethnography. BMJ, 337. https://doi.org/10.1136/bmj.a1020

Restrepo, O., Aristizabal H., G., Pimentel, M., Florez Vergara, C., & Argumedo, C. (2020). Waste Management and the Elimination of Mercury in Tailings from Artisanal and Small-Scale Gold Mining in the Andes Municipality of Antioquia, Colombia. Mine Water and the Environment, 40. https://doi.org/10.1007/s10230-020-00728-0

Riley, D. (2005). Mindsets in Engineering. In Engineering and social justice (pp. 33–45). Morgan & Claypool Publishers. https://doi.org/10.2200/S00117ED1V01Y200805ETS007

Roberts, K. (2022). The Impacts of Climate Uncertainty of Streamflow in Andes, Antioquia, Colombia [M.S.]. United States Air Force Academy.

Robertson, T., & Farrelly, T. (2020). An Ethnography of Entanglements: Mercury's Presence and Absence in Artisanal and Small-scale Gold-mining in Antioquia, Colombia. https://mro.massey.ac.nz/handle/10179/15341

Rusca, M., & Di Baldassarre, G. (2019). Interdisciplinary Critical Geographies of Water: Capturing the Mutual Shaping of Society and Hydrological Flows. Water, 11. https://doi.org/10.3390/w11101973

Saunders, B., Sim, J., Kingstone, T., Baker, S., Waterfield, J., Bartlam, B., Burroughs, H., & Jinks, C. (2018). Saturation in qualitative research: Exploring its conceptualization and operationalization. Quality & Quantity, 52(4), 1893–1907. https://doi.org/10.1007/s11135-017-0574-8

Savelli, E., Rusca, M., Cloke, H., & Di Baldassarre, G. (2022). Drought and society: Scientific progress, blind spots, and future prospects. Wiley Interdisciplinary Reviews: Climate Change. https://doi.org/10.1002/wcc.761

Schwartz, M., Smits, K., Smith J., J., Phelan, T., & Restrepo Baena, O. J. (2021). Incorporating positive deviance into comprehensive remediation projects: A case study from artisanal and small-scale gold mining in the municipality of Andes, Colombia. Environmental Science & Policy, 123, 142–150. https://doi.org/10.1016/j.envsci.2021.05.021

Schwartz, M., Smits, K., Smith N., N., & Phelan, T. (2021). How lessons from an evolving comprehensive approach for water and sanitation can improve artisanal and small-scale mining environmental initiatives. Journal of Cleaner Production, 282. https://doi.org/10.1016/j.jclepro.2020.124457

Scrimshaw, S., & Hurtado, E. (1987). Rapid assessment procedures for nutrition and primary health care: Anthropological approaches to improving programme effectiveness. United Nations University ; UCLA Latin American Center Publications, University of California.

Sierra Musse, L. (2019). "Queremos agua, no oro": Comienza una nueva era de protestas en Santurbán. ¡PACIFISTA! https://pacifista.tv/notas/licencia-ambiental-santurban-minesa-oro-agua-protestas/

Sivapalan, M., & Blöschl, G. (2015). Time scale interactions and the coevolution of humans and water. Water Resources Research, 51(9), 6988–7022. https://doi.org/10.1002/2015WR017896

Sivapalan, M., Savenije, H. H. G., & Blöschl, G. (2012). Socio-hydrology: A new science of people and water. Hydrological Processes, 26(8), 1270–1276. https://doi.org/10.1002/hyp.8426

Spradley, J. P. (1979). The Ethnographic Interview (45219th edition). Harcourt, Brace, Jovanovich.

Teweldebrihan, M. D., Lyu, H., Pande, S., & McClain, M. E. (2021). Smallholder Farmer's Adaptability to Anthropogenic and Climate-Induced Variability in the Dhidhessa River Sub-basin, Ethiopia. Frontiers in Water, 3. https://www.frontiersin.org/article/10.3389/frwa.2021.735004

Troeger, C., Pham, T., & Van Arsdale, P. (2015). Community-Level Perceptions and Outcomes of Water Source Development Projects in Timor-Leste: A Cross-Sectional Study. Human Organization, 74(2), 164–173. https://doi.org/10.17730/0018-7259-74.2.164

Utarini, A., Winkvist, A., & Pelto, G. H. (2001). Appraising Studies in Health Using Rapid Assessment Procedures (RAP): Eleven Critical Criteria. Human Organization, 60(4), 390–400. https://doi.org/10.17730/humo.60.4.3xu3p85amf13avtp

Valbuena, D., Cely-Santos, M., & Obregón, D. (2021). Agrochemical pesticide production, trade, and hazard: Narrowing the information gap in Colombia. Journal of Environmental Management, 286, 112141–112141. https://doi.org/10.1016/j.jenvman.2021.112141

Vanelli, F., Kobiyama, M., & de Brito, M. (2021). To which extent are socio-hydrology studies really integrative? The case of natural hazards and disaster research. https://doi.org/10.5194/hess-2021-638

Veiga, M. M., & Marshall, B. G. (2019). The Colombian artisanal mining sector: Formalization is a heavy burden. The Extractive Industries and Society, 6(1), 223–228. https://doi.org/10.1016/j.exis.2018.11.001

Velásquez, J. R., Schwartz, M., Phipps, L. M., Restrepo-Baena, O. J., Lucena, J., & Smits, K. M. (2022). A review of the environmental and health implications of recycling mine tailings for construction purposes in artisanal and small-scale mining communities. The Extractive Industries and Society, 9, 101019. https://doi.org/10.1016/j.exis.2021.101019

Vlassoff, C., & Tanner, M. (1992). The relevance of rapid assessment to health research and interventions. Health Policy and Planning, 7(1), 1–9. https://doi.org/10.1093/heapol/7.1.1

Wakhungu, M. J. (2019). An ethnography of policy: Water reuse policy in Kenya. Water Policy, 21(2), 436–448. https://doi.org/10.2166/wp.2019.160

Warren, C. A. B., & Karner, T. X. (2009). Discovering Qualitative Methods: Field Research, Interviews, and Analysis (2nd edition). Oxford University Press.

Wesselink, A., Kooy, M., & Warner, J. (2017). Socio-hydrology and hydrosocial analysis: Toward dialogues across disciplines: Socio-hydrology and hydrosocial analysis. Wiley Interdisciplinary Reviews. Water, 4(2), e1196-. https://doi.org/10.1002/wat2.1196

Zapata Restrepo, G. A., & Mejía Aramburo, J. J. (2019). Andes, identidad y memoria: Cartilla de cátedra municipal (2nd ed.). Color Offset.