The consequences of mining induced water pollution on migration in the Peruvian Andes

Maria Fe Garcia Seminario

Contributing authors: mariafegarcias23@gmail.com;

Abstract

Due to the increasing global temperatures, glacial melting is accelerating its pace. Hence, water security is threatened by the indirect effects of anthropogenic activities but also the direct effect of activities such as mining. In South America, particularly in the high mountains, mining production is expanding. Peru is the third country with the most important production of minerals and metals. This research project will assess the impact of mining activities on the hydraulic security and water perception of the local population. A focal point will be drawn towards glacial meltwater that nourish river flows above an altitude of 2500 meters, threshold from which population rely on glaciers as their only source of water. Furthermore, we will be exploring the effects of mining activities on glacial meltwater supply on the socio-economic, health and migration context of the Peruvian high mountains. More precisely, we will study its effects on water security that could force the migration of inhabitants. To measure water security we will use three objects, the level of heavy metal contamination using the threshold provided by the World's Health Organization, the SENAMHI*qualitative parameters such as turbulence, and the river flow. Hence, we will study the relationship between these parameters and the migration fluxes. Hopefully, this will help implement political decisions to assess the migratory situation and prevent further environmental degeneration.

Keywords: Mining, Water security, Heavy metal contamination, Hydro-social parameters

*Servicio Nacional de Meteorología e Hidrología del Perú, Service National de Meteorologie et Hydrologie du Pérou

1 Introduction

Anthropogenic activities have been dramatically striking climate conditions towards tipping points. From melting glaciers to extreme temperatures, the access to water and food resources are being put at risk. The SENAMHI[1] and the Ministry of the Environment have studied the scenario for 2030 and 2050 of glacial coverage and have pointed out the threatening situation of water security in Peru. As a consequence, the quantity and the quality of the water provided by glacial ecosystems are both decreasing, while the risks of landslide and glacial movements are increasing.

Today, according to SENAMHI, we have already lost 56% of the coverage of the Artesonraju glacier. A population census of 2017 estimated that there are more than 8 million inhabitants in the Andes region. In 2019, INEI [2] found that 40,9% of the Andean population did not have access to the water public network. Instead heavily rely on the water provided by glacial meltwater for both human consumption and agricultural activities, especially during dry seasons. Furthermore, over the last decade, there has been a migration tendency from rural to urban areas in the hope of finding more access to drinkable water and electricity (Huarancca, Alanya, Castellares, 2022).[1] Therefore, it is crucial to ensure unprotected populations the access to hydraulic resources before reaching the glacial tipping points and causing a perpetual disequilibrium.

2 Focus on Andean area

The access to water resources in the high mountain population is very limited and relies mostly on glacial meltwater for both domestic and agricultural consumption. Due to global warming and the ENSO phenomenon, these ecosystems are already experiencing high temperatures responsible for glacial retreat and melting, compromising the depletion of water resources. The mining activity not only enhances the contribution to higher greenhouse gasses emissions and climate change, but also has a non reversible effect on the disruption of water resources. In addition, mining activities have only increased during the past decade because of the geographical interest in mineral resources in the area (Aragón, 2013).[2]

First, we will identify the direct contamination of heavy metal on water resources (basins, groundwater, rivers) using the World's Health Organization threshold. Second, we will observe the retreat and physical deterioration of glacial that mining activities might accentuate. Demographic data indicates that these populations are, for most of the cases, under the poverty threshold and even under the extreme poverty threshold. In addition, academic research has focused on water security on the political aspects, highlighting the unfair geographical and social distribution of water across the country (Sosa and Zwarteveen, 2012).[3] The discussion has been

[1] Servicio Nacional de Meteorología e Hidrología del Perú, Service National de Meteorologie et Hydrologie du Pérou

[2] Instituto Nacional de Estadistica e Informatica del Peru, Institut National de Statistiques et Informatique du Pérou

centered around water grabbing, defined as the acquisition of lands to access water resources depriving users from their access. Impacts on water scarcity is a topic increasingly being assessed (Dell'Angello et al.,2018).[4] Concerns about the potential risk on food security (Rulli et a. 2013)[5], on the political and colonial aspects (Gasteyer et al., 2012, Franco et al., 2013)[6][7] and on the rise of conflicts (Wolf, 2007, Dell'Angelo 2017)[8] have been increasing. Nevertheless, for our case we will address the aggravation of water access for vulnerable populations who are already fighting for these resources. Migration will be interpreted as the point of no return, from which water security has failed local communities forcing them to migrate.

Hence, a critical evaluation of all the factors that can encourage migration will be taken into account. These factors include negative effects of mining such as the interruption of water cycle aggravating the lack of food security, landscape deterioration (Carey et al., 2014)[9], conflict over water (Drenkhan et al. 2015)[10], and glacial lake outburst floods (Bellisario et al,. 2013).[11] We will also be looking at possible positive effects , for example the increase in the demand of mining jobs (Aragón et al.,2016).[12] Overall, migration from rural communities towards big cities has been increasing (Huarancca, Alanya, Castellares, 2022)[1] with the incentive to access water, electricity and improve their income. Therefore, the expansion of discovery within the mining industry could be a factor that explains this migration phenomenon. Even though migration seems to go towards densely populated cities (Rodríguez, 2008),[13] living conditions seem to improve in terms of economic income (Young, 2013).[14] Discrimination and racism (Alcalde 2022, De la Cadena 1998)[15][16] as well as lack of education and literacy (Figueroa & Barrón 2005, Crivello 2010)[17][18] can be an obstacle to reach a stable socio-economic situation.

3 Method

For this research, we will implement a difference-in-difference methodological approach. Our treatment group will contain zones pre and post exposed to mining contamination. As for our control group, we will take areas that have not been exposed to mining activity, but have suffered similar climatic conditions as the treatment group to eliminate all biases. This method will allow us to control seasonal variation, ENSO phenomenon and climate change degradation on ecosystems by isolating the mining contamination effect. However, finding two identical groups can be a challenge, other criteria such as the comparison on upstream and downstream (Gittard & Hu., 2023)[19] could be used instead. According to their geographical locations, we will use the data on the distribution of glacial meltwater to identify the zones exposed to heavy metal contamination. Then, we will use three parameters: heavy metal contamination threshold, turbulence and river flow as proxies to measure the water security. Then, will study the possible effects these parameters have on income, health, or conflicts. For this step, we will treat each outcome separately to be able to control for all attrition biases. For our study, we will be looking at the correlation of these parameters with migration fluxes. Therefore, we will be able to deduce the changes mining pollution of water resources induces in migration. The previous and difference-in-difference approach will allow us to separate the common migration from the mining-induced migration. Using the water parameters, we will separate other negative effects generated by the mining activity that could influence migration. Hence, we will be able to establish a point of no return from which mining pollution forces migration.

$$Y_{\text{migration}} = \alpha_0 + \alpha_1 \beta_{\text{mining}} + \alpha_2 \beta_{\text{time}} + \delta(\beta_{\text{mining}} \beta_{\text{time}}) + \alpha_3 X + \epsilon \tag{1}$$

3.1 Data

3.1.1 *Mining*

To localize the mining activities we will be manipulating the data from the Extractive Industries Transparency Initiatives whose goal is to promote the open and accountable management of mineral resources, since Peru is a member of this project. In our case, we will incorporate only mines in close proximity to glaciers. We will be including information on the type of mining.

3.1.2 *Water security*

According to the UN, water security is "the adaptive capacity to safeguard the sustainable availability of, access to, and safe use of an adequate, reliable and resilient quantity and quality of water for health, livelihoods, ecosystems and productive economies". To evaluate water quality, we will be measuring the contamination of heavy metal registered by the 's measurement stations. The threshold provided by the World's Health Organization on heavy metal pollution will be used to address the level of contamination (Cobbina et al,. 2013)[20]. Still, our research will not only rely on biochemical parameters, but also on qualitative descriptions of the water color and turbulence provided by the same dataset. Therefore, we will be able to estimate the changes on the appearance, mainly relying on visual qualities such as turbulence and color. Academic evidence (Rangecroft et al., 2023)[21] has pointed out the importance of the use of both environmental indicators and the water perception of the local population to understand the interaction between the resource and the users. Thus, this is of extreme importance when considering migration outcomes, since heavy metal contamination is slowly perceived.

Using geographical hydraulic data of the stream will help us recalculate the access between neighbors (Gang et al., 2018).[22] Our geographical zones of interest will have to respect 2 characteristics: an altitude above 2500m and a glacier proximity. We will use the altitude of 2500 meters as a threshold since the INEI [3] has used this measure to separate mountain populations from coastal and forest populations. As for the glacier proximity, we are focusing on the security of glacial sourced water, so we evaluate a distance from which we consider individuals are dependent on this water as their only source. In addition, information on glacial retreat both before and after mining activities will be key to evaluate the well being of mountain ecosystems since

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the degradation of glaciers exposed to mining will disrupt the quantity and quality of water provided. All of the data mentioned above will be extracted from the and INAIGEM[4] repositories.

3.1.3 *Population*

High alpine populations share a similar economic and social profile (Padilla, 1999).[23] Since we will be evaluating water users whose access rely exclusively on glacial meltwater, we expect some homogeneity among them. As for the demographic data, we will be using information provided by the INEI [5] on migration profile, dependency on agriculture, household income and composition, as well as health status.

3.1.4 *Limits*

Peru is a country with high levels of illegal mining activity. This creates a gap between the estimated mining leaks and the real mining leaks. Communities that have been included in the control group could have therefore already been exposed to illegal mining (Dozolme, 2016, A. Kumah, 2016).[24][25] Hopefully we will be able to detect an unexpected and drastic change in the water quantity and supply that will indicate to us a possible illegal mining.

4 Academic evidence on mining contamination and environmental degradation

4.1 Acid Mine Drainage

Concerns over the water abundance following the glacial recession and the acceleration of retreat pace has been alarming the scientific community. Many impacts of mining need to be assessed regarding the glacial retreat and pollution. Acid rock drainage (ARD), also called acid mine drainage (AMD) is a process that occurs when mining activities expose rich metals rock to the atmosphere inducing an acidic drainage contaminating waters (Akail & Kodas, 2006).[26] This type of contamination can be extended to surface and groundwater, as well as soils. Scientific evidence has put in light this mining-induced process in the Nevado Pastoruri (Santofimia et al.2017).[27] Nevertheless, to address this contamination we will have to observe site-to-site variation of this process. Overall, scientific evidence indicates policies that accentuated the danger of tropical Andean glaciers (Mark et al. 2011).[28]

4.2 Landscape

Chilean and Argentinian mining operations have been attracting attention towards environmental degradation. Empirical evidence aims to highlight deterioration in the hydrological system. Mining activities induce the destruction of some rock glaciers by

[4] Instituto Nacional de Investigación en Glaciares y Ecosistemas de Montaña, Institut National d'Investigation des Glaciers et Ecosystèmes de Montagne

[5] Instituto Nacional de Estadistica e Informatica del Peru, Institut National de Statistiques et Informatique du Pérou

excavation, deterioration of the glacial landscape or by covering them with mining tailings (Bellisario et al,. 2013).[11]

4.3 Glacial Lake Outburst Floods

In addition to AMD and glacial landscape degradation, glacial lake outburst floods (GLOF) are addressed using hydrological tools due to preoccupation with past events that have caused numerous fatalities (Vilca et al., 2021).[29] In the case of open pit mine, seismic waves are generate to do rock blasting which destabilize the rock and glacial structure. So, along with warmer temperatures, mining induced structural instability may lead into glacial lake outburst floods events (Motschmann et al., 2020, Bellisario et al,. 2013).[30][31] In order to mitigate these risks, others have directed their research towards modeling the impact of GLOF scenario (Villafane et al., 2021).[32] More importantly, the instability generated will reshape the high mountains environment as a dangerous region for inhabitants.

4.4 Water supply

Peru's water security has been alarming authorities at the national and international level. Climate change and the ENSO phenomenon have been compromising the precarious supply of water due to an increase in climate variability (Bradley, 2006, Mark et al.,2010).[33][34] In addition, a potential toxic level of heavy metal contamination and high acidity has been added to the list (Battista et al.,2014).[35] Empirical evidence using the heavy metals contamination index (HPI) has estimated 75% of the water samples of Rio Rimac fall in the high pollution classification category. As for other indexes, on the healthy eating index (HEI) scale 8% of water samples fall into the category of high pollution. Furthermore, the agglomeration of certain metals is highly associated with mining industry pollution (Minga et al.,2022).[36] Other works have focused on the heavy metal concentration of the Santa River watershed, mostly used for agricultural irrigation (Carey et al., 2014).[9] Others have addressed the concentration of heavy metals on the suspended sediments (Mark et al., 2017).[37]

5 Academic evidence on water security

5.1 On environmental indicators of water quality

Metal mining contamination contributes to the deterioration of water used for consumption and irrigation, affecting mostly children at the stage of rapid development by increasing neurodegenerative and cardiovascular diseases. Also, leading to a higher cancer development among individuals (Obasi et al,. 2020) [38]and resulting in the degradation of soil and agricultural productivity (Macklin et al,. 2023)[39]. All these factors could be strong incentives for migration. Moreover, some academics have aimed to evaluate the different water indices used to assess health issues in mountain high wetlands (Custodio ,2019)[40]. This research highlights the need for both physicochemical parameters and biota monitoring indexes to assess water quality. In fact, this article points out the need to take into consideration the stress responses of ecosystems when evaluating water quality. Since our study will focus on the pressure the mining industry will induce in migration response, the best way to address this is by using the World's Health Organization framework.

5.2 On glacial and water perception of local populations

Understanding water perception is crucial to apprehend the socio-political dimension of the water issue. For this case, we will define perception as the qualitative characteristics of the water. For instance, we will consider that variations in both turbulence and water supply are an evident sign of endangered water to inhabitants. Academic studies have addressed climate perception to understand migration (Silvestri et al. 2012)[41]. It is essential to evaluate how the access to hydraulic resources is shaped by water governance (BD Lynch, 2012)[42]. Peruvian researchers have applied this approach by studying the perception of local communities and their relationship with environmental quality of reservoirs. Incorporating perception allows us to understand how environmental degradation as the acid mining drainage (AMD) can affect the perception of water quality of individuals (de Doria, 2010)[43]. The change in the perception can also be caused by water governance and conflicts (Berman et al,. 2017)[44]. The population's perception can be measured through national surveys (Rangecroft et al.,2023)[21]. For this study, we will observe how mining leakages and pollution can increase the levels of heavy metal contamination, but also distort qualitative parameters such as turbulence as well as river flow limiting the quantity supplied. We will evaluate the correlation of all of these parameters with migration of the populations. Thus, we will be able to identify the coupled biophysical and social determinants of water access and hydro-social risks (Mark et al., 2017)[28]. Also, we consider that changes in the perception of glacial ecosystems can also change through the visible retreat of glaciers due to cultural factors (Vuille et al., 2014, Rangecroft et al.,2023)[45][21].

5.3 On migratory fluxes

To study the migratory context, most works use population census data on migration (Strobl & Valfort, 2015, Dallman & Millock, 2017)[46][47]. Migration is heavily influenced by socio-economic (Kinnan et al., 2018, Young, 2013)[48][14]. In the current climate crisis context, more recent factors are taking importance among migration waves such as high temperatures (Cattaneo, 2016)[49], droughts (Findley, 1994)[50], climate change (Marchiari et al., 2012)[51] and environmental degradation (Reuveny et al. 2007)[52]. However, migration due to extreme climatic conditions rely on income factors (Falaris,1979)[53]. Still, socio-economic factors remain having a stronger influence on migration than climate variability. In the Peruvian context, migration towards urbanized cities has been increasing between 2007 and 2017 (Huarancca, Alanya, Castellares, 2022)[1]. Distance migration restricts migratory flux towards cities at a certain proximity of the departure region (Skeldon,1977)[54]. Migrants usually have incomplete or asymmetric information on the living conditions improvements of migration Pessino (1991)[55]. Our study will analyze migration variations for exposed and unexposed groups. However, other effects potentially behind migration fluxes will be rigorously analyzed. These could go from outcomes in health (Macklin et al,.

2023)[39], glacial landscape deterioration (Carey et al., 2014)[9] and water governance and conflict issues (Drenkhan et al., 2015, Sosa and Zwarteveen, 2012, Vergara et al., 2007)[56][57][58]

6 Motivation

As a Peruvian I do not only have an enormous appreciation for the glacial landscape of the Andes, but also for the people who live in these habitats. Living in Peru has taught me that social fragmentation and discrimination plays a key role on the people we listen to. People living in the Andean areas under difficult conditions, are very often marginalized. Nevertheless, these people are the first on the line when it comes to climate change outcomes, even though they are in constant danger because they heavily rely on these resources to survive. To me, this project has a special value. It matches perfectly with the skills that I am aiming to acquire on the internship at the IRD on the subject of geographical mapping flood risk using QGIS, a program that I was already familiarized with during a class on “Spatial Analysis”. In addition, I am expecting to develop my programming skills on the manipulation of data on the macroeconomic level during the internship at the Central Bank of the Reserve of Peru (BCRP). It matches my main motivation which is to produce knowledge surrounding outcomes of exposed inhabitants to extreme climate change variations. Also, this research project allows me to follow the interdisciplinary and trans-disciplinary aspect of my academic background that I hope to preserve for the rest of my career. In fact, the knowledge acquired in the classes of my Major in economics and social sciences. Some examples of the courses are“Macroeconomics of the Environment”, “Economics of Natural resources”, “Microeconomics” and “Econometrics”. These courses have guided me to build the basis of this project. In addition, my expertise given by the courses of my Minor in Geosciences such as “Dynamics of continental surfaces”, “Tectonics”, “Ocean in all of its dimensions” and “Physics of the Climate” have helped me recompile the vast hydrological literature on the topic and manage all the scientific concepts required to understanding the subject. From sociological to hydrological studies, the bibliography research I have highly dedicated my time to has been extremely enlightening to see that we cannot look for solutions without a broad perspective on the subject. Finally, this aligns with my beliefs on immediate and radical actions towards anthropogenic activities that harm both the high mountain ecosystem and local population. Migration fluxes could dramatically overflow the cities water capacities since the more contamination there is on the rivers, the more treatment the water needs in order to be drinkable. Thus, rural migrants are usually settling in shantytowns in which the water prices rise as both the treatment and transport cost rise too.

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