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Theorical studies and practical approach on measuring urban resilience: the Mariana (MG) case study

Alessandra Peverelli

Nota autore

Alessandra Peverelli after a bachelor's degree in international sciences and European Institutions at the University of Milan, obtained a Master's Degree in Policies for International Development Cooperation at Università Cattolica del Sacro Cuore in Milan, during which she attended the University of Coimbra as an exchange student. She works in an NGO dealing with the administrative sector.

Abstract

Faced with a world in which the number of people living in the city is increasing, the theme of urban resilience becomes central. However, we are faced with numerous definitions that contribute to making a general evaluation process difficult, creating different models based on different interpretations of the term. In this study, different models of urban resilience evaluation will be presented and confronted, the ones produced by scholars or private organizations. Starting from this comparison, one of the model, the one of Cutter et al. (2008), will be used for analysing the case of Mariana (MG). The dam collapse, one of the worst environmental disaster in Brazil, caused damages in two States, along the course of Rio Doce, spreading pollutant for over 600 km. A final evaluation is carried out considering 6 different dimensions – ecological, social, economic, institutional, infrastructural and community – each of them divided into multiple variables.

Keywords

Urban resilience, complex systems, practical measurement, urban resilience index.

1. Introduction

On 5 November 2015, the rupture of a dam near Mariana, Minas Gerais, generated a chain of events that led to one of the worst ecological disasters that have ever occurred in Brazil. The district of Bento Rodrigues was wiped out, but the negative repercussions caused by pollution were spread along

the entire course of the Rio Doce, affecting the neighbouring State, Espírito Santo, more than 600 km away. Flora and fauna were deeply affected, as well as the river communities.

The disaster affected an estimated 2 million people, according to *Justiça Global*, but here the focus will be only on Mariana, the closest and most directly affected by the mud and water. The theme of the city and its resilience is a complex problem, which we are learning to face today, finding ourselves living in an era in which large urban complexes start to exist as metropolises and megacities. According to UN Habitat forecasts, there is a trend in continuous growth in the number of inhabitants in cities since the '50s. Urban resilience therefore becomes an issue whose research and study become essential for the analysis of future situations, in a perspective that sees the centre of attention a growing interest in risk, disaster and how it is possible to recover and prevent.

The attention that the concept resilience has received over the time is remarkable, but this combined with the lack of a universally recognized definition made it difficult to use tools for its evaluation. In this study will be presented and confronted different models used by scholars or private companies/organizations to measure urban resilience; the Mariana case will be then analysed using the more suitable index and the urban resilience evaluate.

2. Urban resilience

The presence of multiple definitions that could be connected to the term resilience makes it clear right away how this term is widely used, since it could be encountered in dozens of different definitions, applied to countless disciplines, such as sociology or psychology, just to name a few. The versatility in the application has meant that there are various definitions, but this has also triggered criticism from the academic community, making resilience an object that is difficult to measure or concretely use (Matyas & Pelling, 2012; Vale, 2014; Weichselgartner and Kelman 2014). The term resilience was first introduced by Thomas Young in 1807, but, in more recent times, Holling was the one who decided to choose this word by reinterpreting and adapting it to another field: *ecological systems resilience is a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables* (1973).

The concept of urban resilience develops from the term resilience but adds a more specific component, limiting its application to a very specific environment. What do we refer to when talking about urban resilience? Surely we refer to the part relating to the aggregation of human beings in complex systems of housing and lifestyles. The four components that could define

what are the main characteristics of a city can be encountered in Meerow et al. (2016): networks of governance, materials and energy, infrastructures and socioeconomic dynamics.

A significant distinction that must be introduced before continuing is about the differences between territorial, environmental and urban resilience. The territorial resilience is linked to a more limited context, in which the emotions of the individual come into play, where the sense of belonging to a place emerges (Giuliani, 2003), which can come from individuals or communities. The bond that is created is not merely physical, but is mediated by aspects related to an intangible dimension, such as cultural or religious beliefs (Michelson, 1976; Virden and Walker, 1999; Mazumdar and Mazumdar, 2004). Therefore what makes these territories important is the "experience-in-place" that is linked to them (Manzo, 2005). Studies on this perspective have been carried out by scholars such as Cuba & Hummon (1993), which showed that attachment can be developed at different levels, from the home to the city dimension.

As for the environmental resilience, related to the ecological resilience of which Holling was the forerunner, from its definition we can see how the system considered is a complex one, within which there is not a single equilibrium, and where the transition from one state to another is expected rather than the return to a previous situation.

Finally, as far as urban resilience is concerned, the characteristics highlighted above are the starting point from which deduce two important features: the recognition of the city as a complex system, where there is no single equilibrium but continuous re-adjustment among its part, and the possibility of individuals to develop links with territories or even smaller environments, such as cities.

Numerous definitions of urban resilience have been made in these recent years, with slightly differences between one another. In this case, it has been preferred to refer to the definition provided by Meerow et al.: *Urban resilience refers to the ability of an urban system and its constituent socio-ecological and socio-technical networks across temporal and spatial scales-to maintain or rapid return to desired functions in the face of a disturbance, to adapt to change, and to quickly transform the current or future adaptive capacity* (2016). The definition appears to be extremely accurate, containing the concept of urban as a complex system, the notion of non-equilibrium, positive concept of resilience, adaptation and timescale of action.

When we talk about a complex system we refer to a system inside which there are many components, but as Ilmola (2016) points out, this is not enough, because it is necessary that these elements interact with each other, influencing one another in a continuous process of re-adjustment that leads

to an adaptive process, where there is no single balance. The interactions in complex systems take place within it but also towards the environment around them, between members close to each other and all the parties can influence and can be influenced by others, the interactions do not have to be physical but there may be transfers of information or energy: these are the elements considered fundamental to define a complex system (Ilmola 2016, Yamagata and Maruyama 2016). A sub-category of complex systems are complex adaptive systems, where interactive and adaptive agents are present (Morel and Ramanujam 1999), whose intervention contributes to maintaining the dynamism of the system. Given the high number of these agents, the system does not have a single balance but an unstable one because *small changes in behavior can produce small, medium or large changes in the next set of outcomes* (Ilmola 2016).

The definition by Meerow et al. (2016), therefore, highlights how the vision linked to resilience has evolved, abandoning a more engineering vision, linked to the return to the initial condition, relating everything to the presence of a single balance. Now, however, what is proposed is a concept that is far from being static, where there is no equilibrium and the agents, through their actions, contribute to create a situation in constant change, which is readjusted at every change.

2.1 Theoretical models

As mentioned in the previous paragraph, one of the criticisms made by scholars is the high number of definitions that contribute to making difficult the creation of a single framework for evaluating or operationalizing resilience. Here some indices or theoretical models of urban resilience evaluation elaborated by some scholars will be presented.

Model by Xu and Xue (2017)

The model taken into consideration comes from a fairly recent study, with a more engineering approach. The study focuses on the CUPSs: *multi-layer structure integrated into three-dimensional space have been constructed in many cities* (Xu and Xue, 2017). Beyond that, however, there is not much room left for an analysis of the society, the infrastructural aspects of a city remain the main topic. The model uses as reference definition: *resilience is a kind of ability to resist risks*, (Xu and Xue, 2017), where no mention is made about multiple equilibria or a complex system. The analysed dimensions are 6, each subdivided into further categories: governance and management, for the role played by decision-makers in pre- and post-emergency situations; physical infrastructures and their stratification; crowd clusters and their weaknesses; the natural environment surrounding the cities, which the latter

influences and is influenced; accessibility to traffic; economic development. The model consists of 46 indicators, and the final evaluation is given using quantitative and qualitative data, interviewing decision makers and consulting pre-existing data.

Model by Cimellaro (2016)

This model, unlike the previous one, uses a definition that is oriented towards an adaptive view of resilience, moving away from the idea of a single equilibrium, even though has an engineering approach. In the book "*Urban Resilience for Emergency Response and Recovery*" (2016) a list of existing indicators is presented (Mileti, 1999; Renschler et al., 2010; Cutter et al., 2003, 2008, 2014; Burton, 2015; Norris et al., 2008; Morrow, 2008; Tierney, 2009; Colten et al., 2008; Center, 2002; World Bank, 2015; Berke and Campanella, 2006; Vale and Campanella, 2005; Murphy, 2007; Godschalk, 2003, 2007; Enarson, 2007; Burby et al., 2000; Sylves, 2007). The index developed has 5 main themes: social, economic, community, institutional and environmental. Each of these dimensions is then divided into categories for a better analysis. The information can be obtained from pre-existing data, but Cimellaro underlines how a high number of indicators can be misleading and instead suggests a selection of some indicators depending on the research area (2016).

Model by Cutter et al. (2008)

Here it is briefly introduced the model which we will use later on for our case study. The definition that the authors used in their research is this one: *resilience is the ability of a social system to respond and recover from disasters and includes those inherent conditions that allow the system to absorb impacts and cope with an event, as well as post-event, adaptive processes that facilitate the ability of the social system to re-organize, change, and learn in response to a threat* (Cutter et al., 2008). The index has six dimensions: ecological, social, economic, institutional, infrastructural, community competence. The variables are only mere indications, and it is not established whether a qualitative or quantitative approach is better because *despite these varied conceptualizations for describing and assessing resilience, none [...] have progressed to the operational stages where they effectively measure or monitor resilience at the local level* (Cutter et al., 2008).

Model by Sharifi e Yamagata (2016)

Even in this index model, presented in the book "*Urban Resilience*" (Yamagata and Maruyana ed., 2016), the authors adopt an adaptive view of resilience, where cities are defined as socio-ecological systems, and the adaptive approach is identifiable by some characteristics, which are considered fun-

damental for strengthening urban resilience: robustness, stability, flexibility, resourcefulness, coordination capacity, redundancy, diversity, foresight capacity, independence, connectivity and interdependence, collaboration capacity, agility, adaptability, self-organization, creativity and innovation, efficiency, and equity (Sharifi and Yamagata, 2016). This index is divided into 5 main areas: economic, social, government and institutions, infrastructures, materials and environmental resources, each divided into different criteria. For the final evaluation, resilience matrices should be used, as proposed by Fox-Lent et al. (2015), using both qualitative and quantitative indicators.

Model by Suárez et al. (2016)

The last model taken into consideration is the one of Suárez et al., which identify 5 factors of urban resilience: diversity, modularity, tightness of feedbacks, social cohesion, and innovation. This model uses very accurate information, and proposes an assessment of progress based on Local Agenda 21, while ranking Spanish cities in accordance to it and the progress they made.

2.2 Models elaborated by private companies and organizations

In addition to the models developed by scholars, there are some models developed by private organizations or companies, which will be briefly introduced here.

City Index Resilience

Project created by Arup, a company of consultants and technicians specialized in design, architecture and engineering, supported by the Rockefeller Foundation. The CRI is part of the *100 Resilient Cities*, which aims to assess resilience and its progress. The definition of resilience adopted is as follows: *Urban Resilience is the capacity of individuals, communities, institutions, businesses, and systems within the city to survive, adapt, and grow to the point of chronic stresses and acute shocks they experience* (City Index Resilience, 2015). Seven key qualities are identified for a resilient system: *reflective*, constantly evolving, with its members applying the things learned in the past to future situations; *robust*, able to not be damaged in the event of a disaster; *redundant*, diversity; *resourceful*, being able to satisfy our needs no matter the condition; *flexible*; *inclusive*; *integrated*, the components of the system interact with each other (City Index Resilience, 2015). The dimensions taken into consideration are 4 -*Health and well-being*, *Economy and society*, *Infrastructure and environment*, and *Leadership and strategy*- each divided into three components, for a total of 52 indicators. By collecting data on the field, through interviews, group discussions and workshops, the index is compiled,

creating a quantitative and qualitative profile; but only 5 cities were used as a test (Conception, Liverpool, 55 Arusha, Hong Kong, Shimla).

New Zealand Resilience Organization

Another measurement index is the one of the New Zealand Resilience Organization, which focuses more on the community aspects, but the approach can be also applied to cities (Ilmola, 2016). The definition of reference for this project is that of McManus (2008): *resilience is a function of an organization's overall situation awareness, management of keystone vulnerabilities and adaptive capacity in a complex, dynamic and interconnected environment*. All scientific documentation has been produced by John Vargo, Erica Seville and Amy V. Lee from University of Canterbury. The analysed dimensions are 3, *networks*, *leadership & culture*, *change ready*, divided into 13 indicators. Data are collected via questionnaires.

Global X-Network

Global X-Network is an international group of researchers, which has recently revised its studies for the assessment of urban resilience (Ilmola, 2016). The starting definition used evaluates the analysis of resilience over time, and presents the 4 A: *awareness*, *adaptation*, *agility* and *active learning*. The analysed dimensions are 4: *operations*, *structure*, *planning*, and *resources*, each divided into 3 or 4 factors. The data are derived from pre-existing macro-parameters.

Resilience Alliance

Multidisciplinary research organization, it does not deal directly with urban resilience, but studies complex socio-ecological systems (Ilmola, 2016), and has not produced an index but a reference framework. The definition of reference is the one proposed by Holling in 1973. The research mainly takes place through workshops and historical statistics, since the idea behind this study is to understand how the system will evolve and how fast this change will take place.

2.3 Comparison between theoretical and private companies and organizations models

The indices for measuring urban resilience are not many, and some have not even been created for that purpose. Looking at those from the private organizations, it is possible to see that only one is born with the clear intention of evaluating urban resilience, while others can be adapted to this. The data used for the studies are in prevalence the ones already existing with the exclusion of the City Resilience Index and the New Zealand Resilience Or-

ganization, which opt for an approach mostly related to questionnaires and interviews. The framework proposed by Cutter et al., does not appear to be so rigorous and for this reason it allows total freedom, since the indicators have not been established, permitting it to be remodelled.

3. Method

The choice of Cutter et al. model is due to the fact that it presents 6 different dimensions – environmental, social, economic, institutional, infrastructural and community – each of them relevant when it comes to evaluating a city. The presence of social and community aspects, then, distinguished it, compared to other models, which are more related to infrastructure and engineering field.

The research was developed starting from a single case study, the Mariana disaster, with the intention of implementing the study of urban resilience, using the index as a starting point, where the dimensions are maintained while modifying the variables in order to make them universally applicable, suitable for other future researches.

The approach taken, the one considering the city as a Complex Adaptive System, in which there is no single equilibrium and each component of the system influences the others, has therefore impacted how the resilience will be assessed at the end of this work. Every single dimension will be analysed individually, even though it is clear that each one of them can influence the others with its trend; for this reason it is therefore preferred starting analysing the variables separately, and only later to carry out a total evaluation to see what the general trend is.

The collection of data and materials took place through secondary resources, through institutional sources, research institutes and scientific literature. While on the one hand this did not allow access to the places and direct testimonies of those involved, on the other hand it allowed to analyse different variables without the factor of perception of the individuals.

4. Case study

The case study analysed here is the one of Mariana, an event that shook Brazil and turned out to be one of the most serious environmental disasters ever occurred on the national territory. Although the Fundão dam broke out three years ago, the consequences of the disaster are still visible today, not only in the nearest areas but also hundreds of kilometres away.

Near Bento Rodrigues, a district of Mariana, stood a complex of three containment dams owned by Samarco S/A, a mining company controlled by Vale and BHP Billiton. Germano, Fundão and Santarém where the three dams that were used in the palletisation process of metals waste, but only the rupture of Fundão is responsible for the pollution that ensued. On 5 November 2015, during the afternoon, a collapse in the structure of the containment dam caused the flooding of Bento Rodrigues, causing 19 victims and the destruction of almost every house there.

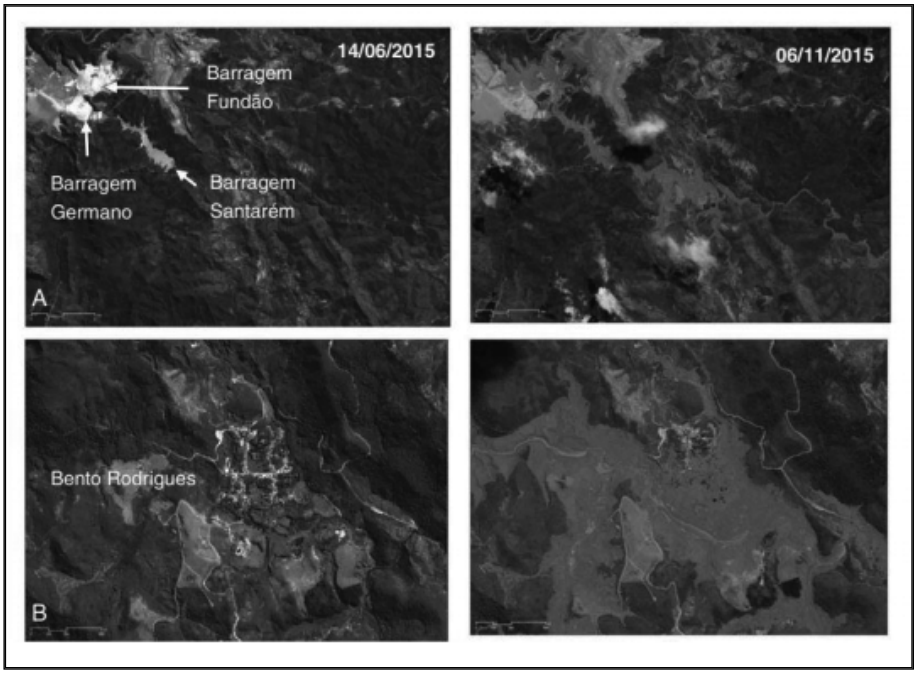

Fig. 1: Before and after the disaster Source: Agência Nacional de Águas, 2015.

How does the rupture of a single dam have caused one of the worst environmental damage in Brazilian history? Bento Rodrigues does not rise directly near the Rio Doce but, favoured by the sloping territory, the mud continued to move, until it reached Paracatu de Baixo and the rural districts of Mariana, and, almost 12 hours later, Barra Longa. The advance of that river of mud, however, did not stop there and was able get into two rivers, Rio Gualaxo do Norte and the Rio Carmo, tributaries of the main one, filling them with the waste material.

The Rio Doce was therefore polluted by its tributaries. When the mud reached this river still it was not possible to stop the diffusion of waste materials: with a total length of 853 km divided into two States, Minas Gerais and

Espiríto Santo, the Rio Doce waters, banks and bed had been contaminated. Due to its length, only on 22 November the residues reached the mouth of the river, at the beach of Regência, Linhares (ES) and then entered the ocean, a total of 17 days after the rupture of the dam.

Cities, small villages and indigenous communities along the river have been severely affected by this disaster; *Justiça Global*, an NGO focused on human rights, estimates that 2 million people have suffered repercussions from the rupture of the dam. The water present in the dam basin contained amines, an organic compound used in the mining industry for the palletisation process, which is basic, altering the pH of the water. The Superintendence of Water Resources Planning (*Superintendência de Planejamento de Recursos Hídricos*) found levels above the limits of Iron, Manganese, Arsenio, Cadmium, Mercury and Nickel.

Even the vegetation suffered serious damages, since the presence of mineral elements and amines is not only polluting for the water but also for the soil, as it is corrosive and toxic (da Silva, Carvalho Ferreira and Scotti, 2016). Along the river there is the State Park of Rio Doce, one of the conservation areas of the *Mata Atlântica*, a particular forest typical of South America. From data obtained by Pinto-Coelho (2016), 1.,469 hectares of land have been lost along the river.

The animal species that populated the river also suffered some consequences. Already a few days after the break of the dam, tons of river fishes have been found dead in its waters. In addition to this, some species, relying on the river for their food, have seen their environment damaged and polluted.

The lack of access to water has proved to be a problem faced by many families, from those in the cities, to those that produced agricultural products for their livelihood. The indigenous community of the Krenak has seen in the pollution of the waters a brake to the traditional activities of the community, putting at risk their lifestyle.

Samarco itself had to block its activities, leaving its workers and all those small companies that depended on them without employment. The industries whose production relies on the use of water, such as the paper industry, for cellulose whitening processes, suspended their activities, as well as hydroelectric plants, worried about residuals damaging the turbines. Fishing activities have been interrupted, just as tourism has suffered a severe arrest.

Only in 2016 there was a development with the signature of the Treaty of Transition and Adjustment of Conduct (*Termo de Transação and de Ajustamento de Conduta*, TTAC), subscribed by the Brazilian Institute of Environment (*Instituto Brasileiro do Meio Ambiente*, IBAMA), the Chico Mendes Institute for the Conservation of Biodiversity (*Instituto Chico Mendes de Conservação da Biodiversidade*, ICMBIO), the National Water Agency

(*Agência Nacional de Águas*, ANA), the National Department of Mineral Production (*Departamento Nacional de Produção Mineral*, DNPM), the National Foundation of the Indios (*Fundação Nacional do Índio*, FUNAI), Minas Gerais State, the State Institute of Forests (*Instituto Estadual de Florestas*, IEF), the Mining Institute of Water Management (*Instituto Mineiro de Gestão de Águas*, IGAM), the State Foundation for the Environment and Water Resources (*Instituto Estadual de Meio Ambiente e Recursos Hídricos*, IEMA), the Institute of Agricultural and Forestry Defense of Espírito Santo (*Instituto de Defesa Agropecuária e Florestal do Espírito Santo*, IDAF), the State Water Resources Agency (*Agência Estadual de Recursos Hídricos*, AGERH), Samarco Mineração S/A, Vale S/A and BHP Billiton Brasil LTDA.

Another actor who subsequently came into the spotlight was the Renova Foundation, whose birth dates back to March 2016, and its aim is to follow the recovery and restoration activities, as well as the granting of compensation to those who had been involved in the disaster. Already in September of the same year the Mediated Compensation Program (*Programa de Indenização Mediada*, PIM) was launched, through which the victims could request compensation, decided unilaterally by the foundation and the mining companies, in exchange for renouncing to future legal actions. The Foundation has also engaged in environmental cleaning, water monitoring and flora restoration. In addition to this, it also follows the reconstruction of the infrastructure damaged by the mud.

5. Index and variables

As it has been said, the model that was chosen to be the base of this research is the one of Cutter et al. (2008), where the six dimensions were kept but changes were made to the variables.

In the ecological dimension, ample space was given to the environmental assessment that surrounds the city; to the risk factors; to pollution, which effects can last over time and to the legislative aspect to be referred to in case environmental crimes occur. The social dimension presents only two variables, focusing more on the demographic aspect since inequality will then be resumed in the community dimension. City economy and employment are the two variables in the economic dimension, which, in this specific case, are closely related since there is only one big company in one sector. The institutional dimension instead considers the presence of risk reduction programs, at every level, and focuses its attention on the civil protection system that has been established and on one aspect that weakens the institutions, corruption. From an infrastructural point of view the division of the city, between the industrial and the residential area, and who the municipality is connected

through the road system are the two variables considered. Finally, in the community dimension, 5 variables were selected: education at all level; health, considering infrastructures and availability of doctors; inequality; security and risk understanding by the population.

Main dimensions	Variables
Ecological	Environmental assessment
	Biodiversity
	Risk factors
	Laws for protection
	of the environment
	Pollution
Social	Demography
	Inequalities
Economic	City economy
	Employment
Institutional	Risk Reduction program
	Defesa Civil
	Corruption
Infrastructural	Transports
	Accommodations and industries
Community	Education
	Health
	Inequalities
	Security
	Risk comprehension

Tab. 1: Urban Resilience Index, adapted from the Cutter et al. (2008) index.

5.1 Ecological dimension

Environmental assessment

Regarding the environment where the municipality of Mariana rises, it is important to underline how geomorphology of the territory is a crucial factor that can influence positively or negatively, according to the conditions and the intensity of the crises. The city, in fact, stands on a territory which altitude varies between 500 and 1,400 meters, and in which are present numerous waterways. The city is located in an area characterized by the presence of the *Mata Atlântica*, in which there are a State park (*Parque Estadual do Itacolo-*

mi), a municipal park (*Parque Municipal da Estância Ecológica do Cruzeiro*) and a protected area (*Área de Proteção Ambiental do Seminário Menor*).

Biodiversity

Brazil is one of the countries with the greatest biodiversity, which is endangered by human activities such as deforestation and over-exploitation of resources, from fishing to industrial pollution, to the introduction of invasive plants that have proceeded to supplant many of the local ones. The Ministry of *Meio Ambiental*, (MMA), compiling an index of biodiversity conservation, put Minas Gerais at the 21st place out of 27.

Risk Factors

In this variable we wanted to include all those features that could be a risk for the city life, considering external and internal factors, as environmental and industrial ones. The area is mountainous and rich in rivers, which create a problem of flooding, especially during the rainy season; this phenomenon is the opposite of drought, which equally affects the area, for example the year after the dam rupture was the lowest level ever reached by the Rio Doce. Another risk factor for the city is the presence of a large industry like the Samarco. Although the activity does not take place in the immediate vicinity of the urban centre, the damages caused by the events in 2015 are still visible, and,making a comparison with a similar dam incident, occurred in Itabirito (MG) in the 80s, a decade could the time that could take to proceed in cleaning and restoring the environment.

Laws for Environment

The presence of laws by itself is not a very reliable variable because, in addition to their presence, the laws should be applied. Cavalcanti (2004) estimates that the country is moving at two speeds on this issue: modernity of legislation against a delay in the effective application, in order to the economic interests to prevail. One of the first laws issued in the 1960s concerned the protection of forests, followed later in 1999 by the one that introduced administrative and criminal offenses for illicit acts against the environment. Taking inspiration from the Clean Air Act and the National Pollutant Discharge System Permit Program created in North America in 1981, a system, called *Licenciatura Ambiental*, was introduced for licensing in projects involving exploitation of natural or dangerous resources. The process presents the involvement of a Council, in which all the parties involved should be represented, including civil society, and public hearings to promote collective participation, but Zhouri (2008) notes that there is a lack of transparency and communication. Councils may also arise at the municipal level, but if the

project involves a considerable risk, its approval must be given at other levels, State or federal, as happened in the case of Mariana.

Pollution

The dam complex has been assessed as high polluting potential, with the possibility of wide diffusion in the event of an accident; yet immediately after the collapse the measures to reduce the spread of pollutants have been ineffective, since it was impossible to block the mud via floating systems, without intervening on the river bed, in which metal residues were deposited, and their presence is harmful to humans, animals and crops. This pollution has not only occurred near Mariana but is widespread throughout the river, up to its mouth. In 2017, Greenpeace published a report in which are recorded the effects on the health of the inhabitants, such as depression, skin allergies, itching, respiratory allergies, rhinitis, insomnia, anxiety and headaches.

5.2 Social dimension

Demography

According to estimates of the Brazilian Institute of Geography and Statistics (*Instituto Brasileiro de Geografia e Estatística*, IBGE) in 2017 the municipality of Mariana should have reached 59,857 inhabitants, with a density of 45.40 inhabitants per m2, twice the national one. The city population is young, considering that 75% of it is under 45 years of age (IBGE, 2010). Data from the United Nations Development Program have seen an increase in life expectancy, 77.4 years (latest data available 2010). Child mortality has fallen to 11.8 deaths per 1,000 children, as well as mortality for children up to 5 years reached 13.8 per 1,000 children, with a fertility rate of 1.7 children per woman. Population growth data, available from the IBGE for the entire region, show an annual growth rate of 1.4. As for the net migration rate, the only data available are those of UNICEF, which show that in the period 2010-2015 the rate was -0.19, so the number of immigrants is slightly lower than that of emigrants.

Brazil is a multi-ethnic society, so the 2010 IBGE census proposes a differentiation based on colour or race. In the municipality territory, the *parda*[1] population appears predominant, representing about 50% of the total, followed by whites and blacks. The *amarela*[2], almost 3% of the whole municipal

[1] "*Pardo*" is a term used by IBGE for identifying a colour skin/ethnic category in the Brazilian census. It is often used to refer to Brazilians of mixed ethnical ancestries, but there is no specific colour or background – a mix between white, afro, Asian and Native Brazilians.

[2] According to IBGE, *amarela* can be defined the population with Asian ancestry.

inhabitants, and Indian population, with only 186 members, are the minorities.

Inequalities

Inequalities are a major obstacle that is affecting Brazilian society. The main focus will be given in the community dimension, however it is important to highlight how, in the recent years, the progresses that had been made disappeared, while the Country is living a social and political crisis. Medeiros (2016) underlines how, reducing the numbers of people living in poverty, the inequalities between poor and rich people did not decreased, but instead increased.

5.3 Economic dimension

City Economy

The State of Minas Gerais is known for the extraction and processing of metals and precious stones; in the data released by Simonato, Magalhães and Domingues (2017) taken from the Financial Compensation for the Exploration of Mineral Resources (*Compensação Financeira pela Exploração de Recursos Minerais*, CFEM), referring to the year 2015, between January and October, Mariana was the first producer with a total extraction operations equal to 5,072,693,352 R$. The workers related to mining activities were almost 6,000, making this sector the first for employment, but the halt of activities due to the rupture of the dam has blocked any activity, leaving many without jobs. The other commercial activities are of minor importance, and not even the tourism sector records large numbers, lacking of accommodation facilities in the city (Cymbalista and Cardoso, 2009).

Employment

As mentioned in the previous paragraph, the mining industry is the main industry in the area, it also follows that, since the activity was blocked, the situation has changed, leaving many unemployed. In 2017, from the data of the General Census of Employed and Unemployed (*Cadastro Geral de Empregados and Desempregados, CAGED*), it emerges that 23% of the population does not have a job; compared to the previous year's projection, 4 thousand more are unemployed.

5.4 Institutional dimension

Risk Reduction Programmes

Brazil is a federal republic, for this reason we must distinguish between initiatives undertaken at federal, state, regional and municipal levels. At the federal level, the National Week of Disaster Reduction (*Semana Nacional de Redução de Desastres*) is planned to increase the perception of citizens' risk, but is declined differently depending on the country. At the state level there are some plans: against the fires and the rains. At city level there is a SMS system to alert residents and the Facebook page of *Defesa Civil* where information on climate warnings and behaviours to be kept are posted. Internationally, there is a cooperation between Minas Gerais and the Aichi Province, Japan for exchanges of experience and materials, with seminars and interchange of specialists, researchers and operatives.

Defesa Civil

The responsibilities for disaster prevention, response and recovery are on multiple levels, since the obligations could be found for the State entities, the federal districts and the municipalities. At municipal level the COMPDEC (Municipal Coordination and Civil Defense Coordination) centralizes the operations of the SINPDEC (National System of Protection and *Defesa Civil*) and contributes to the planning, coordination and execution of programs and projects, identifying risks at the municipal level. The community is called to participate as it can be organized in Community Centers of Protection and *Defesa Civil* (*Núcleo Comunitário de Proteção and Defesa Civil*, NUPDEC) to assist the activities of the COMPDEC.

Corruption

Corruption has always proved to be an obstacle to growth, influencing negatively the lives of those who have to reside there. It was the corruption scandal that kicked off the political crisis that has hit the country in recent times. Transparency International positions Brazil in 96th position in 2017. The Federation of Industries of the São Paulo State calculates an annual loss from 1.38 to 2.3% of GDP due to corruption. Small towns are not excluded from this, in fact in 2016 the Secretary of Government and Institutional Relations of Mariana was arrested. At the municipal level, however, an attempt was made to give an image of transparency through the publication on the municipal website of acts relating to wages, services of suppliers and property. Parliamentary commissions have been created in order to investigate the disaster but, as it was discovered by different newspapers (G1, Uol Notícias), various members had received money for their electoral campaigns from the

Vale group; although legal, this behaviour undermines the trust that inhabitants can have on their institutions.

5.5 Infrastructural dimension

Transport

The railway network, in the Minas Gerais State, is managed by MRS Logística S/A, Centro-Atlântica S/A and Vale S/A, the mining company that owns part of the Samarco shares. A train station is present in Mariana but there is only one route to Ouro Preto, which is used mainly as a touristic attraction. The *Departamento de Edificações e Estradas de Rodagem* of Minas Gerais handles more than 27.000 km of roads in the State, and has jurisdiction on toll roads and State roads. The maintenance and the intervention are done all over the year, but more often during the rainy season, because sections of the roads are closed as a precaution or for landslides. Private bus companies guarantee daily services for other cities nearby.

Accommodation and Industries

The latest data on the housing situation in Mariana date back to the 2010 IBGE census, where particular permanent domicile[3] or collective[4] ones are registered. The vision is not complete because are missing all of those who live in buildings whose use has been modified, such as commercial ones, those outside the urban area and those who do not own a house. From the data emerge 14,242 houses, 100 collective houses, with an average of inhabitants by domicile of 3.40. After the rupture of the dam, however, there was a noticeable change since all those who had lost their homes had to be relocated: some enjoy Samarco's support by receiving money, housing and compensation, while others have to rely completely on the city social services. The most developed industry is the mining one, which however does not rise in the city but in its vicinity. There are no other industries with such polluting potential in the area.

[3] According to IBGE: "It is the domicile that was built in order to serve exclusively for housing and, at the reference date, was intended to serve as a dwelling for one or more people".

[4] According to IBGE: "It is an institution or establishment where the relationship between the persons resident or not, at the reference date, was restricted to rules of administrative subordination. Types of collective domicile are: asylums, orphanages, convents and the like; hotels, motels, campsites, pensions and the like; housing of workers or students, student republic (institution); penitentiary, prison or house of detention; and others (barracks, military posts, hospitalized hospitals and clinics)".

5.6 Community dimension

Education

In Mariana there are 71 schools, of which 44 are municipal, 13 are state and 14 are private; the number of teachers, excluding university ones, exceeds 900 units. IBGE records a steady decrease in enrolment in high schools and universities, while there is an increase in enrolment in compulsory schools, a trend recorded from 2009 to 2015, the latest data available. 10.2% of the population is illiterate (IBGE, 2010), but a plan has been presented at the municipal level to eliminate illiteracy.

Health

35 Health Assistance Establishments have been registered (*Estabelecimentos de Assistência a Saúde*) (IBGE, 2010), which classifies all public and private institutions and/or companies dedicated to the health of individuals. In 2016, the municipality took part in the federal program "*Mais Medicos*", "More Doctors" to receive Brazilian or foreign doctors in order to provide basic assistance. After the dam collapse, cases of diarrhoea, skin allergies, depression, tremor, renal dysfunction or pneumonitis were recorded (Greepeace, 2017), which could be a consequence of the release of heavy metals into the environment (Duruibe, Ogwuegbu, Egwurugwu, 2007; Verma and Dwivedi, 2013; McCluggage, 1991), but it is still early to evaluate the phenomenon.

Inequalities

Here the theme of inequality is taken up again, being a problem that can influence a possible return to normality after the disaster. The theme of poverty reduction has always been one of the cornerstones of the government, as when Lula established in 2003 the *Bolsa Família* program with the aim of providing monthly payments to families who meet certain conditions, such as school attendance of children, vaccinations and growth monitoring of the children. The program is set up at the federal level but it is up to the municipalities to identify, monitor and manage the monthly distribution: if we look at the 2015 data, Minas Gerais received 1,968,423,470 R$, of which 8,422,925 R$ to Mariana, divided into 46,217 payments.

Security

Insecurity turn out to be a sensitive theme now in Brazil, since the last statistics produced by the Brazilian Forum of Public Security (*Fórum Brasileiro de Segurança Pública*) show that in 2016 the number of violent intentional deaths reached the extremely high number of 61.158 people. If we look at the data given by the Ministry of Health, with its System of Information on

Mortality (*Sistema de Informação sobre Mortalidade*), the average number of the homicides in Mariana is 27 per month, about 320 per year. To cope with insecurity, the prefecture has increased the number of patrolling agents during the whole day, trying to assure a 24/7 control.

Risk Comprehension

The Brazilian government is engaged in promoting the National Week of Disaster Reduction, which differs from one State to another, to present information and prevention activities. At the State level, in 2016, the program More Resilient Minas (*Programa Minas Mais Resiliente*, MMR) was launched, with courses aimed at the improvement of more than 500 *Defesa Civil* operators, including municipal coordinators, firefighters and policemen. The *Defesa Civil* is promoting campaigns to inform citizens, including through its website. Only after the dam rupture took place a drill simulating an evacuation, in November 2017, where 11 communities of the municipalities of Mariana and Barra Longa participated, alongside with the local *Defesa Civil* and representatives of Samarco and *Fundação* Renova. Also the *Fundação* Renova, through its publications and its radio channel, as well as giving information on the reconstructions, provides information on possible risks and how these can be dealt with by the community, providing contact telephone numbers in case of emergency.

6. Focus on case study

Now we will proceed to evaluate the various dimensions that have been presented in the previous paragraphs, analysing them individually.

In the case of the environmental dimension the resilience capacity was influenced negatively by some variables, such as geomorphology, pollution, biodiversity, lack of laws application. The conformation of the territory, mainly mountainous, puts the population at risk because of the danger of landslides; on the other hand, we need to add that in the area there are plenty of rivers and streams, therefore at risk of flooding during the rainy season. The position of Samarco dam complex, which was located 2.7 km from Bento Rodrigues, in an elevated spot compared to the district, has facilitated the process of the mud descent.

Recovery measures have been going on in the last years but pollution has endangered the survival of many species living there, animals and plants. The Renova Foundation is engaged in recovery and compensation activities

but there are many voices against it, such as the *Atingidos por Barragens*[5] movement, which disputes how the protests have not been taken into consideration or how the renunciation of consultations with their own lawyer is requested for those wishing to access to reparation. Also with regard to the pollution caused by the residues present in the waters of the dam, the timing for cleaning proved to be extremely slow: just think that, in the case of 1998 in Andalusia, Spain, already three days after the dam collapse a cleaning plan had been presented to the authorities, and after 12 months about 7 tons of material had been removed (Ginige, 2002; WWF, 2002). Of course, a similar case may not be repeatable, but the progress that took place in the first year was much lower, since the TTAC was signed only in 2016.

The measures taken against the companies involved in the management of the dam complex have resulted in fines, but, as reported by El País, in August 2017 only one out of 68 fines imposed had been started to be pay, corresponding to 1% of the total over R$ 550 million. Just to make a comparison with another disaster, when in 2010 the oil spill occurred in the Gulf of Mexico, BP Petroleum had been fined for a total of $ 18.7 billion.

Considering the demographic dimension, the assessment is not so negative, finding ourselves faced with a growing young population, whose problems relating to the overcoming of poverty are tackled at federal and municipal level through support programs.

The dependence of Mariana from the extractive industries has proved to be disastrous, since in its vicinity there is only one, the Samarco, which on the one hand has allowed the creation of many occupations, but on the other hand has also led to an increase in unemployment, once the mining operations have been halted, with negative repercussions also from those companies that earned thanks to extraction-related activities. The blocking of activities meant the loss of income for many families, which all of a sudden have had to rely on the subsidies of the Renova Foundation or the municipal social system. The dependence on a single industry, which could take years to recover at pre-disaster levels, contributes in slowing down the normalization process for the inhabitants, exacerbating the precarious situation of the economic sphere, which in turn contributes to worsening the other dimensions here analysed.

For strengthening urban resilience the institutional level must be able to act and react in case of an emergency, but Mariana is facing problems such

[5] The *Movimento dos Atingidos por Barragens* (MAB) started in the late 70s, during the period of military dictatorships. The movement at national level started only at the end of the 80s, as a political and popular movement to defend the environment and the populations affected by disasters linked to the dams.

as the lack of local risk reduction plans and the negative impact of corruption. At national level, there are plans for specific threats and yet only line guides are provided, while drills have been totally absent. The municipal *Defesa Civil* has not been able to deal with the disaster, having to resort to the national and regional level, since the mud has been pushed beyond the city limits into other municipalities and State.

Regarding corruption, the problem seems to be widespread at every level of the administration, from the federal to the municipal one, as suggested by the arrest of 2016. The seriousness of the problem, however, cannot be addressed only through secondary sources because it does not reflect the real measure of the phenomenon. It is clear, though, that this kind of issue can undermine the trust of the citizens in their institutions.

At the infrastructural level, the situation of Mariana related to transports is not so bad, having a good paved road network, even if the situation becomes precarious in some periods, particularly in the rainy season, which could cause landslides or disruption of the roads. The railway line operates with limitation, mainly for tourist transport; private bus lines connect the city to other centres daily.

The housing situation appears to be mostly positive, although the analysed data are not able to fully record all kinds of housing, considering only two. The area of Bento Rodrigues that had been hit, where almost all the houses had been destroyed, will be rebuilt, but, in a different place, about 10 km away. The division of the city between the inhabited part and the industrial zone is clear-cut, the main company, the Samarco, has its activities kilometres away.

The last aspect to be taken into consideration is the community dimension, which can only receive a negative evaluation of all its variables. Although there are many schools in the area, and the number of teachers is considerable, the level of illiteracy remains high at the municipal level, although there is a program to reduce it, and there is a reduction in the number of enrolments to secondary schools and universities. In terms of health, as also seen here, there is no shortage of facilities, but rather of doctors, which are recruited joining a federal program. In the long run, also, there may be negative consequences for the health of the inhabitants, caused by the pollution from heavy metals; to date there are no accurate studies on the symptomatology that is taking place.

Inequalities remain a serious problem at national level, even though national interventions have been able to significantly reduce the number of people below the poverty line. In the case of Mariana, the program, which is managed at the municipal level, has seen an increase in the number of people who have access to it, and on the government website it is possible to

see how much and how many times the money were given to a every single person who beneficiated.

Security remains a sensitive issue that affects the entire nation; in a city like Mariana, which certainly does not have the numbers of the great metropolis, the homicide rate is 1 per 156 inhabitants, without mentioning other crimes. The idea of increasing the frequency of patrols could reduce the incidence of delinquency but it should not be forgotten how not acting on the causes could also not give the desired effects in the long run.

Finally, on understanding the risk, it should immediately be underlined that there had not been large-scale education initiatives by the *Defesa Civil* before the disaster, as well as no drills have been carried out for the areas potentially at risk, or at least not before the rupture of the dam. At national level there are information campaigns and one week a year dedicated to risk reduction but the topics covered and the initiatives undertaken vary from one State to another, sometimes leaving part of the territory uncovered. Only recently the Renova Foundation has started to campaign for risk prevention and promote educational projects, but it is still a private entity that acts on a small territory.

By giving a final assessment, we can only state how the shortcomings and delays that have been previously presented have negatively affected urban resilience. Certainly, in some fields, such as the legislative one, it is clear that an intervention that exceeds the city level is necessary, but we must also consider how even minor interventions can positively influence some variables. The Safer Cities program of UN-Habitat is one example of this: ensuring the increase of city security through targeted interventions, one of these is the spread of street lighting in Nairobi (Mueke, 2014). In addition, a crime prevention approach is proposed, which, as suggested by Palmary (2001) tackle the issue with a problem-solving method, trying to identify the causes.

Prevention plans have certainly been lacking, but it remains true that these should be supported by trained personnel. The preparation, however, must not be limited to operatives, but should also be directed towards all those who wish to become volunteers, becoming an investment in the event of future crises. Their attendance has multiple advantages: they are present in the territory and already have strong ties with the inhabitants; moreover, this experience could act as a moment of union between different members of society, which usually do not come into contact, therefore increasing social cohesion.

7. Conclusions

The final evaluation that emerges on Mariana is therefore generally negative, even if we find ourselves faced with one of the most serious cases of

pollution in Brazil, the recovery has not yet taken place. Dimensions such as community, environmental, institutional or economic ones have shown that are not able to adapt quickly to the new condition, nor be able to overcome problems in the short and medium term, although it remains clear that changes are always possible.

In this study the aim was not just to present a variation to the index of Cutter et al., but include a broader analysis, presenting and then investigating the various variables considered, on a case study in an area that appears little considered, South America and Brazil, by foreign scholars.

Many of the measures that have been presented and implemented by local and national institutions appears to be simple remedies, too late, when the disaster already occurred, and to a fairly small extent. It emerges above all how the lack of involvement of civil society, the lack of preparation to react to an event of this magnitude and the lack of education about potential risks, have been a weak link that could have been avoided. Even if they had accurate and updated prevention plans, training and informing the population could have ensured a faster response to the emergency, but a simple preparation or knowledge about risks and countermeasures were lacking before the rupture.

Clearly a complex system presents numerous obstacles, first of all the presence of a large number of agents involved, but a solution to this problem could be in operating on several dimensions and levels at the same time, since the modalities of influence -both positive and negative- between agents have been underlined. The crucial actors in the city, communities and institutions, working in synergy, could make long-term improvement possible, which would also influence other dimensions, contributing to positive results in the field of urban resilience.

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