Contents

Flood Vulnerability of the Peruvian Coast

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Abstract

In the context of the climate crisis, the increase in the frequency of extreme climatic conditions and catastrophic events are raising concerns. In Peru, coastal populations are submitted to both ENSO and climate change stress which increases future *huaycos* and floods events enhancing their vulnerability facing natural hazard. Assessing vulnerability is crucial to build policies that will aim to support and protect the population at more risk. Moreover, adverse effects of climate disaster will not be proportionally distributed throughout the population. The recover capacity of marginalized and low income communities place them at greater danger when facing flood events. Hence, we will be focusing on the social, economical and institutional dimension of vulnerability using the more accurate methods used in the literature: the Flood Vulnerability Index composite [1] and the SoVI Index [2]. Finally, we will display a vulnerability map and compare the results between the two methods.

Keywords: Flood, Vulnerability, Climate hazard, Risk

1 Introduction

ENSO-induced flooding is becoming a bigger threat to the coastal population of Peru. The ENFEN report announced that the 2017 event affected the regions of Tumbes, Piura, Lambayeque, La Libertad, Ancash, Lima and Ica due to river overflow and extreme rainfall. Other major EL Niño events, with bigger impacts per capita, took place in 1982-1983 and in 1997-1998 [3]. A flood, according to the World Health

Organisation can be induced "by heavy rainfall, snowmelt or a storm surge from a tropical cyclone or tsunami in coastal areas". In the Peruvian context, the 2017 Niño event was characterized by intensive rain in the coastal area that led to an increase in the magnitude of the river overflow, leaving behind a large social and economic impact. In Peru, the common term to refer to this type of climate phenomena is huaycos, a notion that is defined by extreme rain, landslides or mudslides and flood events. The magnitude of all climate phenomena, including huaycos, is intensified by both ENSO and global warming. Flood risk is expected to double by 2050 under the unabated greenhouse emission scenario [4].

Due to global warming, events such as El Niño are expected to intensify [5]. ENSO's frequency of prompting climatic catastrophic events such as heavy rainfall, droughts in the Amazon forest, glacier instability, and retreat can extend the population's risk and exposure to natural hazards [6],[7]. The increase in the frequency of heavy rainfall naturally leads to an exacerbation of flood risk in the Andean area but mainly in coastal areas. Due to these abrupt events, many shocks are expected to hit the economic, health, social, and housing systems, and academic evidence shows that low-income classes are more exposed to flood risk, accentuating their vulnerability to climate change outcomes [8],[9],[10]. Hence, to properly assess the socio-economic inequalities of the country, we need to assess the social vulnerability of low-income populations to climate disasters such as floods. An impact evaluation of floods can influence economic and political decisions to address the risk assessment of natural hazards.

Even though there is a lot of research on the forecasting of the ENSO climate phenomena [11], physical impacts cannot be predicted. Recent research in the modeling field aims to model some possible outcomes following a glacial lake outburst flood [12], or to estimate flooded areas [13],[14] using satellite data. Yet, effects are scattered throughout the whole system, making social and economic outcomes unpredictable. According to the Peruvian Central Bank, climate change is going to cause a loss of 20,2% to 23,4% of 2050's potential GDP [15]. Therefore, there is a major interest in focusing on the exposed populations and studying the socioeconomic factors that influence their exposure. Moreover, we will be analyzing their economic resilience post-disaster and search for ways in which we could mitigate these impacts. In the academic literature, vulnerability to climate change is defined as 'the degree of exposure to natural hazards and the capacity to prepare for and recover from any negative impacts' [16]. Vulnerability is composed of both exposure and resilience to natural hazard disasters in the unabated greenhouse emission context[17].

Furthermore, in the particular context of the climate crisis, it is crucial to anticipate future effects and prepare for upcoming increases in the frequency of climate stresses to minimize losses and damages. To do so, we need to breach the existing gaps and reduce the vulnerability of exposed populations to natural hazards to ensure environmental justice [18]. Overall, in the academic literature, we find more evidence of climate migration, due to a temperature rise [19], an increase in droughts [20], and climate change phenomena [21]. As a consequence, rich households will migrate to low-risk areas [22] accentuating the vulnerability of low-income households that are themselves in an already precarious environment [23]. Hence, most studies insist on the integration of socioeconomic factors into the evaluation of climate vulnerability [2], [24], [25]. Thus, this article aims to show a broad perspective of the vulnerabilities considering all of the dimensions involved: the physical, but also the social and economic ones.

2 Focus on Peruvian Coastal area

Scientific academic literature concerning climate change phenomena has been recently proliferating. Evidence concerning the increasing frequency of disaster hazards [26],[27],[5] has been developed to alert about climate variations and the possible rise of exposed populations. Countries with greater income disparities also face greater human impacts of environmental disasters. Developed countries report greater economic losses compared to developing countries when facing natural disaster. However, when dealing with human impact, less developed countries will suffer more fatalities and their livelihoods will be disrupted [28]. In the case of Peru, the PAHO identified 91 deaths, 122 788 victims and 797 789 affected post ENSO phenomena. In the global South, urban poor citizens are more exposed to environmental disasters as they tend to live under lower housing conditions [29].

The focus of our study is the coastal area since according to the INDECI report, 60% of the houses affected by climate emergencies in 2017 were located on Peru's coast. These emergencies were mostly characterized by *huaycos* and extreme rainfall. Academic evidence often studies the impact of climate change in rural areas due to the massive impact it has on agriculture. Yet, little attention has been given to urban areas even though "cities are characterized by interlinkages of various processes and flows" [30] meaning any disruption can easily spread throughout the whole country. Yet, many prefer to prioritize studies in rural areas because rural residents suffer more from climate variability due to their low income and high dependency on farming or fishing activities [2]. In this context, focusing on the cities of the coastal areas is key to understanding the spread of disruptions across the system. Hence, in the case of Peru, poor and marginalized communities have a disproportionate risk of disruption in their livelihoods due to an accumulation of poverty and inequity traps [18]. Many articles have identified informal settlements as a factor accentuating exposure, susceptibility and lack of resilience. Informal tenure has limited the access of households to credit lines and insurance [31] restricting their resilience adaptation and coping capacity. Moreover, informal constructions do not verify the basic regulations of a safe structure, as materials lack resistance to external shocks. According to the Peruvian Chamber of Construction (Capeco), 80% of the housing infrastructure is informal. Cities with unplanned and informal settlements in low and middle-income nations experience rapid growth in vulnerability and exposure [32]. Overall, the exposure and vulnerability to climate change impact have been rising in cities with unplanned and informal settlements, particularly in low and middle-income countries. The vulnerability of highly urbanized cities such as Lima, is alarming due to its high level of informality and "self-built space" because the institutional development does not match with the economic development the city is facing [33]. Populations living under these conditions have to overcome more challenges to access energy [34], drinkable water at a comfortable price ([35], housing [36], and health facilities. The PAHO identified 48 687 houses as being victims of the 2017 event. Moreover, according to their estimates, 14 674 houses were found to be inhabitable and 14 661 collapsed. This event was classified by the ENFEN report as the third most intense phenomenon in the last 100 years, hitting historical records. Given the previous statement, we hypothesize that we can use the information of the reports of the 2017 event to form an idea of the type of impacts we should expect for upcoming El Nino events. Hence, we hypothesize that there is a higher degree of exposure, susceptibility, and lack of resilience to climate hazards for informally settled households due to the materials used, the lack of housing regulations, and the topography of the area.

To comprehend why these populations suffer from the aggravation of these factors, we have to study the perception of risk, the social construction of risk, and the more recent phenomena of migration and gentrification. Some academics raise their concerns about the lack of governments not making a priority of knowledge-building regarding potential disasters, [37], often delegating disaster management risk to low-capacity institutions [18]. The social psychology research indicates that when people are often exposed to risk, they normalize it afterward [38]. As a consequence, people are less willing to evacuate and later be relocated post-disaster. Also, there is a cultural dimension to consider, people tend to consider that these rare events are unavoidable and the only solution left is to "accept its fate" [39], an aspect that increases their vulnerability. Many other barriers could obstruct a possible evacuation such as financial assets, gender vulnerabilities, cultural beliefs, and a place attachment [40]. Risk tolerance is shaped both by social structures and norms as well as by individual processes. So, even though relocation could be considered as an option, many obstacles exist in the current situation.

In the Peruvian floods context, coastal urban cities led to rapid geographic expansion of the population towards the "Cerros" in the absence of formal planning [36]. The housing deficit is estimated at 40,9% according to the Ministry of Housing (2003). The increase in the population is explained by rural migration induced by a pursuit of low-income households towards higher incomes and access to some basic needs such as electricity or drinkable water [41]. Hence, low-income migrants occupy the areas at greater exposure without being aware of the risk of landslides. This vertical expansion is not only fueled by the lack of housing policies [42], since informal land occupation is the poor's housing policy, but also by spontaneous actions from local authorities that will for example help the construction of steep stairs that will allow the access to the higher and more exposed areas, increasing the risk. As a consequence, newcomers occupying upper areas live in more precarious situations since geographic isolation is an obstacle to acquiring drinkable water. In fact, the higher house occupation rises in altitude, the higher is the potential collapse for all the infrastructure located beneath them. This last point highlights the lack of resilience of these communities after a possible collapse.

The event of El Niño 2017 hit a rainfall record of 258,5mm per day reporting "extreme rain", and "very strong rain" in many departments, setting a state of emergency in 13 out of the 24 departments. According to the INDECI, El Niño left 1,782 316 people affected and injured. Coastal departments such as Piura, Lambayeque, Tumbes, and La Libertad were hardly hit by abundant floods leading to the destruction of housing infrastructure, roads, agricultural parcels, and educational and health institutions. ENFE's report states that in the region of Piura, 27 000 water's access was affected post disaster. The production in Piura of drinkable water was suspended due to high turbidity. The 2017 event of El Niño has been previously studied by academics, using different angles and approaches. In the hydrology and geography sphere, the areas under risk have been detected through satellite images [14].

In the economic sphere, most of the evidence has used the percentage of GDP loss to evaluate the macroeconomic impact [3],[9]. Some have estimated losses from the events of El Niño de 1997 and 1998 [43] at 800 million dollars, which represents a loss of 14,8% of GDP. All the literature suggests that previous events were more economically devastating than the more recent events of El Niño. Concerning the event of 2017, there is an estimate of 1.5 percentage points of 2017 GDP growth loss [9]. Other estimations point toward 211,000 million dollars of loss in GDP using the MDDA approach [3]. In addition, the PAHO report estimates that the impact of ENSO on GDP growth is -0.5%, 80% of this loss is explained by coastal loss of houses and roads. Despite the economic growth of the country, some populations are still very vulnerable to environmental disasters due to the lack of housing infrastructure and social development [44]. However, some dimensions will be excluded from a GDP economic analysis. The most significant impact is suffered by women who are lacking income diversification. A higher education will also lead to a lower vulnerability. Hence, "unskilled" women will be more harmed when facing climate change phenomena [45]. Therefore, we consider that micro-scale observation is more pertinent to capture all the effects of economic vulnerability. In other words, we cannot assess the socio-economic vulnerability without considering the existing socio-economic inequalities. These gaps inevitably lead to low socio-ecological resilience [46]. Therefore, in order to correctly assess it, we need to consider the intersectional aspect for upcoming politics. In conclusion, it is crucial to use a multidisciplinary approach to assess environmental risk [10].

In addition, we will also be addressing the institutional structure in charge of flood risk management to detect possible deficiencies. The Peruvian literature offers us an overview of the lack of institutional capacities to assess risk related floods (OXFAM 2015) [47]. Yet, we only possess the data on the trust of Peruvian citizens towards the Institutions. Therefore, we will be adding this data to measure the institutional trust of citizens. We hypothesize that a lower institutional trust will lead to a higher vulnerability.

3 Academic Literature

3.1 The MOVE framework

To analyze vulnerability authors have used the MOVE Framework [48][49][50] [51][52][53]. The MOVE framework is a multi-dimensional and holistic framework for assessing vulnerability that relies on three key factors which are: exposure, susceptibility, and resilience. We will consider exposure as the extent to which a unit of assessment falls within the geographical range of a hazard event. Also, susceptibility characterizes the predisposition of elements at risk of suffering harm. Furthermore, we will be describing resilience as the capacity of societies, communities, or individuals to deal with adverse consequences and the impact of hazard events. The notion of resilience is composed of two core components: coping and adaptation. The MOVE framework encompasses multiple dimensions of vulnerability such as the social, economic, physical, cultural [54], environmental [55], and institutional. For instance, each dimension will address different aspects that will in most cases be inter correlated. The social dimension will highlight the characteristics that could potentially jeopardize human well-being after the disruption. The economic dimension will focus on the damage cost such as the losses in the productive capacity or the capital assets. Finally, institutional vulnerability can be defined as the potential for damage to governance systems, organizational form, and function. For this case, we will be analyzing both the social, economical and institutional dimensions with a certain priority. Other dimensions such as the cultural and environmental, aim to observe the intangible values of culture and nature. We do not neglect the importance of these other dimensions, however these remain harder to observe given the data we possess.

There are many other options when it comes to vulnerability analysis and other existing frameworks such as the DROP Model [56], which introduces depth to the concept of resilience and recovery, the BBC framework [50]which is a holistic framework similar to the MOVE framework that links the sustainability concept to the assessment of the disaster [57]. Addressing vulnerability has emerged among disciplines such as geography, and disaster risk, however, given the increase in the frequency of disastrous natural events due to the unabated greenhouse gas emissions, this issue is also addressed by the field of climate change science. For this particular case, we have chosen the MOVE framework because it is more adapted to the focus we want to give to the socio-economic dimension without neglecting the importance of the other dimensions. Hence, we will be creating an index for social, economical and institutional dimensions to quantify the vulnerability without neglecting the risk perception.

3.2 Index

To measure vulnerability, authors use and develop various indexes. Other indexes used in similar contexts such as the Disaster Risk Index (DRI) used focuses on the lethal aspect and the economic loss through the measure of the GDP, the Natural Disaster Hotspots global risk analysis, the Disaster Deficit Index (DDI) that evaluates the financial exposure to disaster and the recovery, the World Risk Index (WRI) that aims to describe "the complex interplay between exposition and physical as well as social vulnerability in a simplified indicator-based way [16]" and its used on a country's scale and for multiple types of natural hazard. The Global Risk Analysis (GRA) studies 6 types of hazard geography (United Nations 2011), the Risk Management Index (RMI) [58], as well as many others. Even though these tools have contributed to the expansion of the natural disaster risk literature, their flaws, and their strengths have also been signaled [16],[52]. Other indexes have been more recently developed as The Australian Natural Disaster Resilience Index (ANDRI), in which authors take a top-down approach using a hierarchical design based on coping and adaptive capacities representing the potential for disaster resilience [59]. In addition, we have the Community-Based Disaster Risk Index (CBDRI) which can be employed in cases where resources are managed by the community[60].

For statistical analysis, many techniques have been deployed to establish the correlations and the weights of each dimension. This first step aims to establish all the possible correlations that could exist to create our index per component. Then, we examine possible biases such as the omitted variable bias or the reverse causality bias, cases in which we should investigate possible instruments that could help us correct the bias. In the context of our study, we will be facing these types of biases due to the multiple correlations existing between social and economic factors. To cite an example, a woman who has not received a high education, due to her social conditions as a woman, may also be restricted to income diversification, amplifying her vulnerability when facing natural hazards. Hence, we should consider that many biases will arise in our study and that we will have to correct each one of them.

The statistical tests that have been run when working within the MOVE framework vary a lot from paper to paper. For instance, some have implemented the LCA (Latent Class Analysis) often used when a lot of the factors are related to one another, was used in the first place to identify the exposed groups, and then determine their characteristics [61].Others have implemented uni variate analysis (UA), in which we display histograms to study the population's characteristics followed by multiple correspondence analysis (MCA) and hierarchical agglomerate clustering (HCA) [62]. The SoVI index uses as a first step the Principal Component Analysis (PCA) applied mostly in cases in which each factor observed is correlated to another one, amplifying the total effect [63]. Yet, the main literature observing vulnerability tends to use the FVI index [62], [64],[65],[66],[67],[68],[69] an index that uses a formula that contains exposure, resilience and susceptibility [1][70].

3.2.1 Physical factors

In the academic literature, different disciplines use different tools to assess vulnerability. In the hydrology and climate field, vulnerability is assessed through computer models, satellite imagery, comparative techniques [14],[71], [72],[73],[74] to identify the areas exposed to the flood events. Others address vulnerability using the Flood Vulnerability Index (FVI) [75], [76] which relies mainly on physical and hydro logical parameters. In addition, others use forecasting and a prospective approach [77]. However, risk models have many limitations [78] because the information alone is not directly translated into actions or measures and neglects the importance of the social structure. A perfect example is that according to OXFAM, an earthquake of magnitude 8 may cause the death of 80 000 people in Lima whereas in Santiago de Chile it could cause the death of 200 people. This example emphasizes the attention on household infrastructure and local institutions. Many articles point out that vulnerability can only be assessed by changing social systems and infrastructures [79]. Furthermore, recent models focus on specific cases such as the pluvial flood or the coastal flood [80] using indexes such as the Coastal City Flood Vulnerability Index (CCFVI) [1][70] that integrate social, economical and ecological dimension.

3.2.2 Social factors

Focusing on the social dimension of vulnerability, most research papers use the SoVI Index (Social Vulnerability Index) [2],[56],[81]. Hence, many factors that could have contributed to the social vulnerability facing natural hazards have been identified such as age [82] , family structure, education, population growth, occupation, renters, infrastructure, employment loss, commercial and industrial development, social dependence, medical services, race and ethnicity, socioeconomic status, and gender [2]. Also, the PCA (Principal Component Analysis) method deployed retains the most important variables and expresses the information as a set of principal components that will describe the characteristics of each group. Furthermore, it provides us with a spatial and visual analysis through the QGIS program [83]. The SoVI index has been used to analyze vulnerability facing natural hazards in Italy [63], Colombia [84], Indonesia [85], , and the United States of America [56].

Within the social dimension, some academics include the evaluation of the impact on health. In the current context of our study, we will be including the health dimension within the social dimension of our analysis. Still, we have to consider that the link between environmental factors and health outcomes is complex and difficult to establish [86]. The report of the PAHO and the World Health Organization declared that in the event of 2017, many health establishments remained not operational, some even lost a lot of equipment. The MINSA reported that 22,94% of the health establishments located in the emergency areas were affected. According to the existing literature, flood-exposed populations, due to their economics and social vulnerability, do not have proper access to sanitation, which exacerbates the risk of flood-related infectious diseases [87]. Due to the lack of water facilities, defecation will accumulate in open space [88], experiencing a higher risk of fecal contamination through floods [89]. Another risk prominently rising is dengue fever, the PAHO reported dengue outbreak in 82 districts constituting for a total of 280 cases and 1000 probable cases. Yet, little academic literature has been developed on the subject. Researchers suggest creating flood-tolerant health facilities where electricity power and water sources will not be interrupted. Furthermore, authors suggest that we need to address mental health effects post-disaster [90].

3.2.3 Economic factors

To estimate the economic damage or loss post-disaster, academics may use different tools such as the percentage loss of GDP and GNP growth [9],[91], micro scale methods to evaluate local economic activity [92], exposure at default [93], the impact on lot prices [94] or some indexes such as the Integrate Economic Vulnerability Index (IEVI) [95]. In other cases, credit and debit card transactions have been used to detect consumption behavior [96]. However, we argue that the GDP or the credit and debit card transactions do not capture the entire impact floods have on economic activities. Since our dataset provided us with some micro-scale information on each household's income, income's perception, savings, access to loans, access to retirement pensions, and employment status, food expenses, we decided to include all of these factors in our analysis to capture the economic impact of floods on each household.

3.2.4 Institutional factors

Institutions should serve as a support to communities to absorb the risk facing natural hazard. Nevertheless, in countries that have a low institutional capacity and trust, communities will be facing negative impacts on their own. These communities will be more exposed to flood and will be less able to recover since their institutional protection is precarious. Also, a low institutional trust influences the evacuation decision, if citizens do not feel fully supported by institutions, they will be less willing to evacuate or relocate their home [97]. In our study, we are not only dealing with institutional trust but also with how familiar citizens are with the institutions, so we will be evaluating if people have or not an identity card or a birth certificate or if they participate in the informal labor force. Given the political and social context of Peru, institutional trust is becoming a more important issue due to the heavy government repression of the past years. To provide some short context on the situation, the United Nations identified more than 60 victims and recognized the "excessive and disproportionate" use of force from Peru's government during the protests of December 2022. This event, along with the political instability that has been dominating Peru over the past years, raises the interest to take institutional trust into consideration.

4 Data and variables

For this paper, we will be using two of the most judged accurate and rigorous methods to examine flood vulnerability at a micro-scale. The first method we will be using is the FVI index, which is going to be based on the MOVE framework to analyze and classify the social, economic, and institutional dimensions of vulnerability using also the axis of exposure, susceptibility and resilience. The second method we will use is the SoVI Index that uses PCA as their analytical method.

For this study, we will be using the ENAHO survey and the INDECI dataset on reported damages from the 2023 El Niño event. Our goal is to study the vulnerability of the population using the most recent datasets that were provided.

According to Birkmann, exposure describes the extent to which a unit of assessment falls within the geographical range of a hazard event. It encompasses the physical aspect of social structure because it is often measured with spatial and temporal units. On the other hand, we will consider that susceptibility is independent from exposure. A person can be exposed to a danger without being fragile or susceptible to harm. When describing the susceptibility, we are examining the existing conditions an exposed community possesses in common. Hence, we do the inventory of the factors that could cause them harm. Finally, we will be considering resilience as the capacity to cope and recover from the shock.

4.1 Social dimension

For our first selection in the social dimension, we considered that the materials of construction will indicate to us the physical resistance of the infrastructure to floods and extreme rainfall. The variables retained were the condition of the street in which the house is located, for example if the street was not paved then the house is at greater exposure. In addition we used the INEI indicator of the condition of the dwelling. The first condition verifies that the house is adequate, the second condition verifies if the house is located in an overcrowded space, and the third indicates the presence of toilets.

On the susceptibility axis, we consider that some pre-existing conditions will accentuate the vulnerability of some individuals. For instance, women, children and retirees will spend more time in the house, increasing their exposure time [45]. Therefore, we consider both age and sex as a factor of vulnerability. Disabled people could find more difficulties to evacuate and exit their home in time. Moreover, families with a large number of dependents or with a single parent have limited finances affecting their resilience [2]. The migrant condition also accentuates the social and economical instability leading to the patterns explained in the exposure paragraph. Furthermore, we will be considering race and ethnicity as well as a migrant condition since in most cases these two categories are going to be linked. For instance, rural migrants face more racism hence restraining their job opportunities. On top of that, the level of education received and the level of literacy, lower among Quechua-speakers and women, accentuates their marginalization in the labor force and within social circles [45]. So, we will consider that people whose mother tongue is not Spanish, but a native language, are more vulnerable. More educated people also attain higher salaries, increasing disparities between educated and uneducated populations [2]. Also, the education of both the parents will influence the level of education of their children, so we consider these factors as well. We considered some factors as the house condition 4, established by the INEI which indicates if the kids from the household assist at school. Furthermore, we also included some variables that portrayed the stability of the house such as family violence, or conflict related to eviction from home. Evidence supports that all of these factors exacerbate their vulnerability and are a consequence of the social structure of the system and the social identity of the individuals.

As for resilience, after the disaster the access to a phone line, Wi-fi, cell phone device could be crucial to ask for help. A second home could be in some cases, the only alternative for shelter, so we hypothesize that families that possess only one house could find more trouble if their house is inhabitable after the disaster. Also, renting evidences the lack of financial means or credit to acquire a home, so we will hypothesize that renters are more vulnerable than non renters [45],[2]. Finally, proper access could make a difference to improve the sanitary situation after the incident.

4.2 Economic dimension

As for the economic susceptibility, we argue that unemployed people are more vulnerable [2] since it will instate a slower recovery. Furthermore, if a person was recently unemployed, after the incident, their chances of being reinstated into the labor force are reduced. Also, we found that the fifth house condition pre established by the INEI indicated a high economic dependency, which increases the vulnerability.

Economic resilience is a key aspect when dealing with anticipation policies. Hence, we will be examining the expenses required for food supply. Following that path, we could analyze if people have restrained access to food resources post disaster. As for low income people a similar situation will arise since their job will be more at risk in a crisis. We decided to include the income perception since it describes the individual's perception of the income and it is more accurate than just using the income since we do not know the economic distribution of each household. In addition, we included the saving capacity of the household and their poverty status established by the INEI. As a way to measure their capacity to resist the shack we verified the population that had access to any type of pensions either private or national, and we hypothesize that people that are not a part of any pension plan are more vulnerable to recovery. At last, we wanted to evaluate if populations in post disaster situations do have access to credit to build or rebuild their home, so we verify if they possess credit lines. Unfortunately this last variable had a missing value percentage too high. Yet, more research could be done on the subject since micro-credit is a very useful tool to allow low income classes of informal settlements to access credit lines, which could be a useful tool in the context of natural hazard [98].

4.3 Institutional dimension

On the institutional susceptibility axis, we find that institutional trust is our key variable to measure how institutionalized citizens are and the type of dialogue established between the two. So, the first factor that we include is if the individual has an identity card or not. Hence, we included the institutional trust in the National Election Jury, the ONPE (National Office of Election Processes), and the RENIEC (National Registry Office). We argue that these factors capture the trust individual's put on democracy which is an important factor to consider given the Peruvian context. In addition, we find on this axis the trust people have on the Ministry of Education, which can draw the line between schooled and non schooled children.

On the institutional resilience axis, we will find the institutional trust put on the institutions that could help post disaster, for instance the National Police, the Town Council, the Defense of the People. We argue that people are more vulnerable when they do not trust institutions since they will benefit less from possible aids.

4.4 Risk perception

We also included a variable in the social susceptibility axis that identified the people that had already experienced a natural disaster. According to the literature, people who have experienced a natural disaster like floods are more prepared for another [99],[100]. We hypothesize that people who have lived through natural hazards are less vulnerable than those who did not.

5 Method 1 Flood Vulnerability Index

The first step to apply the FVI method is to find the corresponding factors amplifying the vulnerability by acting on the exposure, susceptibility and resilience of populations.Overall, the evidence based the index using the following formula:[70]

$$FVI = E \cdot S \cdot R \tag{1}$$

E accounts for exposure
R accounts for resilience
S accounts for susceptibility

Then we process the normalization of the factor's values and then aggregate them into their respective components. The attribution of weights depends on the method used, some have chosen entropy [66], equal weight [64],[101],[102], inverse variance

[67], PCA [1], LCA [69] or a focus discussion group with local experts to verify the weight of each variable [65]. The final step is to verify the results obtained through an R2 test and t-test [69] , Cronbach's Alpha [62][103][68]. While most studies focus on precise regions, some aim to compare across multiple regions by implementing LCA through group analysis [61]. In our case, we will do a comparison across coastal regions. The data establishes 4 regions to our interest, the Coastal North region, the Coastal South region, the Coastal Center region and as a particular case, the Lima region also located on the coast. To build our index we classified each variable in the previous mentioned categories. Unfortunately we were not provided with the rain anomaly dataset required to fulfill the physical dimension.

Finally we performed a Cronbach's alpha test, whose value of 0.765 indicated a very good level of accuracy of our index.

6 Method 2 SoVI Index

To perform our analysis on the social, economical and institutional vulnerability we selected the variables that seem pertinent to our analysis, at the end we had a dataset containing 103 variables to measure our three domains. Then, we looked at each variable to convert them into binary values if possible so 1 will be assigned when this variable increases the vulnerability and 0 when it does not. Also, we treated missing values in the cases where it was possible by assigning the mean value of the column and we eliminated the columns with high missing values (over 80%). Our dataset retained 73 variables. The next step was to do a collinearity test, so we plotted the correlation matrix (Annex) and we eliminate the highly correlated values. We performed a multi regression model to then do a VIF model to verify for multicollinearity. With the remaining 38 variables, we proceed to standardize, clean and name them. In order to perform the PCA analysis, we had to first draw the covariance matrix and then we moved into the analysis. By looking at our scree plot (Fig 1) that represents the variance explained by each dimension, we selected the first 9 dimensions since they explained a cumulative of 89,2% of the entire variance.

Once we selected our 9 dimensions we analyzed the coordinates of each dimension to understand their composition. In cases where the dimensions explained an increase in vulnerability but were negatively correlated we multiplied by a negative value so all the dimensions would be coherent. For instance, we displayed a table indicating the biggest components of each dimension (Fig 2). We empirically attributed a name to each dimension.

Hence, we have identified a dominant component for each dimension. For the previous exposed reasons, we have lots of academic evidence supporting the coherence of each variable.

Table 1 FVI Index according to the FVI composite (Method 1)

	Dimension			Domain			Object
Department	Exposure	Susceptibility	Resilience	Social	Economic	Institutional	FVI
ICA	0.1775000	0.9711111	1.671111	0.8802778	0.6588889	1.280556	2.819722
LA LIBERTAD	0.1492857	0.9835714	1.683929	0.8503571	0.7357143	1.231429	2.816786
LAMBAYEQUE	0.1539394	0.9024242	1.716061	0.8521212	0.7615152	1.159394	2.772424
LIMA	0.2024675	1.0216883	1.646234	0.9070130	0.7003896	1.264416	2.870390
MOQUEGUA	0.1800000	1.0360000	1.604000	0.8820000	0.6080000	1.326000	2.820000
PIURA	0.1842000	0.8710000	1.676800	0.8812000	0.7346000	1.115400	2.732000
TACNA	0.1976923	1.0307692	1.774615	0.9561538	0.6984615	1.352308	3.003077
TUMBES	0.1576923	0.8961538	1.706923	0.8946154	0.7507692	1.114615	2.760769

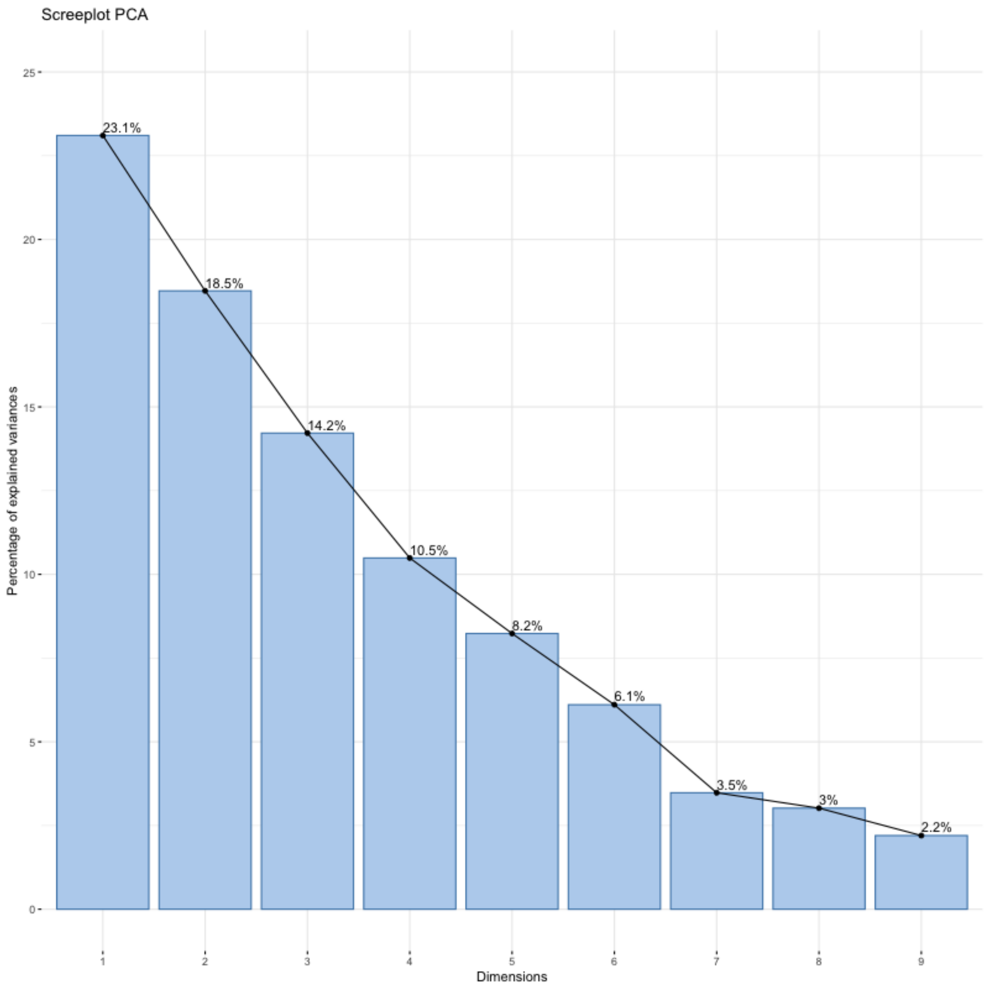

Fig. 1 Variance explained by 9 dimensions

Institutional trust The first component describes the institutional trust of citizens towards multiple institutions such as the National Jury of Elections, the Town Council, the National Police, the Ministry of Education and . The dominant variables being the trust on the Ombudsman's Office, an institution in charge of "defending and promoting the rights of the people, supervise the effectiveness of the performance of the state administration and oversee the adequate provision of public services so that all Peruvian men and women may benefit from them, specially in situations on vulnerability" . The existing academic evidence using the MOVE framework focuses on how institutions assess risk zones [1] and the aids brought post disaster [64] [**?**],[68] as a way to measure their institutional capacity. Yet, in the case of Peru, there is a lack of centralisation of risk management as mentioned in the OXFAM report of

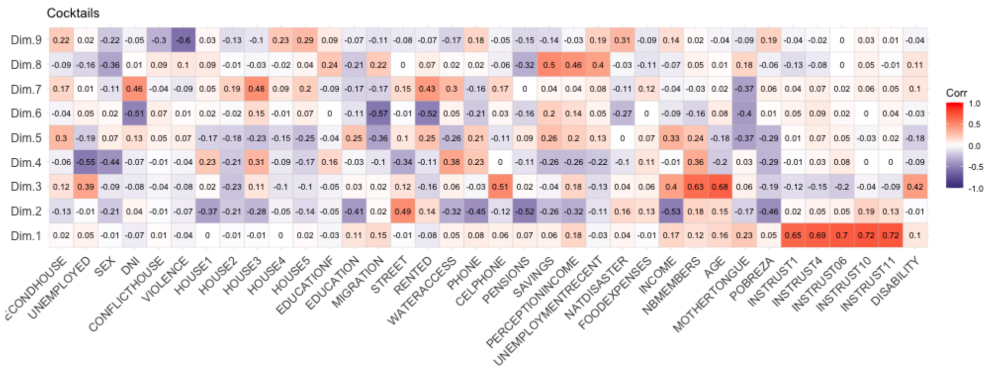

Fig. 2 Decomposition into 9 dimesions

2015. Hence, we argue that measuring institutional trust will give us a broad perspective of the actions of institutions to help the population in situations of distress such as natural disasters. Furthermore, this is imperative due to the already mentioned political context of Peru, and also due to the low level of social trust existing in the country which can influence the resilience of these populations facing natural hazard.

Income The second dimension is dominated by income. Found in many other academic articles, this is a determinant axis to describe vulnerability [2]. In this same component, we find alongside income other factors such as the access to pensions, the degree of poverty, income perception as well as the three first conditions of a vulnerable house, all being factors income-related. As a reminder, these three conditions are the inadequacy of the house, the overcrowded neighborhood, and the lack of access to toilets within the house. Poorer households will lack resilience to face the consequences post-disaster.

Non participants to the remunerated labor force/ Unemployed The third dimension encompasses all unemployed citizens, within numerous families, lacking

Table 2 Dimensions Decomposition

Dimension	Name	Dominant variable	Variance Explained	Coefficient
1	Institutional trust	INSTRUST11	23,1%	0.72
2	Income	INCOME	18,5%	-0.53
3	Non remunerated labor force/ Unemployment	AGE	14,2%	0.68
4	Living conditions	UNEMPLOYED	10,5%	-0.55
5	Mother tongue	MOTHERTONGUE	8,2%	-0.37
6	Migrant renters	MIGRATION	6,1%	-0.57
7	Informality	HOUSE3	3,5%	0.48
8	Savings capacity	SAVINGS	3,0%	0.50
9	Destabilizing events	VIOLENCE	2,2%	-0.6

Source: PCA Analysis.

access to a cell phone, perceiving a low income, in some cases having a physical disability and whose age corresponds to either under 15 or over 65 years old. Dominated by this last factor, we can deduce that this group is composed of retirees and children that do not necessarily participate in the labor force or that they are not correctly remunerated. In other academic papers, this group is named "dependent person" [2][1]. However, due to the lack of recognition and remuneration of house tasks among families, we argue that not remunerated members is a more appropriate term. This group of people, due to age limits or disabilities, could have harder chances to reach the exit at the appropriate time. On the other hand, since they are not necessarily or fairly remunerated they would need to rely on their family members income to overcome the flood impact.

Housing/ Sanitary conditions The housing/sanitary aspect can be found within the fourth dimension, which describes the lack of access to toilets and water. In addition, we can find that these families are numerous, enhancing the precarious sanitary condition. In the previously mentioned academic evidence, many warn about the prominent risk of flood acting as a vector for disease [87],[89],[86] Also, considering the dengue fever context of Peru, this remains a crucial dimension to take into account.

Mother Tongue This fifth dimension is dominated by the mother tongue variable and illustrates how an individual's social identity shapes their vulnerability in an unequal racial structure. Non Spanish speakers have a harder time integrating the labor force [45]. We found that 55.7% of non Spanish speakers are women. Having fewer labor opportunities, they are less resilient to flood related disasters.

Migration The sixth dimension represents the migratory status of citizens. Alongside migration, we find a lack of identity cards and a rented house. Similarly to the mother tongue dimension, geographical and cultural identity also shapes the opportunities of integrating the labor force of newcomers migrants. Again, this dimension reduces their financial capacity to overcome disasters.

Informal housing infrastructure The housing infrastructure is determinant in the Peruvian aspect. As already mentioned in several articles studying the housing policies in Peru, and more precisely in Lima, acquiring a house in a shantytown is usually done through informal transactions that do not require owners to have an identity card. In this dimension dominated by the lack of identity card alongside with poor housing conditions with a lack of access to water, we identify this type of informal acquisition of land [42],[18]. So, not only does an informal housing infrastructure increase the level exposure of the family, but also their capacity of adaptation post disaster.

Savings capacity Within the economical dimension, the savings capacity of a household is crucial to take into account to overcome unprecedented and unexpected events. If a household cannot save enough or at all, they will have a harder time when dealing with post disaster situations. In some cases, being affiliated to a national or private pensions of retirement can relieve the financial burden the disaster can cause. The recent unemployment status can also affect the saving's capacity of a household, making them even more vulnerable. Also, we find the income perception factors, which describes the extent to which a family considers that their income is enough.

Other destabilizing events The last dimension is dominated by the factors that indicate if a member from the household has already been a victim of a house conflict, intra-family violence or a natural disaster. For instance, we considered that a natural disaster experience will increase people's awareness and resilience since they might be able to have a more clear idea of the possible impacts. Hence, this variable will act as a relief of vulnerability. On the other hand, being the victim of a house conflict is evidence that members have struggled to pay the rent or credit on occasions, facing the possibility of eviction. In addition, being a victim of house violence can disturb the family bonds not only necessary to the well being of family members, but only to their resilience as a family to floods. Many evidence suggest that communities with high social trust and mutual aid overcome natural disasters more easily [99]. We argued that these two last factors will enhance the flood vulnerability since it will instate a social capital that will be a valuable resource to be more resilient to flood disasters.

Using QGIS, we plotted a map of Peru's coast vulnerability index calculated through the PCA analysis. The map indicates the different levels of vulnerability of each department, province and even district *(ubigeo)*.

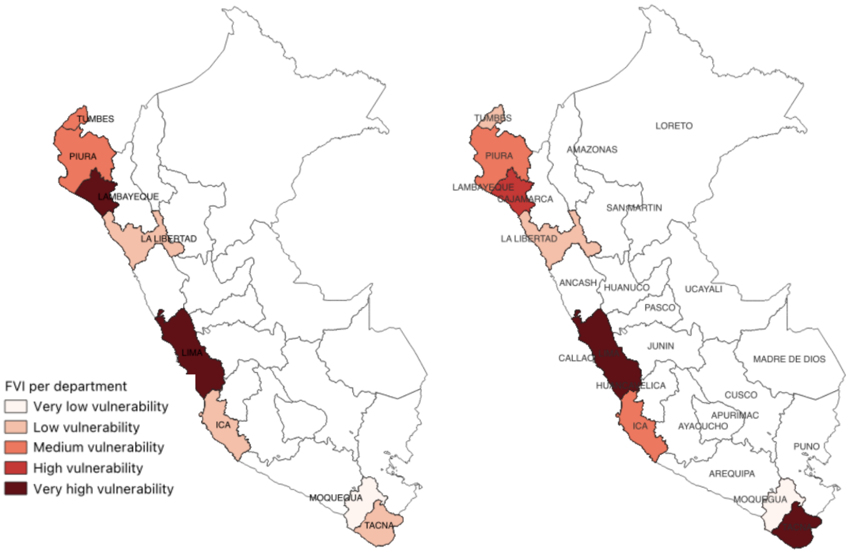

Fig. 3 Vulnerability Index with Method 1 (right) and Method 2(left)

7 Results & Discusion

In 2017, La Libertad, Piura, Lambayeque were the departments who reported more victims and affected households. According to our estimates, 33,2% of La Libertad's population was affected, placing this department as the most vulnerable to flood related and extreme rainfall events. The two methods have similar results when it comes to vulnerability analysis. Overall, highly vulnerable departments are Lambayeque, Lima, Tacna and La Libertad.

The first method allows us to analyze each domain (Fig 5). For instance, in terms of social domain, we find Lima and Piura at greater risk. Both of these departments contain two of the largest cities of Peru, meaning there is a higher rate of migrants. As we previously saw, social identity plays a major role in accentuating the vulnerability of the most socially marginalized communities. Also, in the economic domain, we find Lambayeque and Tacna showing a higher monetary poverty compared with other coastal departments. Finally, for the institutional axis we observe a larger institutional mistrust in the capital (Fig 3).

On the other hand, for the exposure dimension (Fig 4), we find that Piura and Callao remain the departments with poorest and most informal housing infrastructure. As for the susceptibility dimension, we find that Lima and Tacna are at the highest vulnerability, followed by La Libertad, Moquegua and Ica. The degree of susceptibility expresses the presence of the population at danger of harm in each department. Ultimately, within the resilience dimension, we see Lima and Lambayeque being very vulnerable. Due to the high level of economic disparities combined

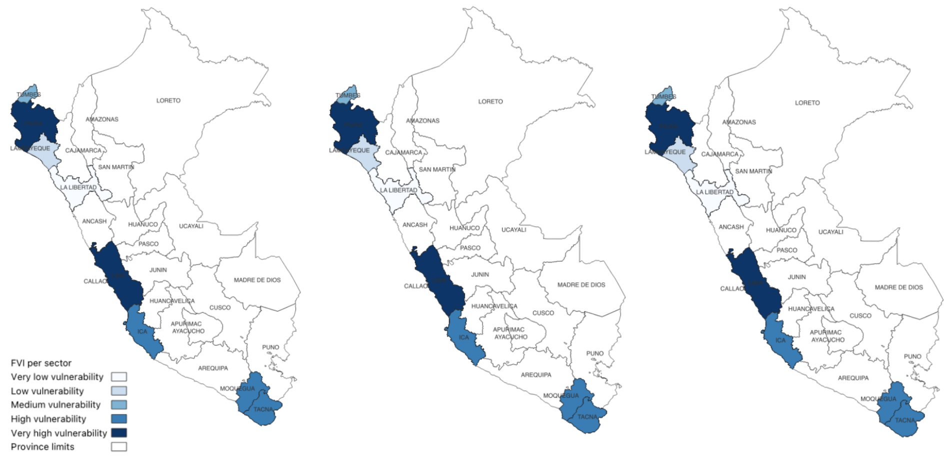

Fig. 4 FVI Method according to dimensions:exposure, susceptibility and resilience by department

with the poor housing conditions, these households will have a hard time recovering from the economic impact of floods due to their limited financial capacities.

Moving to micro-analysis, we can distinguish, thanks to both methods, the districts that we have to prioritize when assessing flood risk (Fig 6). For instance, the PCA analysis identifies Rímac, El Agustino, La Victoria and San Juan de Miraflores as the most vulnerable whereas the composite FVI will add to the list Independencia, San Juan de Lurigancho, Villa María del Triunfo, Ate, Lince, Pueblo Libre and Barranco. The district closer to the edges of the cities as Ancon, Carabayllo, Santa Rosa, Puente Piedra, are also recognized as the more vulnerable and were called by the INEI as the poorest districts in 2023 of the Department of Lima.

8 Limits

A major limit this study contains is the lack of physical or environmental indexes. In fact, the most affected departments are the ones located on the North Coast since they experience more frequent rain anomalies than on the South Coast. In order to achieve that, we would need the data on the rainfall anomalies and the average rainfall per department. On the other hand, another metric that we could have included is the distance to a river flow which can increase the exposure of the household to river overflow. Yet, these factors could be easily integrated into our analysis once we receive the appropriate data. However due to the distribution of the meteorological stations in Peru, crucial information could be absent for some departments or provinces.

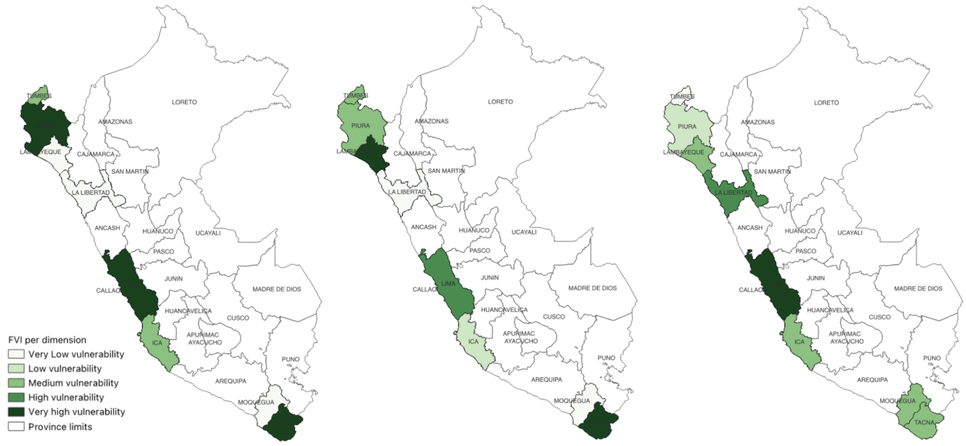

Fig. 5 FVI Method according to domain: social,economic and institutional by department

9 Conclusion

The goal of this study and these indexes is to serve as a tool for policy makers to implement the correct policies that will protect vulnerable communities. Yet, when it comes to instating solutions for climate resilience, indexes are not taken into consideration since they are not replicated. However, Birkmann insisted on the importance of urban adaptation arguing that high concentration of individuals increases the “urban adaptation as they regulate the practicability and, in particular, the efficiency of certain measures”. In some cases, this might even increase the feasibility and political acceptance of some measures [30].

In order to assess climate resilience, we need the “*concertación*” of the actors, an action consisting of arranging or composing the part of the structure that is not working [47]. Furthermore, we need to include the intersectional aspect into policy making strategies to support communities at higher risk [45]. Ultimately an expansion towards the health and sanitary area needs to be done to prevent and anticipate the effects of vector borne diseases as the cases of dengue fever rise in Peru.

Some of the academic evidence comments on the possibility of relocation, but given the already precarious context, it is hardly a solution to this situation. Hence, the index using the composite FVI method (Method 1) allows us to dig deeper into each dimension and domain to correctly assess vulnerability. Academic evidence not only needs to expands this type of analysis to other El Niño related phenomena but also other possible scenarios with more rigid climate measures that could save

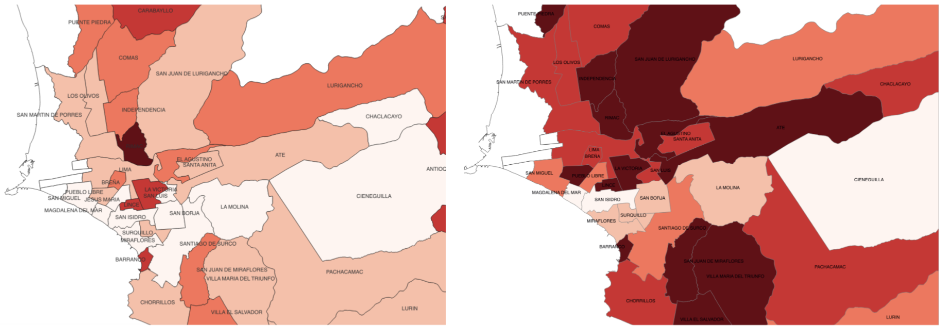

Fig. 6 FVI Method in Lima according to district

vulnerable lives.

Appendix A

array lscape geometry
geometry array booktabs rotating caption

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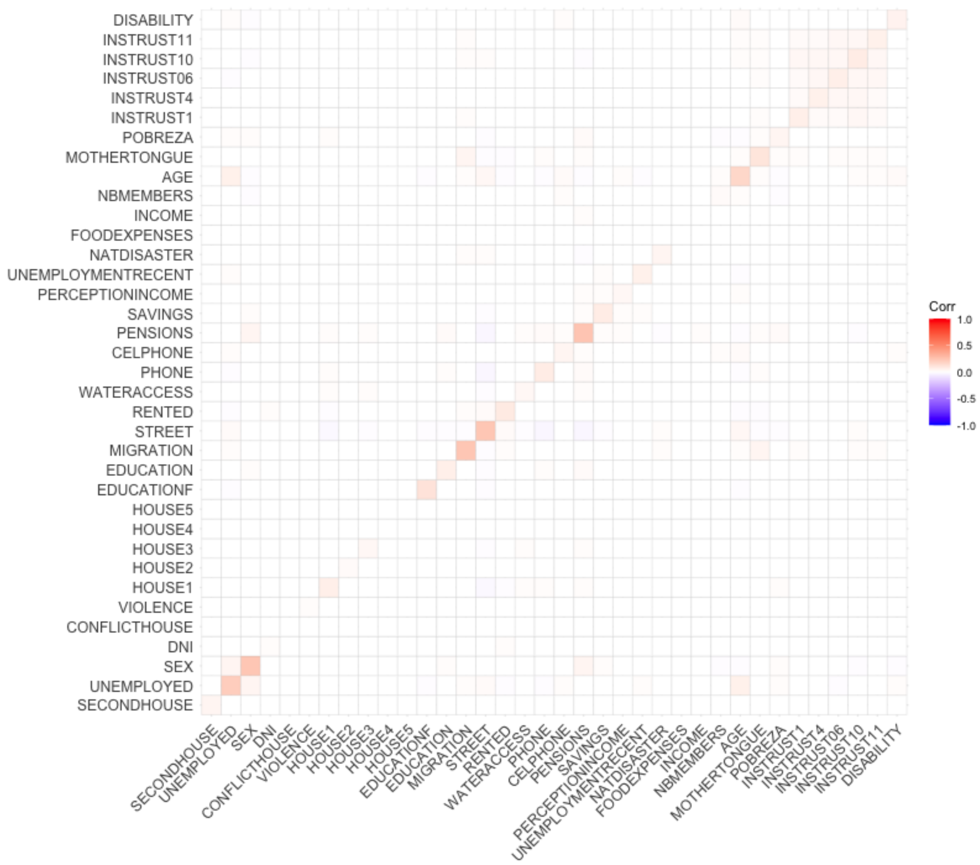

Fig. A1 Covariance Matrix

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Variables	Name	Variables	Name
P22	SECOND HOUSE	P25.2	PAVED STREET
P110A1	DRINKING WATER	P102	EXTERIOR WALLS
P110C	INTERMITTENT WATER ACCESS	P103	FLOOR MATERIAL
P501	UNEMPLOYED	P103A	ROOF MATERIAL
P502	FIXED EMPLOYMENT	P104	NUMBER OF ROOMS
D107D1	CREDIT TO BUY A HOUSE	P104B1	CONSTRUCTION LICENSE
D107D2	CREDIT TO BUY LAND	P104B2	CONSTRUCTION ASSISTANCE
D107D3	CREDIT TO IMPROVE HOUSE	P105A	RENTED
D107D4	CREDIT TO BUILD HOUSE	P110	WATER ACCESS
P510B	INFORMALITY INDICATOR	P1141	PHONE
P514	MORE THAN 2 JOBS	P1142	CELL PHONE
P5046	INTERN	P1144	WIFI
P5047	DOMESTIC WORKER	P507	SELF-EMPLOYED
P5048	PRODUCT MANUFACTURER	P511A	CONTRACT
P210	IRREGULAR EMPLOYMENT/UNEMPLOYED	P512A	COMPANY SIZE
P207	SEX	P523	MAIN OCCUPATION
P302	ILLITERATE	P524A1	TOTAL INCOME
P401C	DNI	P558A5	PENSION SYSTEM
P107E	DIFFICULTY PAYING CREDIT	P32	PERCEPTION OF SAVINGS
P503	OWN BUSINESS	P34A	PERCEPTION OF PENSIONS
P5041	WORKS IN OWN BUSINESS	P34B	PERCEPTION OF PROGRAMS
P5042	PROVIDES A SERVICE	P37	PERCEPTION OF INCOME
P5043	DOING SOMETHING AT HOME TO SELL	P40.1	RECENT UNEMPLOYMENT
P5045	ARTISAN LABOR	P40.6	NATURAL DISASTER
P5049	FARM/ANIMAL CARE	SG23	FOOD EXPENSES
P24_4	EVICTION CONFLICT	INGMO2HD	INCOME
P24_7	FAMILY VIOLENCE	MIEPERHO	FAMILY MEMBERS
NBI1	INADEQUATE HOUSING	FACTOR07	EXPANSION FACTOR
NBI2	NON-OVERCROWDED HOUSING	P208A	AGE
NBI3	HOUSING WITHOUT SANITARY SERVICES	P209	MARITAL STATUS
NBI4	CHILDREN NOT ATTENDING SCHOOL	P300A	MOTHER TONGUE
NBI5	HIGH ECONOMIC DEPENDENCY	POBREZA	POVERTY
P401H1	DISABILITY TO MOVE	P558E1_1	SAVINGS ACCOUNT
P401H2	DISABILITY TO SEE WITH GLASSES	P558E1_2	FIXED-TERM ACCOUNT
P401H3	DISABILITY TO SPEAK	P558E1_3	CURRENT ACCOUNT
P401H4	DISABILITY TO HEAR	P558E1_6	DOES NOT HAVE
P401H5	DISABILITY TO UNDERSTAND	P558E1_7	CTS
P401H6	DISABILITY TO RELATE	P1.01	JNE
P4092	FAR HEALTH CENTER	P1.02	ONPE
P4091	HEALTH CENTER NOT AFFORDABLE	P1.03	PROVINCIAL MUNICIPALITY
P22_1.01	RACISM	P1.04	DISTRICT MUNICIPALITY
P22_1.02	DUE TO ACCENT	P1.06	NATIONAL POLICE
P22_1.03	CLOTHING	P1.10	EDUCATION
P22_1.04	ORIGIN	P1.11	OMBUDSMAN
P22_1.10	SEXUAL ORIENTATION		
P22_1.11	DISABILITY		
P45_1	FATHER'S EDUCATION LEVEL		
P45_2	MOTHER'S EDUCATION LEVEL		
P301A	EDUCATION LEVEL		
P401G1	MIGRATION		
P401F	NEW IN DISTRICT		

Table A1 Variables and Names

Table A2 Classification of Variables by Exposure, Susceptibility and Resilience

	Exposure	**Susceptibility**	**Resilience**
Social	SECOND HOUSE, POTABLE WATER, INTERMITTENT WATER ACCESS, PAVED STREET	SEX, AGE, MARITAL STATUS, MIGRATION, EDUCATION LEVEL, MOTHER TONGUE, NO OVERCROWDING, EVICTION CONFLICT, FAMILY VIOLENCE, NATURAL DISASTER, DISABILITY, FAMILY MEMBERS	PHONE, CELLPHONE, RENTED DWELLING, SECOND HOME, WIFI, WATER ACCESS
Economic		UNEMPLOYMENT, JOB LOSS, LACK OF HYGIENIC SERVICES	SAVINGS, PENSION SYSTEM, INCOME, INCOME PERCEPTION, POVERTY, FOOD EXPENSES
Institutional		ONPE, ELECTION OBSERVER(RENIEC), MINISTRY OF EDUCATION, IDENTITY DOCUMENT, PROVINCIAL MUNICIPALITY	DISTRITAL MUNICIPALITY , PUBLIC DEFENDER, NATIONAL POLICE