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YSSP Report
Young Scientists Summer Program

WHO IS AT RISK? DIFFERENTIAL VULNERABILITY TO CLIMATE-RELATED HAZARDS IN THE CITY OF BELO HORIZONTE, BRAZIL

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Program: Population and Just Societies
30 September 2021

This report represents the work completed by the author during the IIASA Young Scientists Summer Program (YSSP) with approval from the YSSP supervisor.

It was finished by 29/09/2021 and has not been altered or revised since.

This research was funded by IIASA and its National Member Organizations in Africa, the Americas, Asia, and Europe.

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ZVR 524808900

Summary

Abstract

As much as 16.5% (390,000 people) of the population of Belo Horizonte, the sixth most populous city in Brazil, live in areas prone to hydrometeorological risk such as floods, landslides, mudslides, and other extreme events related to rainfall patterns. People living in high-risk areas of urban centers are particularly vulnerable due to a combination of lack of access to public services, socioeconomic disadvantages, and exposure to environmental extreme events such as heatwaves, storms and mass movements. There is however a lack of knowledge on who lives in areas at risk and who has been relocated. This study thus investigates whether and to what extent the population living in such areas differ from the relocated population and the general population.

Based on the data from 2010 Brazilian Census and the municipal registers of relocation between 2010 and 2020, we explore demographic and socioeconomic characteristics of: 1) the inhabitants of areas at risk; 2) populations resettled from risk areas between 2010 and 2020; 3)and the city's general population. This approach allows to capture the interactions between social, economic, and demographic factors underlying vulnerability, and consequently enabling the understanding of differential vulnerability of those at risk and those permanently resettled from areas threatened by environmental stress. We find that while those relocated permanently compared to those relocated temporarily are more likely to have been exposed to heavy rainfall, they tend to have higher income and live with a partner and children. These results can be used to differentiate demographic and socioeconomic profiles of the temporary and permanently relocated populations and further provide information for policymakers about differential vulnerability and resettlement in the context of climate risk.

Acknowledgments

The outbreak of the Covid-19 pandemic in early 2020 caught all of us off guard and we needed to change our original plans. Luckily my plans were just postponed. When I started my Ph.D., I have always thought of being part of IIASA as a far possibility that could one day become true. Working with the "minds" that I've worked with over the summer was an unimaginable opportunity as well. I got selected as a YSSP in 2020 but the pandemic changed everybody's plans and I had to postpone my participation to 2021 when I finally managed to realise my objective. Now that the YSSP program is over, I feel very grateful for this invaluable chance and very happy for daring to dream. Thanks to everyone that helped me during this almost 2-year journey until this report got done!

Many thanks to the YSSP Team for taking good care of us and arranging this virtual format so competently!

Thanks to my supervisors, Raya and Thomas, for all the guidance, the joyful mentoring sessions and, for giving me the opportunity to work with them.

A big thank you to the social committee for setting up some virtual escapes from work that YSSP brings with it!

Thanks to the ones that were always there to provide some laughs, virtual coffee breaks, research tips, and company over this summer, Iulia, Helena, Peta, Mark, Henrique, Nariê, Amelie and Cristina! I do hope that we all can meet in person one day!

1 Introduction

The urbanization and modernization processes in urban centers of Brazil led to the formation of spaces populated by disadvantaged subgroups of population whose basic rights in health, basic sanitation and housing are often neglected. Typically, competition for the best spaces in the centers of big cities was prioritized to the richest while the poorest were pushed to occupy less secure peripheral areas with little access to public services. In addition, these spaces, now known as favelas, slums or villages, are more susceptible to external environmental shocks due to a poor housing structure and deteriorated conditions of life (Martine, 1993). This coupled with the socioeconomic disadvantages make these subpopulations particularly vulnerable to climate-related hazards.

Pelling (2003) argues that urban centers are like epicenters of disasters due to agglomerations in unhealthy living spaces, failed governance around social welfare policies and engagement in precarious jobs that increase exposure to sudden events. Also, in urban areas, the ones inhabiting informal settlements, slums and other areas characterized by poor infrastructure tend to be the most in need with low coping capacity. Usually, informal settlements are occupied by individuals with no or little formal education, being engaged in low-income economic activities, having limited source of income and being a migrant, living in areas commonly with absence of public services such as freshwater and water supply systems, sewage services, energy availability and transportation (Abunyewah, Gajendran, Maund, 2018).

According to the Brazilian Institute of Geography and Statistics (IBGE) states that currently there are around 8 million people living in areas prone to risk of natural hazards such as floods, landslides, mudslides and other events related to climate and rainfall patterns in Brazil. The report adopts the definition of areas prone to risk of hazards as “the area likely to be affected by natural phenomena or processes that cause an adverse effect. The people who inhabit these areas are subject to damage to physical integrity, material and property losses” (IBGE, 2018). Most of this population inhabits large metropolitan areas and medium-sized cities.

In Latin American countries, rapid urbanization led to the replacement of low-skilled workers to automated processes, causing unemployment and informal housing in urban centers that were already very populous around the 1970s and 1980s. Rapid city expansion coupled with the lack of urban planning made quality housing unaffordable. The remotest and least

secure areas thus were occupied by poorer families making them vulnerable to external shocks such as environmental and climatic ones (Ojima, 2007). Vulnerability is defined according to the IPCC's 4th report (2007, p. 883) as "the degree of susceptibility of a system, and the inability to deal with adverse effects of climate change, including extreme climate variations". However, the impact of climate change is not distributed evenly across population subgroups and the capacity to adapt varies (Muttarak, Lutz and Jiang, 2015). Therefore, it is highly important to investigate demographically differentiated vulnerability in order to understand why some groups are more vulnerable than others. In the context of fast growing "urban Brazil", understanding demographic and socioeconomic heterogeneities in settlement patterns allows for identifying vulnerable subgroups of population including where they live and why some of them chose to leave the areas at risk and others do not.

While there exists abundant empirical literature focusing on whether and to what extent environmental/climate change drive migration (Borderon et al., 2019; Hoffmann et al., 2020), little emphasis is placed on understanding differential characteristics between those who moved, those who stayed in the areas prone to climate-related hazards and the general population. This question is highly relevant for urban policy planning. If vulnerable populations are likely to stay in the areas at risk, they may be somehow "trapped" in these regions and become part of the phenomenon of immobility in the face of increasing climate-related hazards due to climate change.

To this end, this study aims to: 1) explore whether people who live in areas at risk differ from the general population; and 2) identify who lives in areas at risk and who moved out using the case study of Belo Horizonte city. In Belo Horizonte, some peripheral areas are considered "areas at risk" for being prone to climate-related hazards such as floods, landslides, mudslides and others events associated with rainfall patterns. Around 390,000 people live in these areas at risk, that is equivalent to 16.5% of the city population. The city also has an urban policy responsible for the relocation of families living in areas prone to risk disaster since the 1990s. To date, more than 3,000 families were relocated on a temporary or permanent basis from areas at risk of disasters (PBH, 2016).

We hypothesize that some households are more vulnerable than others given its characteristics such as income, family composition, gender and marital status, determining where people live and affecting their vulnerability to climate-related hazards. This knowledge would be important for better planning of ex-ante disaster risk reduction, with consequent reduction of human damage in urban settlements, as well as for better targeting ex-post disaster relief. Therefore, the research question this paper aims to answer is:

" *How does the population in areas at risk of climate-related hazards differ from the relocated population and the general population in terms of demographic and socioeconomic characteristics?* "

The remainder of the paper is organized as follows: Section 2 discuss the theoretical approach adopted to understand vulnerability, disasters and their convergence in urban centers. Section 3 presents the case study, the city of Belo Horizonte in Brazil. Section 4 describes the sources of data and application of chosen methods. Section 5 concludes with outlines from our main results and suggestions for future studies.

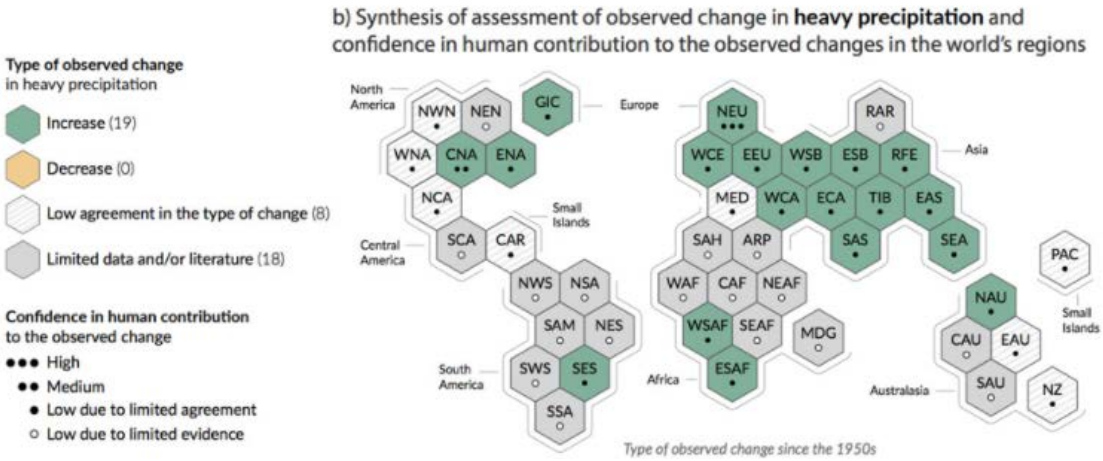
2 Disasters, Urban Centers and Vulnerability

2.1 Exposure of Urban Centers and Disasters

Extreme events can potentially be destructive in urban centers due to high population density, social and economic inequality, and lack of preparation and policies to enable adaptation. Climate change further exacerbates vulnerability of disadvantaged subgroups of population through increasing the frequency and intensity of climate-related hazards (Pelling, 2003). According to the trend in Brazil is that climate change increases frequency and intensity with which disasters happen. In particular, poorer communities would be more vulnerable to effects of these disasters mainly because of scarcity of material resources to deal with these phenomena and because they inhabit, in large part, areas at risk of extreme events with limited capacity for adaptation (Alvalá and Barbieri, 2017).

The new report from the Intergovernmental Panel on Climate Change (IPCC) raises awareness about the impact that humans have on climate change and how this is making extreme climatic events more intense and frequent. Figure 1 shows how climate change is affecting heavy precipitation occurrence throughout the world. Each hexagon denotes a region in the world, while the green color indicates an increase in the occurrence of heavy precipitation, yellow denotes a decrease since the 1950s. It is possible to see that the regions of Europe, South and North America, and Asia are experiencing an increase in the frequency of these kind of events (IPCC, 2021).

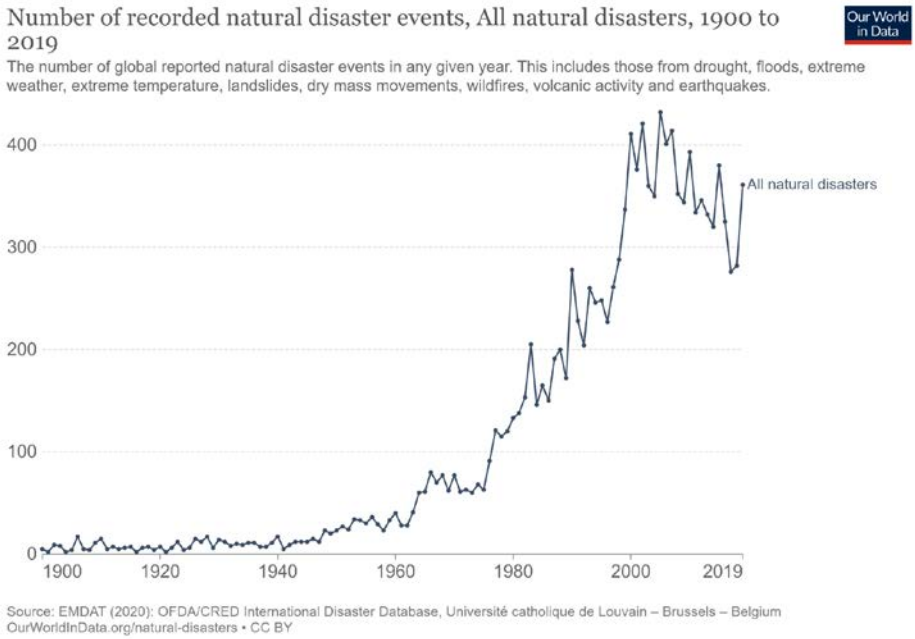
Figure 1 – Change in heavy precipitation patterns since 1950



Source: IPCC (2021, page 12)

Data from the Emergency Events Database (EM - DAT) of the Center for Research on the Epidemiology of Disasters (CRED) at the University of Louvain (Belgium) shows that between the 1980s and 2000s, the number of disasters increased considerably followed by an increase in their intensity, reaching around 450 disasters/year between the first and second decade of the 2000s. Figure 2 shows an increase in the number of global reported disaster events annually, such as floods, landslides, wildfires and extreme weather.

Figure 2 – Number of recorded disaster events from 1900 to 2019



Source: EMDAT (2020)/OurWorldInData.org

Gu (2019) points out that any solutions designed within the scope of the Sustainable Development Goals must have the reduction of environmental risks in urban centers as a key

element, as already in 2018, about 55% of the world population lived in urban areas, an increase in 43% when compared to the 1990s. By 2050, this figure is projected to reach almost 70% of the population living in urban areas.

Pelling (2003) argues that urban centers are epicenters of disasters due to crowding in unhealthy living spaces, poor governance of welfare policies, and precarious jobs that increase exposure to sudden events. Coastal cities further have the aggravating factor due to rising sea levels and population growth (Adger, Safra de Campos, Mortreux; 2018). If solutions aimed at safe housing, transport and, integration of the city around socially and environmentally sustainable goals are not outlined simultaneously in the near future, the consequences of climate change and its associated extreme events in these population agglomerates could be devastating (Pelling, 2003). In particular, public policies should be directed towards tackling vulnerabilities created politically and socially by our societies on a daily basis. This includes the occupation of areas at risks of climate-related hazards, the limited or no access to services such as sanitation, education, employment, safety, health and well-being and the neglect of specific population groups already marked by exclusion (Kelman, 2020).

Wisner (2004) states that besides the natural/geological approach of disaster studies, a social approach must also receive prominence. Vulnerability and exposure must be understood as core characteristics in populations and communities affected by extreme events, especially because these characteristics are part of economic and social patterns of households in areas prone to the risk of climate-related hazards. Understanding hazards as a social phenomenon, and how some individuals and households are more exposed than the others can help design and develop policies that help to minimize their ex-ante risks and ex-post impacts thereafter.

The posterior effects of sudden onset events are intrinsically related to vulnerability and exposure. Floods and landslides only become disasters when they occur in precariously inhabited regions. Disasters are therefore the result of social and political processes that happen over time, and which, in the context of climate change, tend to generate greater exposure to this type of events in communities that have long been neglected (Wisner, 2004; Kelman, 2019).

2.2 Who is Vulnerable? Differential Vulnerability to Extreme Events

It is therefore crucial to identify who is the most vulnerable. This section brings in vulnerability as a key element in understanding the mobility-environment nexus. The concept of vulnerability involves extensive discussions and approaches when it comes to populations

exposed to some type of risk or some prospect of loss. In broad terms, vulnerability involves a risk factor and potential loss due to a certain fragility (Cutter, 1996). In the context of climate change, what is defined as vulnerability is the fragile socioeconomic condition of households in areas defined as areas at risk of disasters. According to Brown (2008), an environmental event becomes a disaster when local communities are not able to implement measures to mitigate risks. The vulnerability of a population thus is directly related to its adaptive capacity, exposure, and level of readiness.

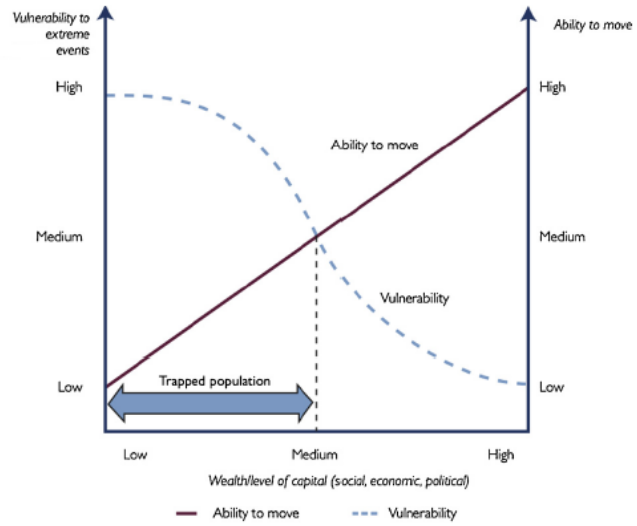
According to Cutter (1996), vulnerability is associated with pre-existing conditions which underlie a lack of responsiveness and severity of the consequences after the event. Some demographic profiles are more vulnerable than others when it comes to the impacts of climate change. The burden that comes with extreme events and its consequences are not equally distributed. Some are less vulnerable due to economic, social and demographic attributes which equip them with better tools to cope with and respond to risk and hazards (Muttarak et al, 2016).

This differential vulnerability between population subgroups is specified in studies such as that by Muttarak and Jiang (2016), where the presence of specific characteristics make some more or less vulnerable than the others. This influences susceptibility to climate-related hazards, ability to implement adaptation strategies and migration decision-making process. Demographic characteristics such as gender, education and family status characterize vulnerability. For example, evidence shows that those with more years of education are better prepared for the possibility of disasters and its consequences (Hoffmann & Muttarak, 2017; Muttarak & Lutz, 2014). Single-parent families and especially single-parent households with women as heads of household are more vulnerable to disasters than their peers compared to nuclear families (Flatø, Muttarak and Pelser, 2017). This is because disasters tend to reinforce the existing gender disparities, particularly those related to access to socioeconomic resources and social networks. Flavell, Melde, and Millan (2020) state that cultural aspects such as norms, beliefs, and values can also act on vulnerability, citing examples such as the cases of flood-related disasters in Bangladesh and Hurricane Mitch in the United States. For the former, women accounted for around 90% of deaths due to failure to communicate evacuation notices by men and the inability to leave home unaccompanied by their husbands. For the latter, men tend to have risky behaviors and may become more vulnerable when trying to help other people.

2.3 Climate-Induced Relocation as Urban Policy

Climate change is one of the major challenges for a society to provide cooperative and equitable responses. Alongside socioeconomic inequality, extreme events have been deteriorating livelihoods. In areas impacted by extreme events such as floods and debris-flows, migration is used as one adaptation strategy, mainly if predisposing conditions already deteriorated livelihood strategies (Hugo, 1996). However, some groups within the affected communities are unable to migrate due to lack of resources and low capacity to mobilize economic and social capital (Black et al 2013, Nawrotzki, De Waard, 2017).Without rapid and resilient mechanisms for adaptation and protection of vulnerable populations, climate-related hazards coupled with poor infrastructure and socioeconomic inequality, exacerbate disadvantages and can also potentially "trap" some of the most vulnerable in these areas at risk (Nawrotzki, De Waard, 2017).

Figure 3 – Vulnerability to extreme events and ability to move



Source: Black et al (2013)

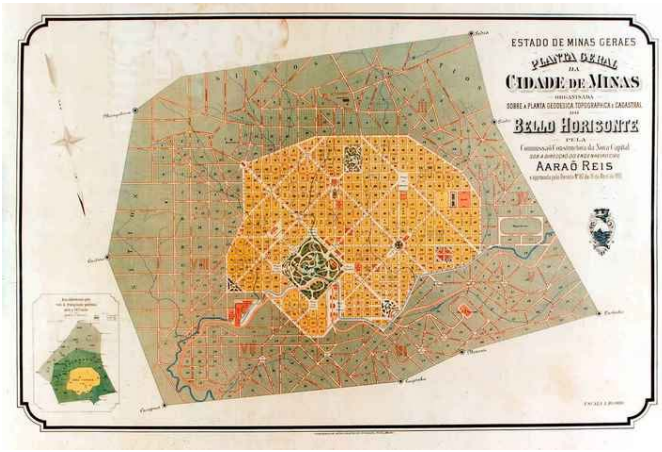
Relocation, resettlement, managed retreat and climate migration thus are one of the most pressing issues for national and international policy decisions (Ferris, 2014). Accordingly, planned relocation could be considered as one resource for those in need trapped in sites prone to disaster risk or exposed to hazards. In urban centers, usually informal settlements, slums, and villages are located in areas with low access to public services, safety, and infrastructure. The inhabitants in these areas, therefore, have fewer tools to ensure adaptation and compromised resilience in the face of a changing climate (Abunyewah, Gajendran, Maund 2018).

3 The Case of Belo Horizonte

3.1 About Belo Horizonte and its Disasters

During its foundation, in the first half of 20th century, Belo Horizonte's model of urbanization contributed for its main urban planning was locked in the city center, around Contorno Avenue as presented in figure 4. Infrastructure and investments in other areas of the city, especially peripherical areas were pretty much neglected. The social organization of the city was then focused on guarantee the well-being of a small social class that could afford to live in the center while the working class and the poorest moved to more distant areas (Monte Mór; Paula, 2001; Brito, 1996).

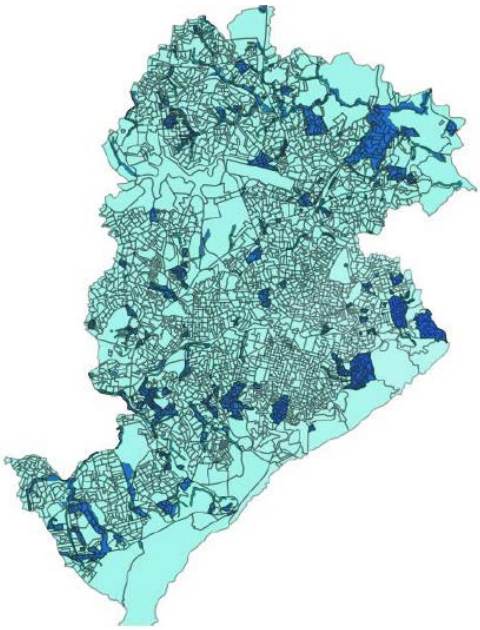
Figure 4 – First City Plan of Belo Horizonte (yellow part circulated by Contorno Avenue)



Source: Arquivo Público de Belo Horizonte

Belo Horizonte is marked by socioeconomic and geomorphological differences in its regions and neighborhoods, that accentuate the inequalities between these places. The south and southeast regions of the city contain the highest altitudes and the highest number of communities living in steep hillsides. Most of the economic and financial activities of the service sector are also concentrated in these regions. In addition, most of the census sectors that are classified as areas at risk are also concentrated in this part of the city as presented in Figure 5.

Figure 5 – Census Sectors (in light blue) and Areas at Risk (dark blue areas) in Belo Horizonte



Source: Own elaboration based on data from IBGE (2010, 2018)

Projected to have circa 200,000 inhabitants, today after 123 years after its foundation, Belo Horizonte has almost 2.4 million inhabitants according to data from the 2010 Brazilian Census (IBGE, 2010). As it can be seen in Figure 6, the city's urban sprawl rose considerably between 1918 and 2018, generating socioeconomic impacts such as gentrification, air pollution, increased traffic and the formation of informal settlements and slums. In the period between the 1950s to the 1970s, the city experienced extremely rapid population growth and the expansion occurred more intensely on the outskirts of the city (Monte Mór; Paula, 2001).

Figure 6 – Urban Sprawl of Belo Horizonte

Source: Belo Horizonte City Hall (2020)

Also, Belo Horizonte ranks as the 4th Brazilian city in an absolute number of people living in areas prone to disaster risk, accounting for around 390,000 thousand people, or 16.5% of its entire population (IBGE, 2018). Facing climate change and extreme events in such areas can be disastrous given the socioeconomic vulnerability already existing in those places. With the increase in the frequency of extreme events, measures are needed to provide adaptation options for these populations. The next section thus discusses the municipal relocation policy.

3.2 Resettlement as Urban Policy

Following the Hyogo and Sendai Frameworks, Belo Horizonte's Municipal Policy for Popular Housing has in its scope the Structural Program in Areas of Risk (PEAR). This program has, as the main objective, assisted families that live in areas prone to disaster risk such as landslides and floods. The policy is managed by the Belo Horizonte Urbanizing and Housing Company (URBEL).

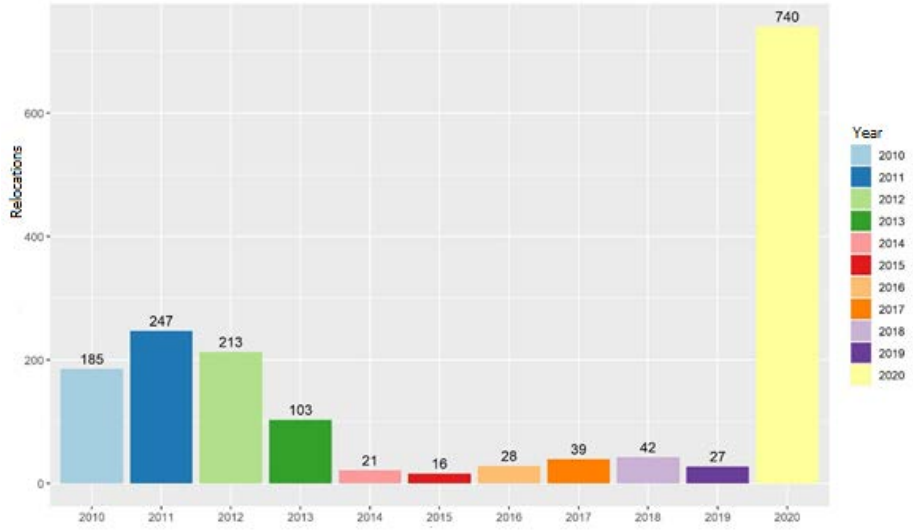
The objective of PEAR is to avoid accidents in residential areas located in spaces with hydrogeological risks that can be worsened due to heavy precipitation. The services provided by URBEL include: inspections, monitoring of risk, preventive and corrective works and, in some cases, relocations. The program also works through partnerships between the residents and URBEL through small-scale works with labor and resources from the residents themselves while the city hall provides only a technical supervision. The program also monitors rainfall levels in the city and passes it on to volunteers from its main assistance centers: the Civil Defense Nucleus Training (NUDEC) and the Rain Alert Nucleus Training (NAC). These assistance nuclei are composed by city hall agents and residents of areas at risk that volunteer to check each house and occurrence during a heavy rain or debris-flow rush. The contact between population and city hall made by the nuclei NAC and NUDEC is extremely important to make sure that this policy is available for those in need. During the rainy season, the program's activities include the dissemination of educational booklets, guidance on prevention and evacuation in case of disasters, and training with volunteers (PBH, 2020).

It is clear that the program has in its dynamic the involvement with the community and the action of the residents themselves as a factor that enables the relocation and assistance to vulnerable families. The inspections are made by city hall agents. The first step in the execution of the policy is carried out by the city government based on the request of residents or volunteers who work as "scouts" for signs of imminent hazards in risky regions. Then, contact

is made in the city hall with URBEL, and, according to the risk assessment, it is decided to renovate the house, relocate the family or carry out works of mitigation/elimination of risk.

According to City Hall data, between 2010 and 2020, almost 1,700 households were relocated through this policy due to risk of flash floods and debris-flow. Of these, 42.5% were removed permanently to other addresses and 57.5% were relocated temporarily. This means that the latter move back to their houses after a period of emergency relocation that lasts on average of about 3 months. As much as Urbel claims that households in high-risk situations have decreased over the years, it can be seen in Figure 5 that the number of removals decreased from 2011 but peaked due to the heavy rainfall and landslides of 2020.

Figure 5 – Yearly number of relocations in Belo Horizonte due to hydrogeological risk



Source: Belo Horizonte City Hall (2021)

4 Data, Methods and Results

4.1 Sources of Data

To answer the research question “How does the population in areas at risk of natural hazards differ from the relocated population and the general population in terms of demographic and other socioeconomic characteristics?”, two datasets are used. First, data from 2010 Brazilian Census; and second, municipal registers from temporary and permanent relocations made by Belo Horizonte’s City Hall between 2010 and 2020.

In a first step, descriptive statistics are used to describe the distribution of demographic and socioeconomic characteristics of specific population groups: 1) the population of the city of Belo Horizonte; 2) the population living in census tracts where relocations occurred due to the exposure to risk of environmental disasters i.e. areas at risk; and 3) the relocated population

which is further subdivided into two groups: the population that opted for permanent relocation and the one that opted for temporary relocation.

The comparison performed as a first step aims to verify how the subgroups differ from each other in terms of socioeconomic and demographic characteristics. For that purpose, only the characteristics that are compatible in all the datasets were selected. For this first comparison we extract from the relocation database only the relocations that occurred between 2010 and 2012 so this information would be comparable to Brazil's most recent census in 2010.

Data were prepared and analyzed using R through RStudio software.

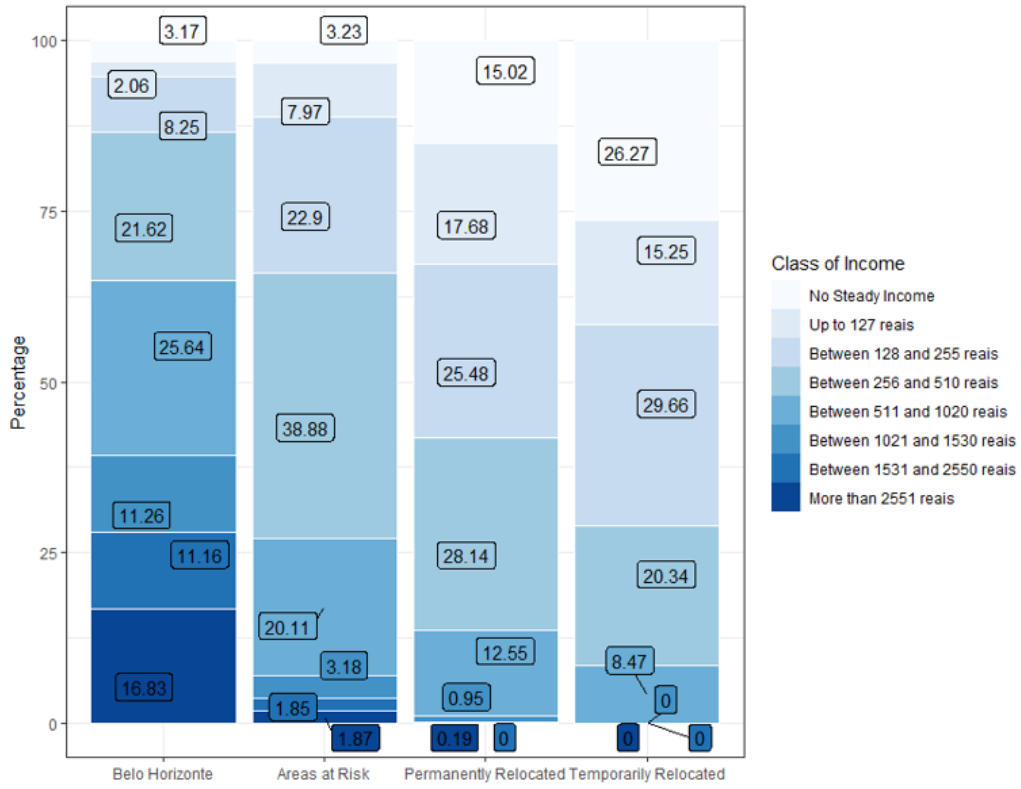
4.2 Descriptive Statistics

4.2.1 Income

The Income data contain monthly information on: household income per capita and, income by sex of the household head. All income information was deflated according 2020 level of the Brazilian currency, the Real. As shown in Figures 6, 7 and 8, the color shades represent levels of income the darker the color, higher the income level.

In figure 6, when comparing classes of monthly household income per capita, it is possible to see that the group with higher income (more than 2551 reais) comprises 16.83% of the city general population while they make up less than 2% of those living in areas at risk. This income group does not exist among the relocated population. Among the relocated both permanent and temporary, more than 50% of the households have less than 255 reais as monthly per capita income. The classes with higher levels of household income per capita ("Between 1021 and 1530 reais", "Between 1531 and 2550 reais" and "More than 2551 reais") are underrepresented among the population living in areas at risk and the resettled. Also, the group with no steady income comprise as much as15.02% among those permanently relocated and 26.27% among those temporarily relocated as compared to only 3% among the city population and those living in areas at risk.

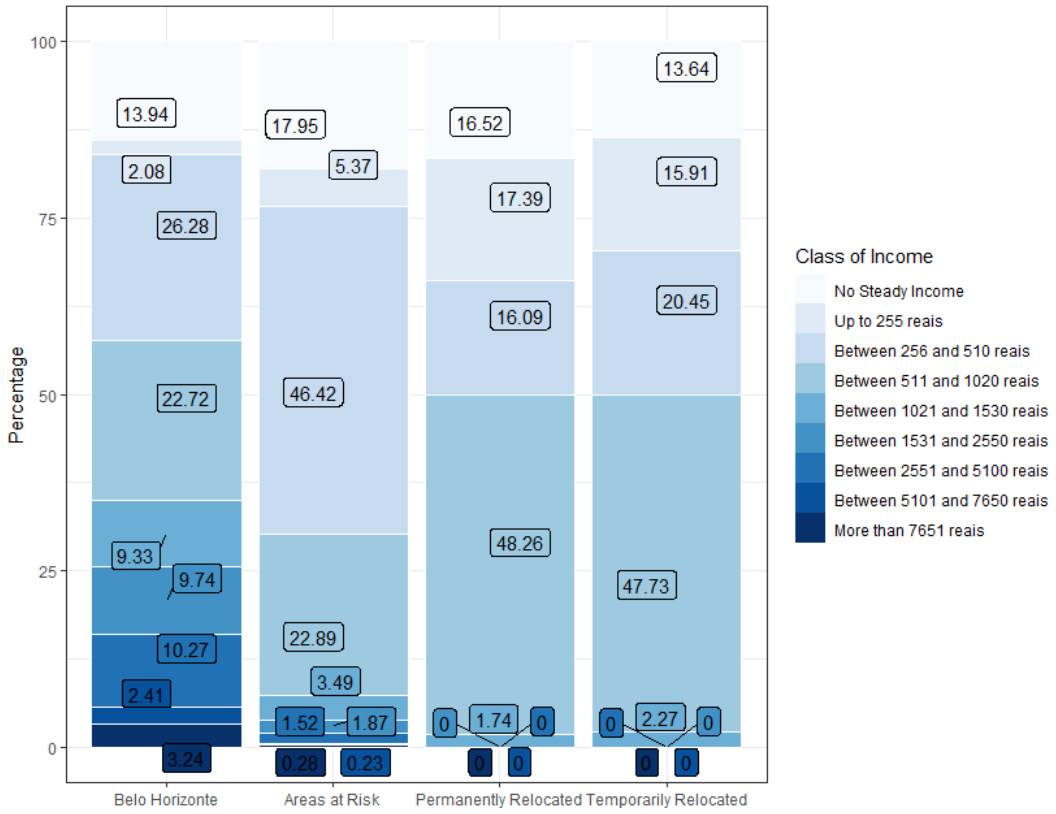
Figure 6 – Classes of Monthly Household Income per Capita



Source: IBGE (2010), Belo Horizonte City Hall (2020)

In figure 7 and 8, differences in income levels become starker when considering income distribution by gender of the household heads. In figure 7, we see that the majority of women heads of relocated households and those living in areas at risk belong to lower income groups when compared to the ones in the city general group. While the group with no steady income correspond to 13.94% in the general population of the city, in areas at risk that percentage goes up to 17.95% and among the relocated is at 16.52% in the permanently and 13.64% in the temporarily relocated group. The four highest income groups ("Between 1531 and 2550 reais", "Between 2551 reais and 5100 reais", "Between 5101 reais and 7650 reais" and "More than 7651 reais) make up 25.66% of the female-headed households in Belo Horizonte general population, but only 3.9% of those living in areas at risk. Among the relocated populations, these income groups do not exist.

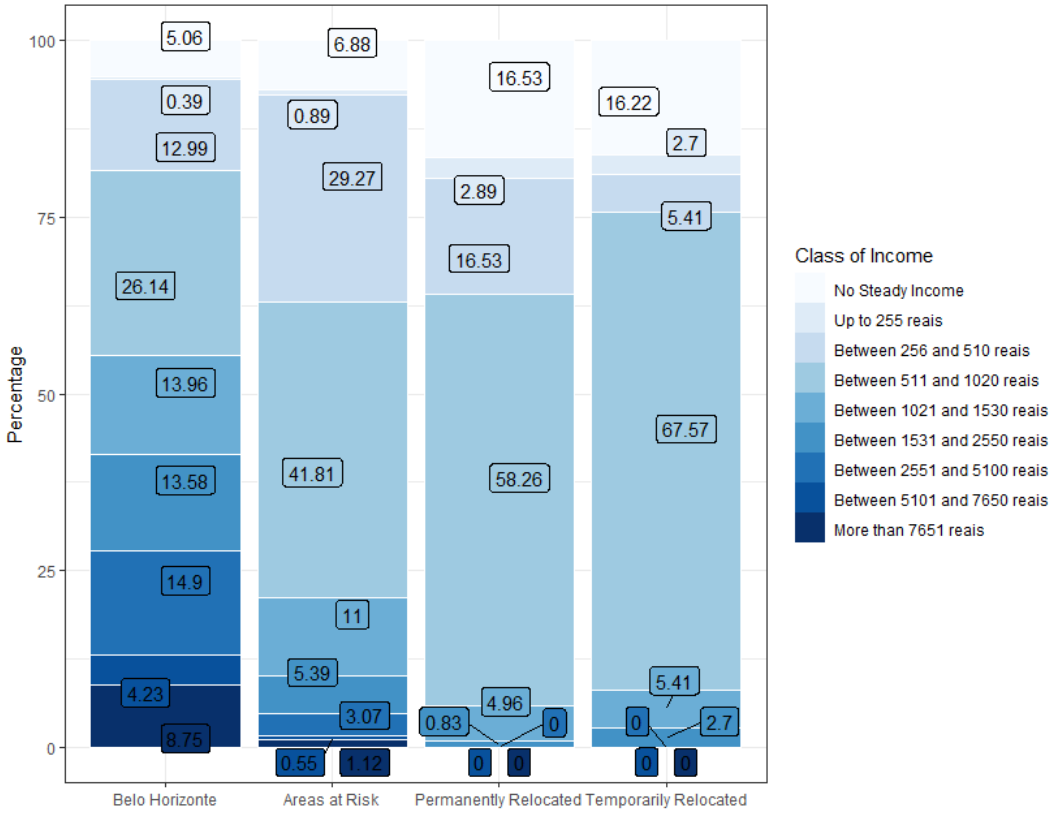
Figure 7 – Classes of income for female household heads



Source: IBGE (2010), Belo Horizonte City Hall (2020)

Similarly, among male-headed households, figure 8 shows that the majority of those living in areas at risk, permanently relocated and temporarily relocated are amongst the lower income groups. Once again, the highest income group ("More than 7651 reais") does not appear in these populations. The group of men with no steady income among the relocated population triples those of the general population, going from 5.06% in the city's general population to 16.53% and 16.22% among the permanently and temporarily relocated, respectively.

Figure 8 – Classes of income for male household heads



Source: IBGE (2010), Belo Horizonte City Hall (2020)

4.2.2 Color/Race

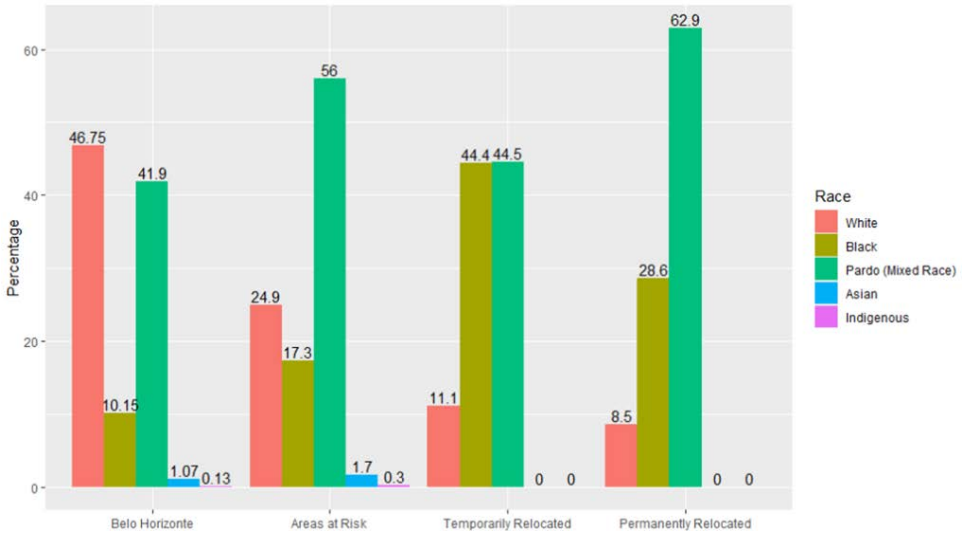
The Brazilian Institute of Geography and Statistics (IBGE) employs five categories for the race/color variable: Branco (White), Pardo (Brown/Mixed Race), Preto (Black), Amarelo (Yellow or of Asian Ancestry), and Indígena (Indigenous/Native People). For comparison purposes, the data from Belo Horizonte's self-declaration in the 2010 Census are used. In the city, 46.75% of the people declared themselves as White, 41.9% declared themselves as Brown or mixed race, 10.15% declared themselves as Black, 1.07% declared themselves as Yellow or of Asian ancestry and 0.13% declared themselves as indigenous (IBGE, 2010).

As it can be seen in Figure 9, the Pardo group constitutes the majority in areas at risk, with a total of 56% of the population according to the 2010 Brazilian census. Whites represent 24.9% of the population in these areas and 17. 3% declare themselves as Black. The Indigenous and Amarelo population groups account for the smallest share with 0.3% and 1.7%, respectively. Data from the relocated population show that Browns/Pardo comprise the largest group, 44.5% and 62.9% in the temporarily and permanently relocated population, respectively. Around 44.4%, declared themselves as Blacks in the temporary relocated group, and 28.6% among the permanent relocated group. Whites are minority in both of these groups,

with 11.1% and 8.5% in the temporary and permanent groups, respectively. There are no Yellow and Indigenous groups among the relocated populations.

It is evident that the racial/color distribution of the population of Belo Horizonte is totally different from the population living in areas at risk and among those that were relocated. While the majority of the city general population is White according to the 2010 census, in the areas at risk, on the other hand, most people identified themselves as Black and Brown. Among the resettled populations, the racial/color distribution resembles that of the risk areas.

Figure 9 – Color/Race profile by group of analysis



Source: IBGE (2010), PBH (2020)

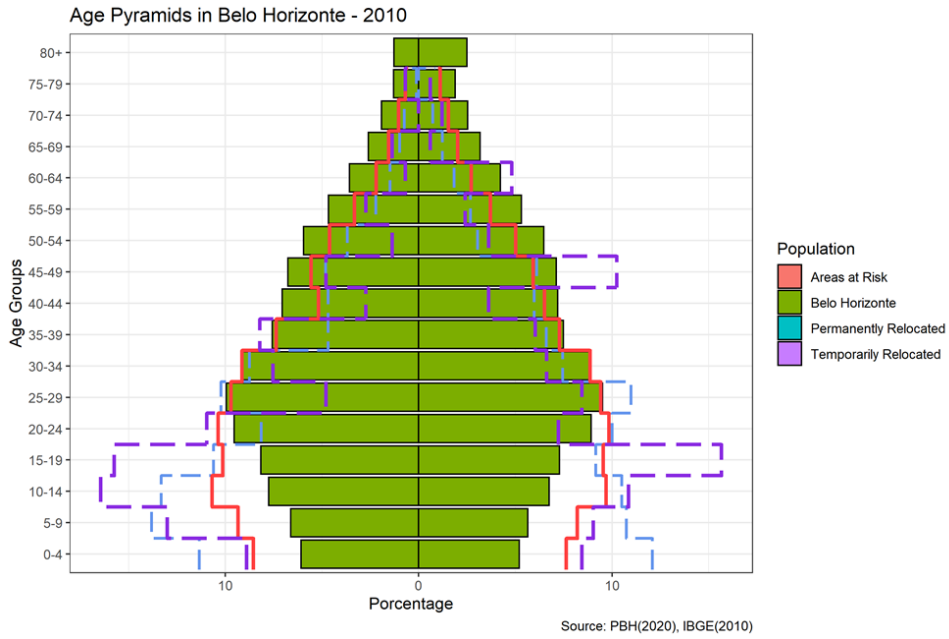
4.2.3 Age Pyramid

Data from the 2010 census register the number of people living in each census tract by age group. Based on this information, the number of people living in each census tract where relocations happened was quantified. Figure 10 shows: (1) in red, the age pyramid of the population in areas at risk in 2010, (2) in green, the age pyramid of the population of Belo Horizonte in 2010 (3) in blue, the age pyramid of the population that opted for permanent relocation and (4) in purple, the age pyramid of the population that was temporarily relocated between 2010 and 2012. For the first two groups, data was taken from the 2010 census, for the last two groups, data was taken from the municipal registers of relocations. In 2010 the age pyramid of Belo Horizonte showed a population that was going through a demographic transition with a thinner bottom which denotes the younger cohorts that are smaller than the ones aged between 20 and 39 years old.

It is evident that the population living in the areas at risk is younger than the general population of the city. The proportion in the younger age groups aged between 0 and 24 years

is larger in the areas at risk than in the city general population. On the other hand, the age groups between 35 to 80 years are larger in the general population. This shows that the population in the areas at risk are relatively younger than the population of Belo Horizonte. Also, data from the city hall, according to the blue and purple lines, reveal even larger proportions of the relocated population in the younger age groups, especially between 10 and 30 years of age.

Figure 10 – Age Pyramids by group of analysis



Source: IBGE (2010), PBH (2020)

4.2.4 Other characteristics

As shown in table 1, it seems that household size in the areas at risk and among relocated population is slightly higher than that of the general population. The average number of children in a household is also slightly lower for the latter.

The percentage of people aged over 65 years in a household is considerably lower for those living in the areas classified as at risk, and even lower among the resettled households, which is less than 3% compared to 8.7% among the city general population.

Generally, for all groups except for those who are temporarily relocated, most households are headed by men. For all groups analyzed, the majority of female household heads (between 64% to 79%) lives with no partner. Among the households headed by men, on the other hand, only around 22.9% to 29.67% live with no partner.

The literacy rates do not vary much either. While in the general population it is around 97%, in the areas at risk is 92.2% and among the relocated is 95.7% and 96.7%, in relocated temporarily and permanently, respectively.

With respect to income, the number of people living with no steady income is bigger among the relocated, almost 50%. The same is observed when we divide those groups by sex of household heads with almost 50% of male-headed households and 49% of female-headed households among those who relocated temporarily having no steady income and almost 45% and 43% of male-headed and female-headed households who relocated permanently, respectively are in this situation.

Table 1 - Differential demographic and socioeconomic characteristics by areas of residence

Variables	**Belo Horizonte (2010)**	**Areas at Risk (2010)**	**Relocated Permanently (2010 – 2012)**	**Relocated Temporarily (2010 – 2012)**
Average Number of Children per Household	1.09	1.4	1.54	1.36
Average Household Members	3.11	3.53	3.4	3.8
Percentage of People 65+	8.7%	4.7%	1.8%	2.3%
Percentage of Household Head by Sex	Male: 56.4% Female: 43.6%	Male: 54.26% Female:45.74%	Male: 51.26% Female: 48.73%	Male: 45.67% Female: 54.32%
Percentage of Household Head living without partners	Male: 22.9% Female: 70.6%	Male: 23.1% Female: 64.3%	Male: 29.67% Female: 63.72%	Male: 28.5% Female: 78.5%
Literacy Rate	97.12%	92.22%	96.7%	95.7%
Percentage of People with no Steady Income	26.5%	35.27%	43.65%	49.6%
Percentage of People with no Steady Income by Sex of household heads	Male: 21.7% Female: 31%	Male: 30% Female: 40.16%	Male: 44.97% Female: 42.40%	Male: 50% Female: 48.9%
Number of observations	762,136 households	50,254 households	576 households	945 households

Source: Elaborated by the author with data from IBGE (2010) and Belo Horizonte City Hall (2020)

4.3 Logistic Regression

The probability of choosing permanent or temporary relocation was estimated using a logistic regression. The outcome variable is the type of relocation that denotes 1 for permanent relocation and 0 for temporary relocation. Other variables such as the presence of children under 15 years old, presence of a partner and the presence of people over 65 years old, the income of household head and the number of days with heavy rain in the year before the relocation are expected to impact the choice for permanent or temporary relocation. Looking into vulnerability differentials by family composition, income and hazard measure could help understand how these characteristics determine the decision to opt for a permanent relocation and how they differ between those who relocated temporarily and permanently. The logistic regression models were also run including other characteristics: Color/Race, Sex and Education of the Household Head. However, I do not find any significant relationships between these variables and the probability of choosing a permanent relocation. Table 2 shows the description of the variables used in the regression.

Table 2 – Frequency Distribution of Selected Variables

Variable	**Description**	**Mean (Standard Deviation)**	**N=1,521 households**
Type of Relocation	Categorized into: 0 – Temporary and 1 – Permanent		62.2% are Temporary Relocation and 37.8% are Permanent Relocation
Does the household head have children under 15 years old?	Categorized into: 0 – No and 1 – Yes		74% does not have children under 15 years old, 26% have children under 15 years old
Does the household head live with a partner?	Categorized into: 0 – No and 1 – Yes		58.5% does not live with partner, 41.5% lives with partner
Does the household head live with elders?	Categorized into: 0 – No and 1 – Yes		96% does not live with elders, 4% lives with elders
Household Head Income	Categorized into: 0 – 100 reais 100 – 500 reais 500 – 1000 reais More than 1000 reais	787.23 reais (595.61 reais)	23.07% has 0 – 100 reais 11.4% has 100 – 500 reais 21.2% has 500 – 1000 reais 44% has more than 1000 reais
Heavy Rain Days (1 – T)	Categorized into tiers: 0-3 days, 3-7 days, 7-10 days, 10 days or more	6 days (4.5 days)	

Source: Elaborated by the author

Table 3 presents the effects of each of the variables on the predicted variable of choosing a permanent relocation. Living with a partner more than triples the chance of a head

of household opting for a permanent relocation compared to the one who lives alone. Living with an elderly person at home seems to have no statistically significant effect on the decision of permanent relocation.

For the households where there are children under the age of 15, the chance of opting for a permanent relocation is 5.76 times greater than a household with no children under that age. With respect to income, the reference category was the income group ranging from 0 to 100 reais. Households in the second income group (100 to 500 reais) is 2.387 times more likely to opt for a permanent relocation than the reference group. The third income group (500 to 1000 reais) is 5.44 times more likely to opt for permanent relocation as compared to the reference group. The income group with more than 1000 reais is 2.62 times more likely to opt for permanent relocation than the reference group.

The number of heavy rain days in the year prior to the relocation is used as a proxy for exposure to natural hazards which can deteriorate livelihoods and impact the decision for permanent or temporary relocation. According to the municipal registers from 2011 to 2020 the number of days with more than 30 mm of rain (heavy rainfall days) were summed and distributed according to each region of the city. According to Nunes, Pinto and Batista (2018), Belo Horizonte, in the last ten years, experienced a change in rainfall patterns i.e. the increase in: the number of heavy rain days, the number of consecutive wet days and the number of consecutive dry days. While the number of consecutive dry days have been increasing over the years, the number of heavy rain days and the volume/day of rainfalls in the city has also increased, indicating that the rain is becoming more concentrated in a minor number of days with heavier intensity. Compared to the reference category of 0 to 3 days, those who experienced 3 – 7 heavy rainfall days are two times more likely to choose a permanent relocation. For those who experienced 7 – 10 and over 10 heavy rainfall days, the probability of choosing a permanent relocation is 4 and 3 time that of the reference category, respectively. These results shows that exposure to heavy rainy days – a proxy for hazard exposure – can influence a decision to relocate.

Table 3 – Odds ratio estimate from logistic regression model predicting the probability of permanent relocation

Variables	**Odds ratio (p-value)**
Household Head lives with partner	
No	Reference
Yes	3.50***(3.08e-07)

Household Head lives with elders	
No	Reference
Yes	2.15(0.0905)
Household Head lives with children	
No	Reference
Yes	5.76***(4.56e-12)
Income Level of Household Head	
0 up to 100 reais	Reference
100 up to 500 reais	2.387*(0.023)
500 up to 1000 reais	5.44***(3.13e-08)
More than 1000 reais	2.62***(0.00038)
Tiers of Heavy Rain days (1-T)	
0 – 3 days	Reference
3 – 7 days	2.07* (0.01301)
7 – 10 days	3.905*** (1.38e-06)
More than 10 days	3.056*** (0.00024)

Notes: *p<0.1; **p<0.05; ***p<0.01

Source: Elaborated by the author

5 Conclusions

We find that the population in areas at risk have a lower income than the population of the city in general. The difference is also notable when we compare groups temporarily and permanently relocated, with the first ones having the lowest income. Also, different from the city general population that is in majority white, people from areas at risk belong to minority ethnic groups such as Pardo and Black.

We show that family composition plays an important role among the ones that live in areas at risk of disasters and a type of relocation. Having children and a partner in the household increase the chances of choosing permanent relocation. According to the census data, almost 65% of female headed-household in areas at risk live with no partner. This implies that female headed households are disproportionately less likely to relocate permanently and hence relocation policy may further exacerbate their vulnerability.

On the one hand, we find that households with a higher level of income in areas at risk tend to be relocated permanently by the municipal policy. On the other hand, the ones with lower income are more likely to return to a situation of exposure to climate-related hazards. This combined with a pre-existing socioeconomic disadvantage results in "trapped" population groups in areas prone to disaster risk. Based on this finding, we highlight that it is vital to further investigate why vulnerability subgroups of population opted for temporary relocation only and design a policy that tackle such disadvantages.

Our findings suggest that the population in the areas at risk and relocated seem to belong to social minorities such as being in an ethnic minority group i.e. comprising Black and Pardo populations with a low level of income. Among those who are relocated, the ones that left the areas at risk permanently seem to be less vulnerable, due to higher level of income and other characteristics e.g. living with a partner that apparently increase the probability of leaving permanently the areas at risk. Those who choose temporary relocation, on the other hand, count as more than 60% of the relocations and being temporarily relocated means that these families will return to the areas at risk and potentially become exposed to natural hazards as seen in the flood events in 2020. These results can serve as an input for urban policies to be better delineated for these specific groups that are more vulnerable and tend to be “trapped” in the areas at risk.

For future research, it is important to understand why these differences exist between those groups, why people do not relocate permanently and how other variables such as time of residence in areas at risk and risk perception can play a part in the decision-making process of

leaving the areas at risk. It may also be useful to understand what can be proposed to policy-makers to design a policy that focus on specific vulnerable subgroups with particular sociodemographic characteristics, and do not leave the vulnerable ones behind.

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