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Abstract

Throughout its history, Brazil has faced recurrent droughts in some regions of the country. Recently, the drought has occurred with greater recurrence in other regions (for example the Southeast) affecting several sectors of the country such as energy and agriculture. The impacts of drought can last several years, and in the regions where this is the case, there are different impact degrees depending on the vulnerability and resilience of communities. This research analyses the case of Rio de Janeiro located in the southeast of the country, because there are not sufficient studies, and in the last years, the state has had to face the impact of drought. The main objective of this research is to evaluate the risk of drought in the state of Rio de Janeiro considering its temporal, social and geographical scale. A drought risk index was developed for Rio de Janeiro, which is composed of an index to calculate the hazard and another index for vulnerability. The assessment of the hazard was carried out using the Standardized Precipitation Index (SPI), and the vulnerability index was assessed by adapting the Social Vulnerability Index (SOVI) to social, economic and geophysical factors. The final result of the Drought Risk Index presented as a risk map, which can be a guide for decision makers at all levels of government, in order to take proactive measures to cope with drought and reduce the vulnerability of communities.

Keywords: Rio de Janeiro, Drought, Risk, Hazard, Vulnerability, SPI

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Zusammenfassung

Im Laufe seiner Geschichte wurden einige Regionen Brasiliens mit wiederkehrenden Dürren konfrontiert. In jüngster Zeit ist die Dürre mit größerer Wiederholung in anderen Regionen (wie dem Südosten) aufgetreten, die mehrere Sektoren des Landes wie Energie und Landwirtschaft betreffen. Die Auswirkungen der Dürre können mehrere Jahre andauern, und in den Regionen, in denen dies der Fall ist, gibt es unterschiedliche Auswirkungen je nach Verwundbarkeit und Resilienz der Gemeinden. Die vorliegende Arbeit analysiert den Fall von Rio de Janeiro in der südöstlichen Region des Landes, auf Grund von mangelnden Studien, und da der Staat in den letzten Jahren vermehrt Auswirkungen der Dürre bewältigen musste. Das Hauptziel dieser Forschung ist es, das Risiko der Dürre im Bundesstaat Rio de Janeiro unter Berücksichtigung zeitlicher, sozialer und geographischer Faktoren zu bewerten. Für Rio de Janeiro wurde ein Dürre-Risiko-Index entwickelt, der aus einem Index zur Berechnung der Gefährdung und einem anderen Index für die Verwundbarkeit besteht. Die Bewertung der Gefährdung erfolgte nach dem Standardisierten Niederschlagsindex (SPI), und der Index der Verwundbarkeit wurde durch die Anpassung des Social Vulnerability Index (SOVI) an soziale, wirtschaftliche und geophysikalische Faktoren erstellt. Das endgültige Ergebnis des Dürre-Risiko-Index wird in einer Risikokarte dargestellt, die ein Leitfaden für Entscheidungsträger auf allen Regierungsebenen sein kann, um proaktive Maßnahmen zur Bewältigung der Dürre und zur Verringerung der Verwundbarkeit von Gemeinden zu ergreifen.

Schlüsselwörter: Rio de Janeiro, Dürre, Risiko, Gefahr, Verwundbarkeit, Standardisierter Niederschlagsindex (SPI)

Resumo

Ao longo de sua história, o Brasil enfrentou secas recorrentes em algumas regiões do país. Recentemente, a seca ocorreu com maior recorrência em outras regiões (como o Sudeste) que afeta vários setores do país, da energia para a agricultura. Os impactos da seca podem durar vários anos, e nas regiões onde é esse o caso, existem diferentes graus de impacto, dependendo da vulnerabilidade e resiliência das comunidades. Esta pesquisa analisa o caso do Rio de Janeiro localizado na região sudeste do país, porque não há estudos suficientes, e nos últimos anos, o estado teve que enfrentar o impacto da seca. O objetivo principal desta pesquisa é avaliar o risco de seca no estado do Rio de Janeiro considerando sua escala temporal, social e geográfica. Um índice de risco de seca foi desenvolvido para o Rio de Janeiro, que é composto por um índice para calcular o perigo e outro índice de vulnerabilidade. A avaliação do risco foi realizada utilizando o Índice de Precipitação Padronizado (SPI), eo índice de vulnerabilidade foi avaliado pela adaptação do Índice de Vulnerabilidade Social (SOVI) a fatores sociais, econômicos e geofísicos. O resultado saiu como o Índice de Risco de Seca apresentado em um mapa de risco, que pode ser um guia para os tomadores de decisão em todos os níveis de governo, a fim de tomar medidas pró-ativas para combater a seca e reduzir a vulnerabilidade das comunidades.

Palavras-chave: Rio de Janeiro, Seca, Risco, Perigo, Vulnerabilidade, SPI

Resumen

Durante toda su historia Brasil ha enfrentado sequías recurrentes en algunas regiones del país. Últimamente la sequía se ha presentado con mayor recurrencia en otras regiones (como la región sudeste) afectando varios sectores del país desde energéticos hasta agrícolas. Los impactos de la sequía pueden durar por años, y en las regiones que se presenta se puede sentir en diferente grado dependiendo de la vulnerabilidad y resiliencia de las comunidades. En esta investigación se analiza el caso de Rio de Janeiro ubicado en la región sudeste del país, debido a que no hay suficientes estudios, y en los últimos años, el estado ha tenido que enfrentar el impacto de la sequía con mayor recurrencia. El objetivo principal de esta investigación es evaluar el riesgo a sequía en el estado de Río de Janeiro considerando su escala temporal, social y geográfica. Se desarrolló un índice de riesgo a sequía para Rio de Janeiro el cual está compuesto por un índice para calcular la amenaza y otro para la vulnerabilidad. La evaluación de la amenaza se realizó con el Índice Estandarizado de Precipitación (SPI), y la evaluación del índice de vulnerabilidad fue por medio de una adaptación del índice de Vulnerabilidad Social (SOVI) considerando factores sociales, económicos y geofísicos. El resultado final del Índice de Riesgo a Sequía en el estado es un mapa de riesgos, el cual puede ser una guía para tomadores de decisiones en todos los niveles de gobierno a fin de tomar medidas proactivas para hacer frente a la sequía y reducir la vulnerabilidad de las comunidades.

Palabras clave: Rio de Janeiro, Sequía, Riesgo, Amenaza, Vulnerabilidad, SPI

1. Introduction

“Drought is the consequence of a natural reduction in the amount of precipitation received over an extended period of time, usually a season or more in length”, although other climatic factors (high temperatures, winds, low relative humidity) are often associated with this hazard in many regions of the world and can significantly aggravate the severity of the event (Wilhite and Svoboda, 2000). Unfortunately, it does not exist a universal scientific accepted drought concept due to the processes that can cause drought, and this leads to confusion about when a drought starts and ends, and also to define if a region is being affected by drought.

The world’s costliest disasters are droughts (Wilhite, 2000), and their impacts affect not only natural habitats but also ecosystems, economic and social issues and mainly food supply, which is important for all vulnerable communities. Furthermore, Grey and Sadorf (2007) established that “the availability of an acceptable quantity and quality of water for health, livelihoods, ecosystems and production, coupled with an acceptable level of water-related risks to people, environment and economies”. Due to the above, the world’s governments and researches are trying to find an accurate way to predict drought and decrease the vulnerability of people and assets.

“Drought indices are currently used to monitor drought conditions in a real-time manner that is easily understood by final users” (Svoboda *et al.,* 2002; Shukla *et al,.* 2011). The World Meteorological Organization (1992) defines a drought index as an index which is related to some of the cumulative effects of a prolonged and abnormal moisture deficiency. The union of drought index and drought vulnerability index outcome in a drought risk index.

Droughts differ from other natural hazards (e.g., floods, tropical cyclones, and earthquakes) in several ways since the effects of droughts often accumulate slowly over a considerable period and may linger for years after the termination of the event (Wilhite and Svoboda, 2000). The onset and the end of droughts are difficult to determine, and by using and comparing drought risk indices can help to identify their impacts, their beginning and end, and how to reduce the vulnerability and enhance the resilience of both environment and communities.

For this purpose, risk analysis is defined as the process of identifying and understanding the relevant components of drought risk as well as the evaluation of the alternative strategies to manage that risk (Knutson *et al.,* 1998).

According to the above paragraphs, the research question that will guide this study is: which is the risk of the population exposed to drought hazard in the Brazilian state of Rio de Janeiro? Two indices have already been developed, to assess drought risk:

1) The Standardised Precipitation Index (SPI) evaluates the hazard, by defining wet or dry conditions of a place based solely on precipitation, on different time scales and 2) Modification of the Social Vulnerability Index (SoVI), to assesses drought vulnerability; this index is very flexible, and the variables to analyse are chosen by the social, economic and biogeographic characteristics of a given study site.

1.1 Justification

This project started as part of the integrated eco technologies and services for a sustainable Rural Rio de Janeiro (INTECRAL 2013-2017), and it is supported by the German Federal Ministry of Education and Research (BMBF) and the State Secretariat of Agriculture and Livestock Project Rio Rural (SEAPEC-PRR). This thesis work is part of the monitoring for decision support in integrated planning and risk management.

Droughts have had a significant social and economic consequence in Brazil, because it is densely populated and concentrates a high economic activity, modern agriculture and intense generation of hydroelectric power (Grimm *et al.,* 1998). The state of Rio de Janeiro is the second largest economic centre of Brazil (Kelman, 2015), and according to the estimates of the Brazilian Institute of Geography and Statistics (IBGE), by 2015 it is the home to 16,550,024 people. However, very few studies have been published about droughts in Brazil, and increasing the understanding of this phenomenon is of great importance for drought risk management.

In Brazil, half of all disaster events caused by natural threats are drought related, and generating half of the impacts in the number of affected persons (Sena *et al*., 2014). Also, in some of Brazil's regions (mainly northeast), an ongoing drought is the worst in recent decades, if not in the last century (Gutierrez *et al.,* 2014).

Drought impacts can last for years, and the regions can feel it in different degrees depending on their vulnerability and resilience. Lately the most affected zone by drought was Northeast Brazil, but in recent years this threat has been hitting the South. For that reason, it is important the improvement of drought policy and management in all level from national to local has been taking proactive measurements to cope and reduce the drought vulnerability.

1.2 Objectives

General objective

- To assess drought risk in the state of Rio de Janeiro considering its temporal scale, social and geographical extent.

Specific objectives

- Drought assessment through the estimation of the Standardised

Precipitation Index, to evaluate drought intensity, duration, frequency, and extent.

- To analyse drought impacts in different sectors (agricultural, hydrological, socioeconomic, and so forth).
- Vulnerability assessment, (to assess people and asset vulnerability to drought)
- Risk assessment
- Risk mapping (To represent the spatial distribution of drought risk.)

2. FRAME OF REFERENCES

Droughts are among the most complex climatic phenomena affecting society and the environment (Wilhite, 1993). The drought impacts can be easily identified as agricultural losses and limited water supply; it also has some indirect impacts that include losses to industry, decreased exports, and increased payments for food imports, all of which may lead to macroeconomic impacts (Benson and Clay, 1998). Drought is one of the most unreported threats because it takes some time to identify its onset (Wilhite, 2000); normally it is determined three months after it started.

In addition to the complexity in determining drought origins, there are also significant difficulties in quantifying their damages, as they affect many people and different economic sectors; drought it is extensive in terms of geographic extension and then the estimation of environmental and social impacts. To face with such difficulties, research on droughts has been oriented towards establishing indices and/or procedures that attempt to define, detect and measure them (Sheffield and Wood, 2012). According to the World Bank's (2012) in their report called "4 degrees" there is a drought tendency to increase in severity in some regions as southern Europe, Brazil, and Southern Africa, among others.

2.1 Definition of a drought

All droughts are caused by a deviation from normal conditions (Tallaksen and Van Lanen, 2004). Drought hazard events are slow onsets with a long duration. They are spatially extensive as compared to other hazards. Direct impacts can include agricultural losses, water shortages, and reduced hydropower supply. The risk associated with drought for any region is a product of both the exposure of the area to the event (that is, the probability of occurrence at various severity levels) and the vulnerability of society to the event (Wilhite, 2000).

For Paiva *et al*., (2017) drought is a normal and recurring extreme climate event, and it can be either in wet or dry regions. By 1993 it was still an absence of a precise and objective definition of drought, it is tough to quantify their social impact and mitigation (Wilhite, 1993). Drought could be present in every hydro climatic region and could appear in different components of the hydrological cycle (Wilhite, 2000).

Wilhite and Glantz (1985) grouped the types of drought into meteorological, agricultural, hydrological, and socioeconomic; these relations depend on the duration of the event (Figure 1). The World Meteorological Organization (WMO, 2009) has indicated that the SPI is the best suitable indicator for meteorological droughts. Meteorological drought is expressed solely on the basis of the degree of dryness, and the duration of the dry period (Wilhite, 2000a). It is usually defined by a threshold of precipitation deficit that is reached during a predetermined period of time (Eltahir, 1992). Meteorological drought depends on the characteristics of the region; the other three types of drought have more social facets and are more linked to anthropogenic activities.

Agricultural drought links some features of meteorological drought to the agricultural impacts, focusing on precipitation shortages that “should account for the variable susceptibility of crops at different stages of crop development” (Wilhite, 2000a). Hydrological drought refers to a deficiency in the flow of a volume of surface or ground water such as rivers, reservoirs and lakes; it can be used to determine the intensity of the drought (Valiente, 2001). This kind of drought may continue for many months or even years, since recharge of reservoir and groundwater is a long process (Wilhite, 2000a). The ability to manage water resources means that hydrological drought does not depend exclusively on the volume of water in natural or artificial deposits, but also how reservoir water is used (Valiente, 2001).

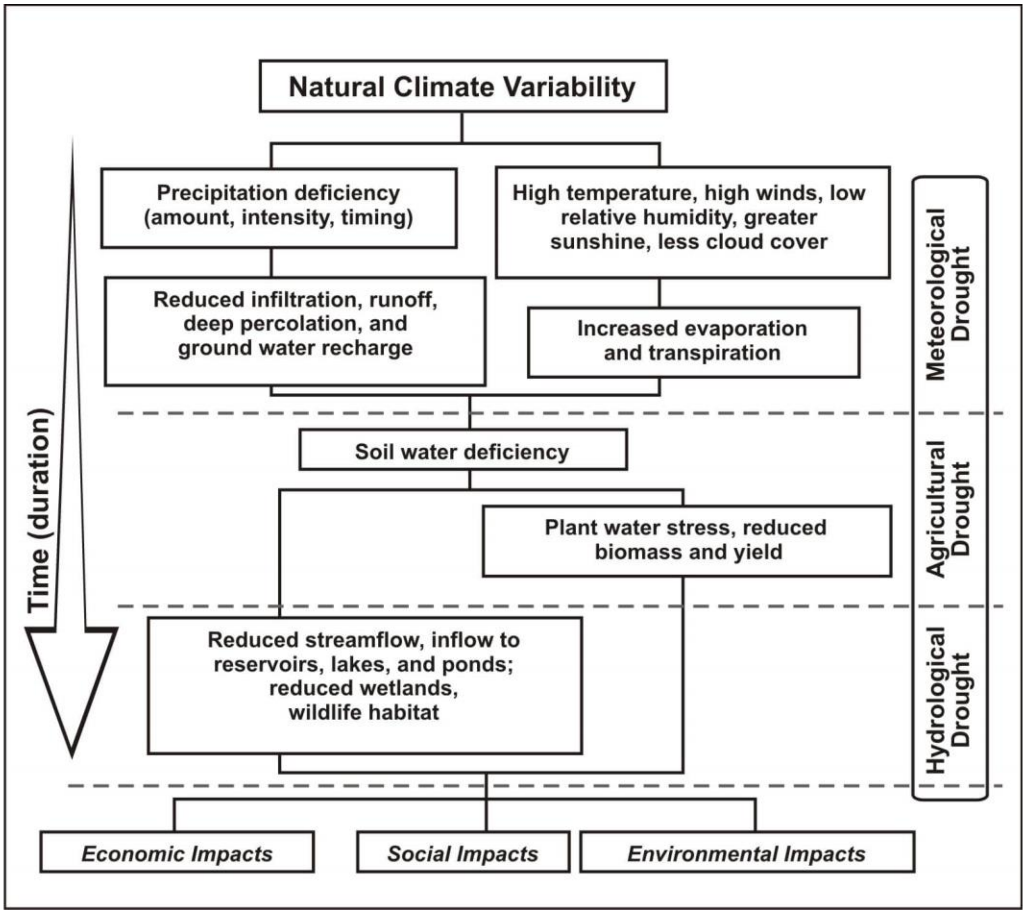


Figure 1. Relationship between various types of drought and duration of drought events (Wilhite, 2000a)

Finally, socioeconomic drought reflects the relationship between supply and demand for basic commodities, such as water, feed or hydropower, which depend on rainfall (Eltahir, 1992). It has elements of meteorological, hydrological and agricultural drought (Wilhite, 2000a). In conclusion, meteorological drought is a result of precipitation deficiencies, agricultural droughts are largely the result of soil moisture deficiencies and crops susceptibility, hydrological is associated with the effects of periods of precipitation deficit on surface of subsurface water supply and socioeconomic it depends on the supply and demand of economic product or services (Wilhite, 2000a).

2.2 Droughts in Brazil

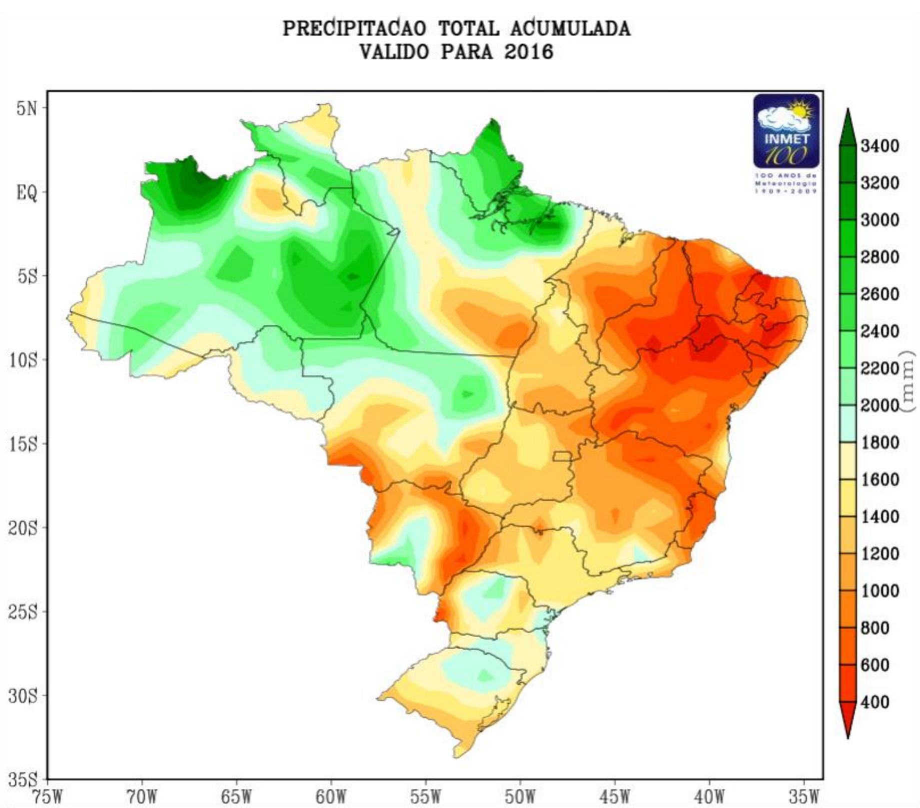
In this section of the chapter two, will be disccussed the brazil's climatic conditions and historic drought events the water access in the country also, will be analysed drought as a health problem in Brazil as well as the drought assessment, drought management, drought vulnerability and drought resilience in Brazil.

2.2.1 Brazil's climatic conditions and historic drought events

Brazil is a wealthy country regarding climate variety; it ranges from tropical in the centre north to temperate in the south. In addition, it has much humidity in the northern part of the Amazon region and semi-arid in a greater part of Northeastern (Gutierrez *et al*., 2014). Brazil has a high climatic diversity due to its continental dimensions, topography, the vast extent of its coast and the dynamics of air masses acting on its territory, all those factors have a strong influence on the condition temperatures and rainfall (Claval and Freitas, 2007).

There are three main air masses (equatorial, tropical and southern polar Atlantic) responsible for the major climatic oppositions in the country from the humid equatorial to the subtropical humid (Claval and Freitas, 2007). The precipitation depends mainly on the anomalous behaviour of the Atlantic Intertropical Convergence Zone (ITCZ), this is a quasi-permanent circulation system, and as a consequence, the interannual rainfall variability is significant and as a result human impact severe (Hastenrath, 2012); this human impact has been shown as their severe socio-economic consequences that led to starvation and mass exodus since the early century of Portuguese colonization, so that "Government initiatives to mitigate the effects of the droughts began in the 17th century. These included public work projects for the unemployed refugees, the construction of dams, plans for the exploitation of wind energy, and the development of alternative settlements" (Hastenrath, 2012).

Brazil has diverse rainfall regimes due to its large territorial area; this variation in rainfall regimes can be seen in the Amazon basin that is characterized by unusually heavy rain, while in the eastern of the country rainfall is modest with a semiarid area in the interior Northeast (NE) Brazil, in the coastal NE Brazil the amounts of rainfall is higher as the country average, while South Brazil is characterized by spatially variable rainfall (Rao and Hada, 1989). In map 1 can be observed the cumulative total annual rainfall for Brazil in 2016 developed by the Insitituo Nacional de Meteorologia (INMET).



Map 1. Cumulative total annual rainfall for 2016 (INMET, 2017).

Significant interannual rainfall variations characterise Brazil and, in some years, severe drought leads to intense human suffering and major economic problems (Brahmananda *et al*., 1993). As mentioned by Viana (2013, cited in Gutiérrez et al., 2014), droughts in Brazil are conditioned by the occurrence of the El Niño Southern Oscillation (ENSO) phenomenon, but the observation over the past decades reveals that its incidence and consequence are increasing linked to human action. ENSO is typically related to droughts in northern Brazil, including the semi-arid Northeast and the Amazon, while La Niña (negative ENSO phase) normally intensifies the drought in the southern part of the country (Gutiérrez *et al*., 2014).

The first drought register made by the European colonisers date from the 16th century; they mentioned the impact on the local indigenous people who fled from the interior to the coastal zone searching for water and food; since that the most frequent drought registers started in the 18th century (Magalhães and Martins, 2011). The country had to face some severe droughts like in 1877, 1900, 1915, 1919, 1932, 1958, 1970-83, 1987, 1998, 2003, 2010, among other years, in every period of drought impacts were big but also there were learning and preparedness during every drought period (Magalhães and Martins 2011).

The impacts of recent drought years, especially in Northeastern Brazil, are not only manifested in the economy but also there are social problems as indebtedness of farmers, migration, malnutrition, among others (Gutiérrez *et al*., 2014).

2.2.2 Uses of water in Brazil

In Brazil, as in other emerging economies countries, there are people who have reliable access to water, thanks to the evolution of the institutes realted to water issues and water and drought management in the country, but there are still diffuse populations and rain-fed farmers who do not have this reliable access to perennial water, but instead they are dependent on piecemeal mechanisms to cope water scarcity, and droughts and mainly the drought management is reactive (Gutiérrez *et al*., 2014). Moreover, the water supply programs to spread to the population still lack the ability to meet the currently observed needs; then the management is poor and does not anticipate need from future stresses (Gutiérrez *et al.*, 2014).

The Brazilian farmers know the risk they have to face with climate change impact on their crops, including droughts, despite this, just a few farmers take out insurance; therefore, it is important to develop a robust agricultural insurance framework under the lead of the public sector (Marc Tüller *et al*., 2009).

Oliveira *et al.,* (2016) analysed the different forms of energy that can be utilised in Brazil. Due to the safe water access in the past the principal sources of electricity are by hydropower, but due to the increase of droughts hydroelectric energy is no longer a viable option, so they identify in their study the different sources of alternative energy sources, their cost, success in Brazil and how the energy can be efficiently delivered getting as a result that wind power could be the best viable option for complement hydroelectric power.

2.2.3 Drought as a health problem in Brazil

Drought can have impacts on different health risk factors as the inadequate water consumption and sanitation; it also can disrupt local health services, can affect to chronic health effects as malnutrition, respiratory conditions, psycho-social disorders, among others (Sena *et al*., 2014).

Prolonged drought in a developing country could result in diseases and loss of lives, while in a developed country it could lead more in economic losses (UN/ISDR 2009 in Sena *et al*., 2014). Some studies about links between some diseases and drought show that women have more levels of anxiety than man (Coêlho *et al*., 2004). If the drought it is too prolonged, migration will take place, which is then causing economic and political instability in both areas the ones that were left and the new areas (Corvalan *et al*., 2005 in Sena *et al*., 2014).

Sena *et al*., (2014) mentioned that the health sector in the country follows a well-documented framework that has three stages: risk reduction, disaster management, and recovery. They also list the relevant health conditions for the semiarid region of Brazil, among which are: access to drinking water, food, and nutrition, air quality, mental health and behaviour, health services, basic sanitation, and hygiene, among others. All these points are important if we want to make an effective drought risk management, and it is necessary to analyse them from all the perspectives and scales.

Coêlo *et al*., (2004) developed a psychological study about the reactions to drought in Brazil. It was the first study to address this kind of response; they found "that participants in the drought area had significantly higher levels of anxiety and emotional distress", which is a common response to slow-onset disasters. Their work was a base to confirm what (Sena *et al*., 2014) found about the great difference in how gender response to a drought event, for example, women living in drought affected areas showed higher levels of anxiety, and men appeared more emotionally distressed than counterparts in areas not affected by drought. "This is likely the consequence of women's drought related impaired role as producers and providers" (Sena *et al*., 2014).

The Ministry of Health in Brazil decided to establish a clear management process to implement actions in management, recovery, and adaptations; to get this it will be a partnership between several areas as climate change, disaster risk reductions, civil defense, health, water resource, among others (Sena *et al*., 2014).

2.2.4 Drought assessment in Brazil

To quantify drought severity and extent, (Paiva *et al*., 2017) proposed to convert the value of the studied variable into an index for further interpretation. Although just one index cannot be applied to the whole world, it is necessary to identify the drought type and which population we are going to analyse, also thinking of the temporal scale, the region and cultural situation.

Different efforts from all the sectors have been made to reduce Brazilian disasters, taking into account all the hazards that can affect the country, but always drought is leading the list. Researches as Almeida *et al.,* (2016) have been working to improve disaster risk reduction in Brazil.

To assess the spatial extent of drought, Paiva *et al*., (2017), propose to use remote sensing data, inasmuch as there are more than four decades of data thanks to spatial missions, and currently it is a good broad data set of observations from the space that provides us global and reliable information from a wide range of sensors. Studies made by (Paiva *et al*., 2017) show the drought more recurrent for Northeast and Southeast Brazilian regions from 2002 to 2014.

Most of all research articles have analysed drought with SPI (Awange *et al*., 2016). This index is exclusive for precipitation, and it requires a long span of precipitation observations; Guttmann (1999) recommends at least 50 years of data, and more for multiyear droughts.

2.2.5 Drought Management in Brazil

According to Gutiérrez *et al*., (2014), Brazil started to focus on mitigating against drought after a harsh drought event from 1877-79, so the central government began the construction of the first reservoir. Since then, the water management of the country has been improving. In 1909 the Inspection Agency for Works against Drought (IOCS) was created with a strong emphasis on building infrastructure for water distribution mainly in the Northeast; after this agency was called the Federal Inspection Agency for Works against Drought (IFOCS), and finally got the name of National Department of Works against Droughts (DNOCS), which is the current agency (Gutiérrez *et al*., 2014). Since then, many new institutions were created, abolished or changed, always with the aim of improving the system of water management and the definition of protection and guarantee for the water use rights. Nowadays there is a National Policy of Water Recourses, a National System of Water Resource Management and the National Water Agency (ANA). ANA is responsible for the implementation and coordination of the National System and undertakes the quantitative and qualitative control of the resource (Gutiérrez *et al*., 2014).

Gutierrez *et al.,* (2014) mentioned that despite the efforts of all ministries and agencies to drought monitoring and early warning, there is an expressed need for a more comprehensive understanding of the institutional relationships and the compatibility between federal and state agencies with respect to meteorological, hydrological, climatological, geological, and agricultural data, information and tools.

There are two special states that can be declared by an affected region during a drought event: Situation of Emergency and State of Public Calamity.The first one is an abnormal situation caused by the disaster that creates damages and losses, which is significant enough for the local government to be partially unable to respond. The second one, State of Public Calamity also refers to an abnormal situation provoked by disaster, but the damages and losses are grave enough for the local government to be substantially unable to respond (Gutiérrez *et al*., 2014). Despite this, in Brazil, there is still a not systematic procedure to distinguish the difference between public calamity and emergency (Gutiérrez *et al*., 2014).

It has been documented the recurrent drought impact in the human living (Carvalho, 1973; Davis 2001; Hastenrath, 2012). The constant droughts in Northeast Brazil have forced people living there to move mainly to Minas Gerais as labour force or to São Paulo, the countries' industrial hub (Hastenrath, 2012)

Brazil has been making a considerable effort in regulating the water management system that now has reinforced a bureaucratic organisation that favours primarily technical knowledge. However, it restricts access and even blocks public participation that is supported by legal principles (Sousa Júnior *et al*., 2016). However, regarding water governance, the heterogeneity with federal and state level arrangements has created a multi-level cooperation that seems to be a promising instrument for the future of water management.

The extensive impact of droughts throughout the country indicates that there is still need to improve drought risk management, recognising the local, temporal, technological and political context from community to national level. Only then it will be possible to develop solutions to every specific sector, as agricultural, industrial, human consumption, for instance.

2.2.6 Drought vulnerability and resilience in Brazil

At least until 2014, when Gutierrez *et al*., analysed the drought preparedness in Brazil, assessments of vulnerability or resilience to drought have not been formalised at the national level, neither the networks for monitoring and evaluating or associated vulnerability indicators, also they still need to consider economic analyses on the costs and benefits of drought preparedness.

There are some archival records that show that drought periods have a recurrence of ten years and may last for periods of three years. Normally, these droughts are known in Brazil from the 16th century in the Northeastern region, when the settlers observed the damages caused by this hazard and the impacts of the economic activities and social life (Claval and Freitas, 2007).

One of the first studies about vulnerability to drought and preparedness in Brazil were in Brooks (1982). He explained all the historical context and conducted some interviews to know the population and stakeholders perception, where most of them wanted to improve their resilience, and with some adjustments in the political preparedness, drought risk would be decreasing every year.

There is still a need for research in social topics related to drought; so far only a few studies have been made, and they cover only a small part of all the social issues that can be aggravated by drought. All the methodologies analysed still have some challenges and limitations, especially in the way to improve climate change perception and drought, but also to link the results to effective politics and help in decisions for stakeholders.

2.3 Drought in Rio de Janeiro State

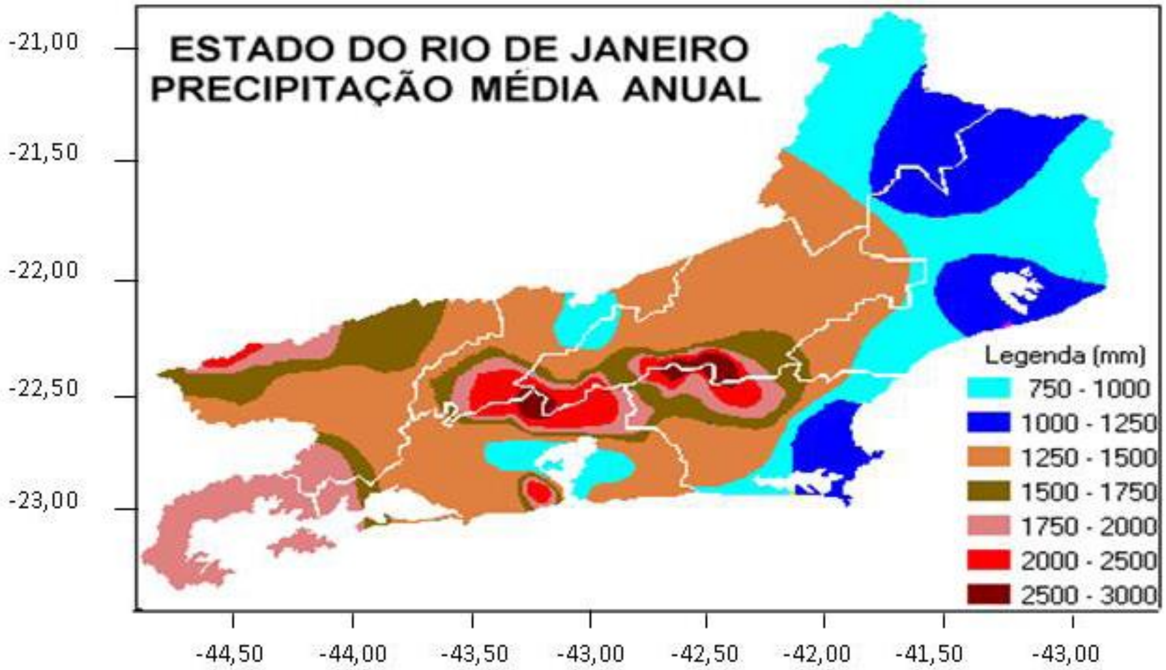
Rio de Janeiro is second-most populous city and municpailty in Brazil. The city is located in the state of the same name, which has about 16.64 million inhabitants according to the estimation by 2016 (IBGE, 2015). The state is divided into 92 municipalities. To the south and east, the state is bordered by the Atlantic Ocean. Also, it has hundreds of rivers, canals, lagoons and marshes; just in the urban area of the state are 217 rivers and canals with a total length of 639 km and four lagoons that total 15.2 km^2 of area, also there is the largest urban forest in the world, the Floresta da Tijuca (3,972 hectares) (Xavier and Magalhães, 2003).

The local water sources in the metropolitan region are insufficient to meet the needs and demands, nowadays, “most of the water comes from the intern-basin transfer from the “Paraiba do Sul River Basin through infrastructure that was originally built primarily to generate power” (Kelman, 2015).

2.3.1 Climatic and hydrographic Conditions in Rio de Janeiro State

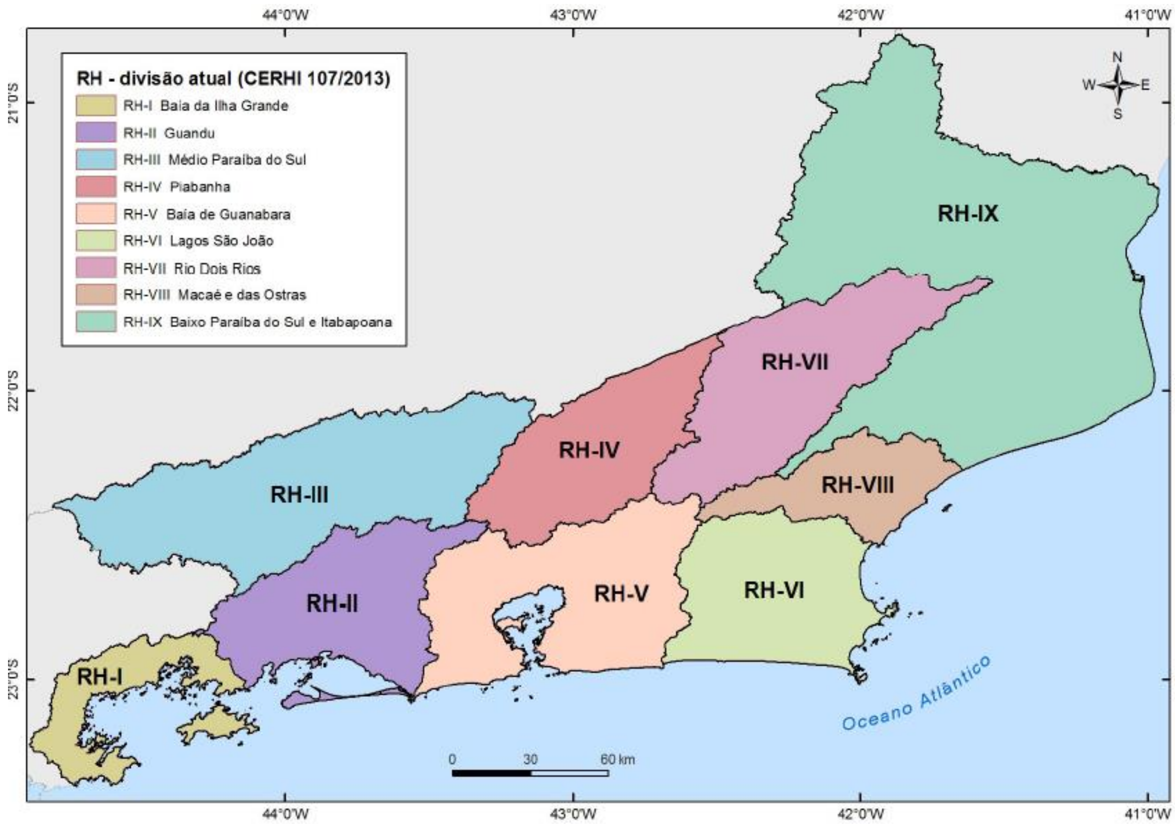
Rio de Janeiro state is located in the tropics, so a tropical climate is predominant, but the state is also marked by plains, hills and mountain ranges, which creates a place with a diversity of landscapes so well delimited physically, that their sinuosities become visible in the amount of precipitation and temperature. This, in turn, “represents the intrinsic relationship between temperature and altitude, relief and precipitation, vegetation cover and evapotranspiration, and all these directly with the solar incidence” (Bastos and Napoleão, 2011).

It can be seen in the map 2 that the rainfall index ranges from 750 mm to 1250 mm per year (André *et* al., 2008). During the year, rainfall distribution shows that most of the rainfall occurs in the period from October to March; part of the north and northwest regions is classified as semi-moist and partly as dry (André et al., 2008). However, there is evidence that there is a visible process of decreasing rainfall in the last 40 years, with negative implications for activities dependent on the water resources of these regions (Marques et al., 2001 in André et al., 2008). Although precipitation is high in the mountainous regions and in the southern part of the State, there are low rainfall rates in the north, northwest and Lagos regions (André et al., 2008).



Map 2 Annual average rainfall distribution for the state of Rio de Janeiro, in the period 1971-2000 (André et al., 2008)

Due to the high climatic variety that exists in the state, 17 bioclimatic domains and nine hydrological regions have been identified (Map 3) (Bastos and Napoleão, 2011).

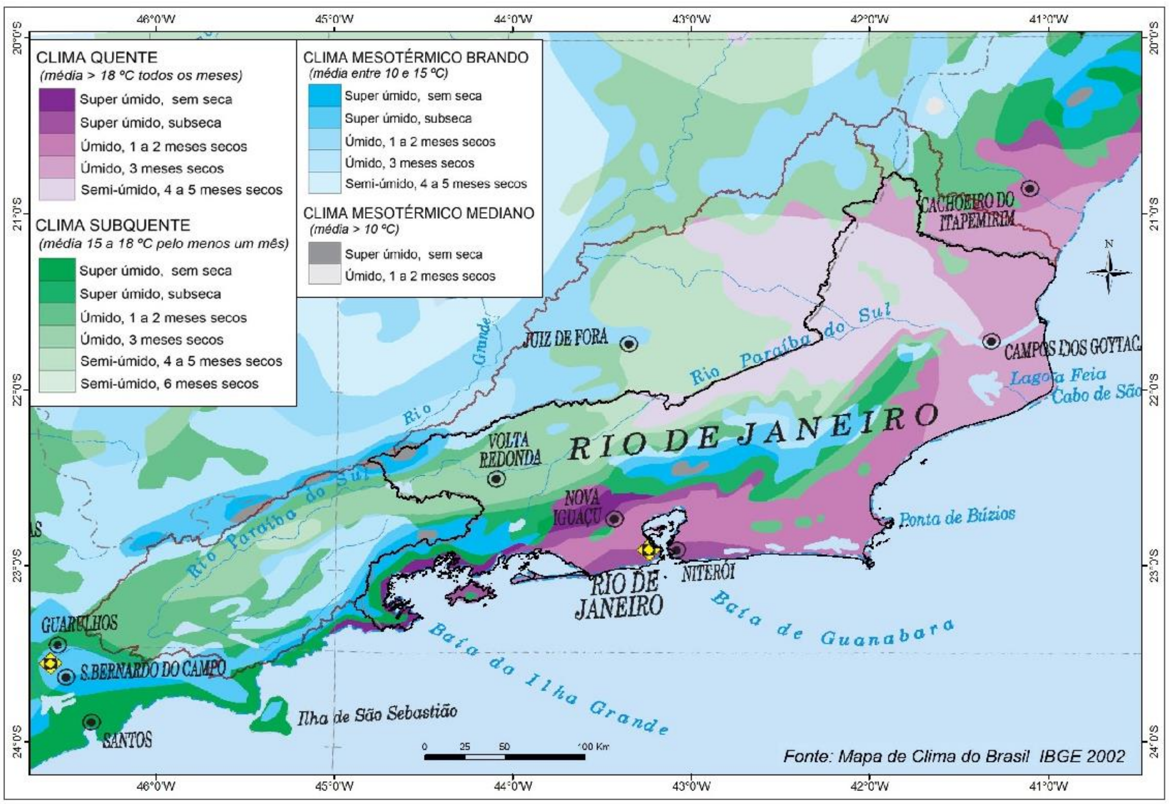


Map 3. Territorial division in Hydrographic Regions of the State of Rio de Janeiro (Fundação COPPETEC, 2014).

In the National Hydrographic Division, the state of Rio de Janeiro is part of the Hydrographic Region called Atlantic Southeast; this region comprises river basins that flow into the Atlantic Ocean, in the southeast part of the country (COPPETEC, 2014). Therefore, from the point of view of the management of water resources, the state of Rio de Janeiro is directly linked to the other states that constitute the Southeast Region of the country, emphasizing that, in the fluvial hierarchy, the territory of Rio de Janeiro is downstream of other states, receiving in their waters the impacts of uses in neighbouring territories (COPPETEC, 2014).

In the classification of the country's climate, it is observed the marked influence of the relief in the great climatic variations that occur in the state of Rio de Janeiro.

The determining role of the great mountain ranges (Mar and Mantiqueira) is clear in the passage of a hot and humid climate of the regions of plains and hills, located between the coastline and Serra do Mar, to a mesothermic climate in the highest areas and a climate dry sub-hot in the interior regions, between the great saws (Map 4).



Map 4 Climate of the state of Rio de Janeiro and shared basins (IBGE, 2002 in COPPETEC, 2014).

Within the classification of Köppen's climate the state of Rio de Janeiro has 2.1% of its territory in the tropical zone with an AF Köppen classification (Without dry season) it includes the capital Rio de Janeiro and Niterói, in the same tropical zone Am (monsoon) climate was identified with a coverage of 5.3% of the state of Rio de Janeiro and it is defined across the edge of Guanabara Bay and finally in this tropical zone was also Aw (with dry winter) climate that spreads all over the north and northwest coastline, without exceeding altitudes of 250-300 m at it covers the 44.1% of the state territory (Alvares et al., 2013).

In the oceanic climate without dry season in the Köppen's climate classification for the state of Rio de Janeiro were identified just two classification the Cfa (with hot summer) in 14.3% of the state territory and the Cfb (with temperature summer) with a coverage of 9.4% of the state; Rio de Janeiro has Cfa climate in a narrow range, between Am and Cfb, in the Serra of Mar mountain and more northerly between Am and Cw, while Cfb climate it is located in west Rio de Janeiro state, this Cfb climate is in 9.4% of the state in the Orgãos Mountain National Park at altitudes above 2,100 m and with annual mean temperature lower than 12°C (Alvares et al., 2013).

Finally in the state of Rio de Janeiro it is the climate with dry winter according to the Köppen's climate classification the Cwa (hot summer) that covers 17.9% of the state territory and the Cwb (temperature summer) which is in the 6.9% of the state; the Cwa coincides with the administrative between Rio de Janeiro, São Paulo and Minas Gerais; while the Cwb climate follows the boundary of the Minas Gerais state in the Serra do Mar Mountain where the altitude is higher than 650 m (Alvares et al., 2013).

2.3.2 Drought Management in Rio de Janeiro State

Brazil began to express its position on the debate about water security in 2012 with the National Water Security Plan, which aims "to define the main structural and strategic interventions in the management of water resources in order to ensure the supply of water for human consumption and for the use in productive activities, and to reduce the risks associated with critical events" (Santos, 2016). This plan was published in October 2016.

Water management in the state is regulated by the state Law 3,239/1999, which established the state water policy and created the water resource management system (Santos, 2016). The state law includes six instruments: State Water Resources Plan; State Program for Conservation and Revitalization of Water Resources; River Basin Plans; Classification of the rivers into classes, according to its predominant uses; Granting to water resources use; Charging users for the water resources uses; and State System of Water Resources Information (Santos, 2016).

Santos (2016) also points out that state of Rio de Janeiro has some instruments that regulate the state's water security, such as the use of hydroelectric power, or the quantity or quality of existing water, among others; and the responsible to authorize water use in the state is the Instituto Estadual Do Ambiente (INEA).

In June 1992, it was stated in the principle 10 of the Rio Declaration on Environment and Development that the best way to deal with environmental issues is to ensure the participation at the appropriate level of all the people involved. Despite this, there is still insufficient mobilisation of those who are involved in water management in order to increment the promotion of water security (Santos, 2016).

Santos (2016) developed a research about water security in the metropolitan region of Rio de Janeiro, and she found that the water scenario is already highly impacted quantitatively and qualitatively. Also there is "a low degree of entanglement between the agents responsible for water management in the state".

2.3.3 Politics and Preparedness

Like other countries, Brazil has been implementing an emergency response to droughts and massive water infrastructure works projects, but despite these efforts, significant impacts from water shortages have persisted (Magalhães and Martins, 2011). As a result, there have been recent efforts to shift Brazils' reactionary response to improvements in resilience and cope capacity by a coherent drought policy at the national and subnational level (Magalhães and Martins, 2011).

Drought preparedness involves monitoring, forecasting, vulnerability, resilience and impact assessments, and, response planning and mitigation measures (Wilhite *et al*., 2005). Furthermore, drought as part of the climatic variability plus the changes by climate change is intensifying the pressure on freshwater systems, quality, and availability.

It is important to work together with government, communities, stakeholders, scientist, so it will be possible to learn from each other and develop capabilities to learn and adapt to drought risk, recognising its vulnerabilities and opportunities and then, to take a more efficient and informed decision by the stakeholders.

Drought preparedness can increase the adaptive capacity, resilience and decrease vulnerability because it moves beyond the traditional reactive approach (Engle, 2012; Hayes *et al*., 2004, cited in Gutierrez *et al*., 2014). Wilhite *et al*., (2005) encapsulated drought preparedness in three basic categories: monitoring and early warning/prediction, vulnerability/resilience and impacts assessments, and, mitigation and response planning measures.

The Brazil Drought Preparedness and Climate Resilience non-lending assistance program (Drought NLTA), was created in July 2013 and it was initiated by The World Bank as a request for the government of Brazil to support a process to shift the reactive paradigm to a proactive drought management (Bretan and Engle, 2017).

Even though Brazil has been facing drought for centuries, a definite solution that reduces the most possible the vulnerability to drought has not been found yet. Different actions as politics have been implemented, but the government has not structured an integrated plan to incorporate all the several sectors, and the develop of related measures are still necessary; it is required a new integrated comprehensive and strategic plan to allow a real solution of droughts (Campos and Carvalho Studart, 2008).

Maneta *et al*., (2009) developed an economic model for agriculture specifically to drought in Brazil so it can be optimised to maximise farmers' yearly net revenues. The model was applied to test capabilities and investigate the economic behaviour of farmers, their agricultural production and the interactions between farming systems and the hydrologic. Maneta *et al.,* (2009) found that severe reduction in the amount of precipitation force farmers to change product and input mix, but the "reduction in net revenues is not proportional to the precipitation cutbacks". The strategy that farmers adopt to deal with decreased rainfall depends on their location within the basin (Maneta *et al*., 2009).

2.4 Risk Assessment

The ISDR (2004) declared that risk should represent the probability of harmful consequences, or expected losses, resulting from the interaction between anthropogenic or natural hazards and vulnerable conditions. This thesis considers the equation described by Dilley *et al*., (2005), where risk is a combination of hazard, exposure and vulnerability components

$$\text{Risk} = \text{Hazard} \times \text{Exposure} \times \text{Vulnerability}$$

Hazard it is understand as the probability of occurrence of a potentially disastrous event during a period of time on a given site, while vulnerability represents the level of losses experienced by an element or group of elements at risk due to the occurrence of a natural phenomenon of a given magnitude expressed on a scale from 0 (no damage) to 1 (total destruction) (Wilhite, 2000). Moreover, exposure represents the overlap as time as spatial distribution of human assets and hazard events (Dilley *et al*., 2005)

“The overall impact of drought on a given country/region and its ability to recover from the resulting social, economic and environmental impacts depends on several factors” (Shiferaw *et al.,* 2014). It is necessary to understand the importance of studying vulnerability thinking in the capabilities of the population, as well as physical, biological, and socioeconomic factors and thus, the vulnerability, can be changed through policies, technology, and so forth. Although drought is a natural hazard, the term drought management implies that human intervention can reduce vulnerability and impacts. To be successful in this endeavour, many disciplines must work together confronting the complex issues associated with detecting, responding to, and preparing for the inevitability of future events (Wilhite, 2000).

Risk management uses the information obtained through risk assessments to provide better ways for individuals and groups to reduce hazards or cope with their effects (Swaney, 1996). One way to assess the drought in a specific region is using a drought index, which is defined as “an index which is related to some of the cumulative effects of a prolonged and abnormal moisture deficiency” (World Meteorological Organization, 1992 in Heim Jr, 2002). Friedman (1957) (cited in Heim, 2002) identified four basic criteria that any drought index should meet:

1. The timescale should be appropriate to the problem at hand.
2. The index should be a quantitative measure of large-scale, long-continuing drought conditions.

3. The index should apply to the problem being studied.
4. A long accurate record of the index should be available or computable.
5. The index should be able to be computed on a near-real-time basis.

2.5 Hazard Assessment

The index more selected for assessing the hazard is the Standardised Precipitation Index (SPI). It was developed by McKee *et al*., (1993) and is designed to take into account precipitation to determine drought conditions. This index interprets observed rainfall as a standardised procedure on a rainfall probability distribution function (normal) and for meteorological drought; the SPI emerges as a highly valuable estimator of drought severity (Keyantash and Dracup, 2002). Furthermore, it can probabilistically describe precipitation shortages across any desired time scale (Redmond, 2000).

The SPI has several characteristics that are an improvement over previous indices, including its simplicity and temporal flexibility that allows its application to water resources on all timescales, also this index would have assisted in being able to detect the onset of the drought and monitor its progression (Hayes *et al*., 1999). The main advantage of the SPI is its capability to analyse drought impacts at different temporal scales (Edwards and McKee, 1997). For instance, the SPI explains a much larger proportion of the observed variability in yield departures in the drier location compared with other indices (Mavromatis, 2007). Serrano *et al*., (2012) stated that the SPI and Standardized Precipitation Evaporation Index (SPEI) tended to record better the occurrence of streamflow droughts than other studies.

Santos *et al*., (2010) in Portelo *et al*., (2005) summarized several advantages of the SPI such as the flexibility, as it can be applied at various time-scales; the less complexity involved in its implementation, (relative to other drought indices); it is adaptable to other hydroclimatic variables; its suitability for spatial analysis, allowing comparison between sites in a given region as it is a normalized index.

2.6 Vulnerability analysis

Vulnerability to hazards such as drought it is still a subject of scientific debate, regarding both its concept and its analysis. This concept has gone from being a nonexistent element of risk or disasters to a level or degree of affectation and, it is considered as a complex social and historical construct that reflects the competencies of the population to cope with and overcome a disturbance generated by Threat (Wilches Chaux, 1993).

The basic concept of vulnerability comes directly from the work of Hewitt and Burton (1971), which was entitled "The Danger of Place." In 1994, Blaikie *et al*., defined vulnerability as the ability to anticipate, cope, resist and recover from the impact of a natural hazard. With this vision was expanded as a social construction and presented the model of pressure and liberation. But in 2009 the UNISDR (United Nations Office for Disaster Risk Reduction) defined vulnerability as “The conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, community, assets or systems to the impacts of hazards”.

In the absence of not a definitive vulnerability definition, Birkmann (2006) created the key spheres of the concept of vulnerability in order to provide an overview of it.

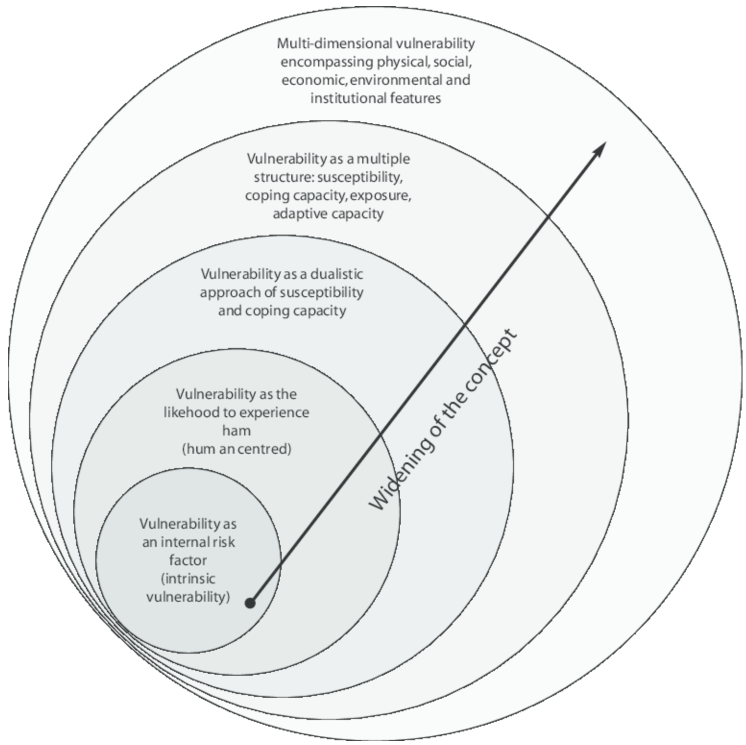


Figure 2. Key Spheres of the concept of vulnerability (Birkmann 2006)

The analysis of vulnerability is complex because it depends on both biophysical and socioeconomic drivers that determine the capacity to cope with drought (Naumann *et al.,* 2013). As it has been stated in previous paragraphs, the main problem with droughts is food and water supply; nonetheless, this will depend on capability failure which depends on market access and people's social, economic, and political entitlements (Sen, 1999).

Another aspect of risk assessment concerns the scale of analysis, mainly with the production of risk and vulnerability indicators and indices (Almeida *et al.,* 2016). Multiple methodologies for assessing drought vulnerability have been developed, but every place is different and has multiple temporal, social, biogeographic, economic, and other factors, thus, the measuring variables for a vulnerability study must be chosen according to the characteristics of the location, in this case, according to the social, cultural, and economic context of Rio de Janeiro state.

2.6.1 Vulnerability factors

For this research, it was decided to use the word "factors" rather than "types" of vulnerability, because in fact, as Chardon and González (2002) explain, no vulnerabilities are belonging to a specific field. The vulnerability is one, depending and composed of different factors.

Vulnerability factors are different for each community, as they have their own social, economic and geographical context. It should be taken into account that the same community will not be affected by the same factors as 50 years ago since social conditions have changed and the vulnerability factors are not the same, even if they combine with the same physical threat. The vulnerability is relative and evolving, so it must be analysed from the smallest spatial scale possible always considering time and space as primordial factors.

The synergy between factors of vulnerability and the strong link between vulnerability and the hazard makes it possible to point out that vulnerability is extremely dynamic, that is, for a given threat and in a given space, vulnerability varies over time, both as qualitatively and as quantitatively (Chardon and Gonzalez, 2002).

A modification of the Social Vulnerability Index (SoVI), developed by Cutter *et al*., (2003) has been used in multiple studies (Burton 2012; Tate 2011; Berry 2008, Cutter *et al*., 2006; Cutter and Emrich 2006; Wood 2010; Schmidtlein *et al*.,; among others). The main advantage of this index is the opportunity to choose the variables according to the place of study, and all the next steps are followed by a simple equation.

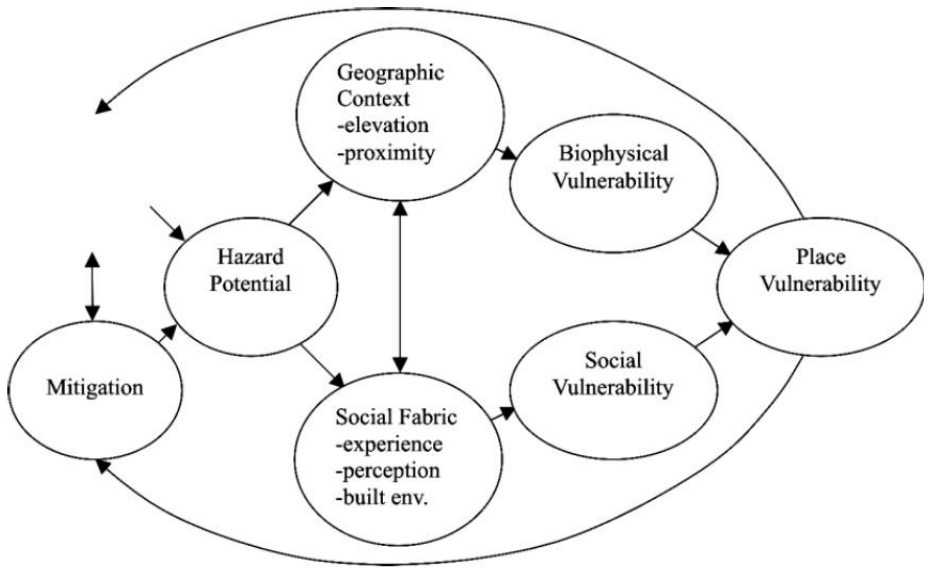


Figure 3. The Hazards-of-Place Model of Vulnerability (Cutter *et al*., 2003)

Cutter *et al*., (2003) shows that the potential hazard is a result of the interaction between threat and mitigation, due to the reciprocal relationship between the number of mitigation measures taken to reduce risk and increase or decrease risk according to the amount of these measures. This potential danger can be moderated or improved by a geographic filter and by the social fabric (reducing vulnerability), while geographical location provides the proximity to the threat or exposition (Cutter *et al*., 2003).

Unlike other authors, Wilches Chaux (1989) considers eleven different types of vulnerability factors, including economic, social, political, technical, ideological, cultural and technological vulnerability. For this study, the biophysical, social and economic factors are analysed, so it was necessary to divide the study into these same variables, which are explained below.

SOCIAL FACTOR

For Cutter *et al*., (2003) the social factor or social vulnerability is a multidimensional concept that helps to identify those characteristics of communities and people that allow them to respond and recover from natural hazards. It is an approach used in demographic studies and measurement of rural and urban poverty. For its part, CEPAL (1998) refers to the importance of the social factor as an element to understand both the objective conditions of defencelessness in which the subordinate sectors of society are and the subjective perception of insecurity derived from the radical modification of the socioeconomic game rules.

This factor can be seen and treated as a more accurate entity; however, it is a multifaceted entity with many different characteristics and attributes. The social characteristics are incorporated to compensate the basis of the general degree of vulnerability according to its geographical and socioeconomic location interwoven with its physical environment (Sebald, 2010).

Cutter *et al*., (2003) point out that there is a consensus with the social scientific community about the main factors influencing social vulnerability. These include lack of access to resources (including information, knowledge and technology); limited access to political power and representation; social capital, including social networks and connections; beliefs and customs; experience and age; physically limited and fragile individuals; among others.

ECONOMIC FACTOR

The economic factor before the occurrence of a disaster is one of the least studied and the current research point to the calculation of the costs generated in the affected place. This is one of the most important factors in the period of reconstruction and resilience of the communities.

Economic vulnerability is the indirect relationship between income at national, regional, local or population level and the impact of extreme physical phenomena. In other words, poverty increases the risk of a disaster (vulnerability of the most depressed sectors, unemployment, insufficiency of income, exploitation, labour instability, difficulty in accessing education, health and leisure services) (Wilches Chaux, 1987).

BIOPHYSICAL FACTOR

Research has given more attention to the study of biophysical vulnerability and the vulnerability of the built environment than the social (Cutter *et al*., 2003). One reason for this is the difficulties in quantifying and measuring the social factor (Kumpulainen, 2006). Also, social matters cannot have the exact formula, even if it is the same community or applied to other contexts.

3. METHODOLOGY

To achieve the objectives of this thesis work, the methodology was divided into four stages:

1) Drought assessment through the Estimation of the Standardised Precipitation Index (SPI).
2) Vulnerability Assessment.
3) Risk assessment.
4) Risk Mapping.

The Organization for Economic Co-operation and Development (OECD) published a manual for building indexes in 2008, which is composed of the following steps:

1. Formulation of a theoretical framework
2. Selection of indicators
3. Measurement error evaluation
4. Data Transformation
5. Imputation of missing data
6. Standardization
7. Multivariate analysis
8. Weighting, aggregation and sensitivity analysis

Although there is no methodology accepted by the scientific community to measure drought risk, some methods have been improved. In this research were assessed two Indexes the SPI and a modification of the SoVI by Cutter *et al*., (2003).

3.1 Drought Assessment using SPI

The next flowchart (Figure 4) shows the methodology steps followed in this research to drought assessment using the Standardize Precipitation Index.” The SPI is a powerful, flexible index that is simple to calculate. In fact, precipitation is the only required input parameter. In addition, it is just as effective in analysing wet periods/cycles as it is in analysing dry periods/cycles” ((McKee and others, 1993, 1995 in WMO, 2012).

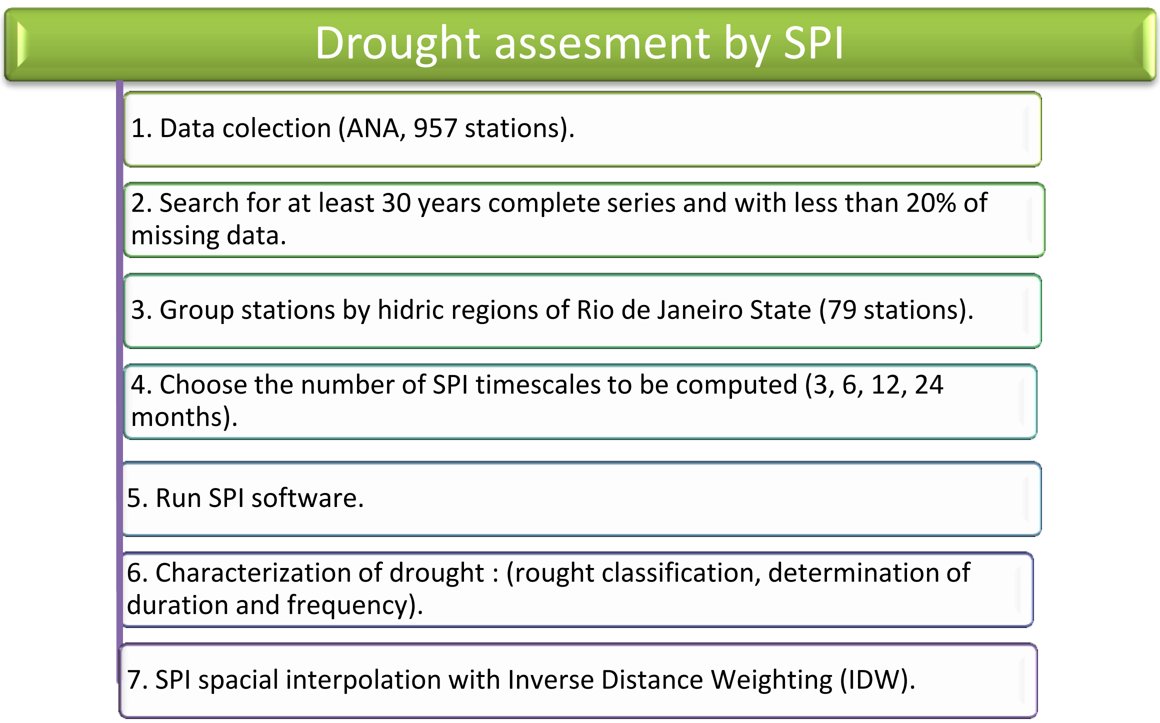


Figure 4.Hazard assessment methodology flowchart

The first factor to analyse in this thesis is the drought hazard, which is defined by the SPI. This index is exclusive for precipitation, and it requires a long span of precipitation observations; Guttman (1999) recommends at least 50 years of data, and more for multiyear droughts. The SPI is determined by normalising the precipitation for a given station after it has been fitted to a probability density function (McKee *et al*., 1993; McKee *et al*., 1995; Edwards and McKee, 1997; Guttman, 1998, cited in WMO, 2012).

The long-term precipitation record is fitted to a probability distribution, which is then transformed into a normal distribution (Edwards and McKee, 1997). Positive SPI values indicate greater than median precipitation, and negative values indicate less than median precipitation. A drought begins when the SPI first falls below zero and ends when the SPI becomes positive (McKee *et al*., 1995). Although SPI can monitor wet periods, it is typically used to assess the length and magnitude of drought events (WMO, 2012). For this thesis, characteristics such as intensity, duration, frequency and geographic extent were estimated.

The SPI it is calculated by taking the difference of the precipitation from the mean for a particular time step, and then dividing it by the standard deviation (Sönmez *et al.*, 2005):

$$SPI = \frac{\mathrm{xi} - \bar{x}}{\sigma}$$

The monthly precipitation time series is modelled using different statistical distributions. Thom (1958) found the gamma distribution to fit climatological precipitation time series well (Sönmez *et al.*, 2005). The gamma distribution is defined by its frequency or probability density function:

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1}\ e^{x/\beta} \quad for\ x > 0$$

Where:

α > 0 is a shape parameter,

β > 0 is a scale parameter,

$x > 0$ is the amount of precipitation,
$\Gamma(\alpha)$ defines the gamma function.

In order to fit the distribution to data requires α and β to be estimated. They are valued for each station, for each time step of interest (3 months, 1 year, 2 years) (Sönmez *et al.*, 2005).

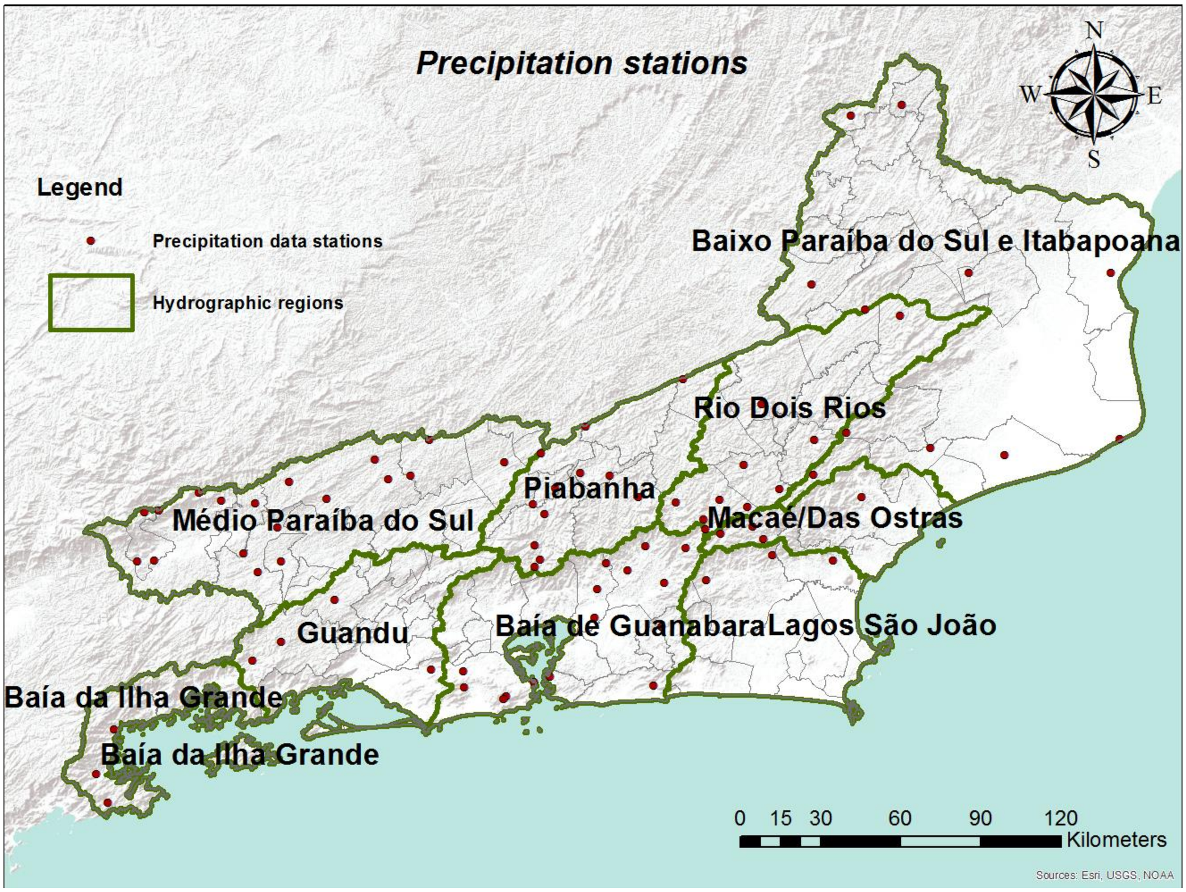
Multiple time scales were estimated; these periods reflect the drought impact on the availability of the different water resources. For this research, as McKee *et al*., (1993) suggested, the SPI was calculated for 3, 6, 12 and 24 months, so that droughts can be characterised according to the affected sector and the type of drought So, for example, 1- or 2-month SPI calculation it is used for meteorological drought, anywhere from 1-month to 6-month SPI for agricultural drought, and 6-month up to 24-month SPI or more for hydrological drought analyses and applications (WMO, 2012)..

Table 1 provides an example of SPI values and Drought Categories by Mckee *et al.,* (2003):

Table 1 Classification of the SPI adaptation from McKee et al., (2003).

SPI Values	Drought Category
0 to -0.49	Near normal
-0.50 to -0.99	Mild drought
-1.00 to -1.49	Moderate drought
-1.50 to -1.99	Severe drought
≤ -2.00	Extreme drought

All precipitation data were obtained from the National Agency of Water (ANA) and analysed by hydrological region. As mentioned before, the state of Rio de Janeiro has nine hydrological regions (Map 3); 79 stations were selected in the whole state with data from 1975 to 2005 (Map 5). The selection was made considering stations with at least 30 years of complete data and having less than 20% of missing data.



Map 5. Used precipitation stations in the state of Rio de Janeiro to run the SPI.

Once all the stations were complete, and the missing data were filled, the program SPI_SL_6 was used. The program is open source and was downloaded from http://drought.unl.edu/MonitoringTools/DownloadableSPIProgram.aspx.

With the SPI results, the characterization of the drought was carried out. This analysis was performed grouping the precipitation stations by their location in each hydrographic region being analysed in total 12 stations for Baía de Guanabara, 8 for Baixo Paraíba do Sul and Itabapoana, 3 for Baía da Ilha Grande, 4 stations for Guandu, 3 for Lago São João, 9 for Macaé and das Ostras, 21 for Médio Paraíba do Sul, 10 for Piabanha and, finally 9 stations for Rio Dois Rios. The determination of a drought event was considered according to Wilhite (2000) from two consecutive months, in this study taken from two consecutive months with negative values. Moreover, “The prolongation of this condition and the degree to which rain decreased permitted the determination of duration in months and intensity of the event” (Nuñez *et al*., 2007).

When the SPI analysis was finalized, and before creating a map, it was necessary to classify them. As the risk analysis is done in quintiles, the drought categories were scaled in five values (Table 2). The same classification (McKee et al., 2003) in quintiles was made for vulnerability analysis.

Table 2 SPI drought categories with their respective hazard scale.

SPI Values	Drought Category	Hazard scale
0 to -0.49	Near normal	Very Low
-0.50 to -0.99	Mild drought	Low
-1.00 to -1.49	Moderate drought	Medium
-1.50 to -1.99	Severe drought	High
≤ -2.00	Extreme drought	Very High

Finally, the most intense and longest drought events for each SPI time scale were mapped by the spatial interpolation of the estimated SPI data at each precipitation station within the state. Also, the ones with moderate negative peaks were mapped and finally the lowest detected peaks, in order to perform the scaled maps in extreme, medium and near normal drought. The spatial interpolation was performed in ArcGIS software using the Inverse Distance Weighted (IDW) technique, which determines a cell values using a linearly weighted combination of a set of sample points.

3.2 Vulnerability Assessment

The methodology used in this thesis to calculate the vulnerability index was based on the one applied by Cutter *et al*., (2003), which follows the same method as other indexes analysed, but this one with the advantage that it consists of a quantitative, retrospective, cross-sectional, comparative, experimental and impartial study.

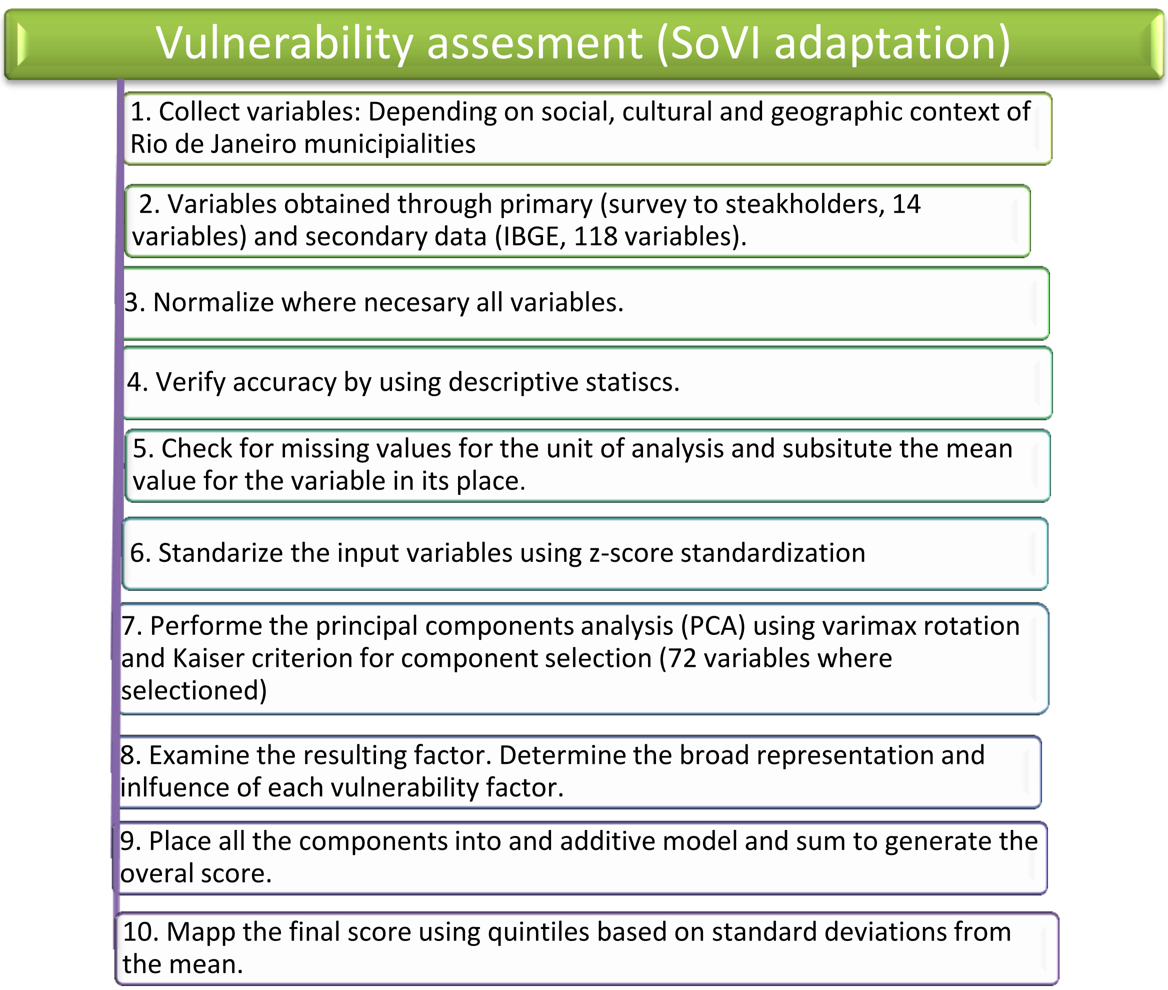


Figure 5.Vulnerability assessment methodology flowchart, adapted from Cutter (2016).

In order to conduct the vulnerability assessment, indicators were needed, and these are defined according to the literature reviewed about determinants of drought vulnerability. The variable component selected should be representative for the state of Rio de Janeiro according to its social, spatial, economic, temporal, and environmental context included in economic, social and biophysical factors. The following table shows some of the selected variables:

Table 3 Indicators and variables for social vulnerability factor

Social	
Indicator	**Variable**
Population	-Population density -People per household
Education	-People illiterate -People over 14 years old without schooling
Poverty	-People in poverty
Disability	-People with disabilities
Knowledge of the hazard	-Knowledge and perception -Internal prevention plans -Answer of the community -Political prevention and mitigation
Management level against the risk of drought	-Agencies (Civil protection, police, firefighters) -Training (organisations, institutions) -Health workers
Health	-Number of Hospitals -Number of Health centres -Number of Health workers -Population without medical coverage
Animals	-Number of Pets -Number Farm animals
Employment	-Kind of employment -Unemployment
Accessibility	-Distance to places to obtain water
Indices	-Gini Index -Health index -Human development index

Table 4 Indicators and variables for economic vulnerability factor.

Economic	
Indicator	**Variable**
Population	-Population density -Economically active population -Occupation rate (employees) -People per household
Land use	-Agricultural surface -Green area -Forest -Commercial -Habitational -Industrial -Forestry -Fishing -Poultry
Economic units (Dollars per month)	-Farming -Tourism -Industry -Fishing/Aquaculture -Commercial -Number of economic units
Employment	-Unemployment -Workers in the main economy
GDP	-Gross domestic product -Poverty Index

Once the variables were selected, data were collected on the statistical basis of the Brazilian Institute of Geography and Statistics (IBGE), the State Environmental Institute (INEA), Environmental Secretary of Rio de Janeiro, risk perception and internal prevention plans surveys for stakeholders. The next step was the purification of the variables that could be used, which were selected and standardised through z-score values, with mean 0 and standard deviation of 1.

To complement the analysis of vulnerability a questionnaire to stakeholders of each municipality was applied; this survey was developed following the model proposed by Taylor *et al.*, (1998) (figure 6), who describes how four elements shape drought perception. These items are experience, memory, definition, expectation and behaviour. In addition to the model proposed by Taylor *et al.,* (1988), some recommendations and methodologies of authors such as Meza *et al.,* (2010) and Udmale *et al.,* (2014) were taken and adapted (Annexe 1).

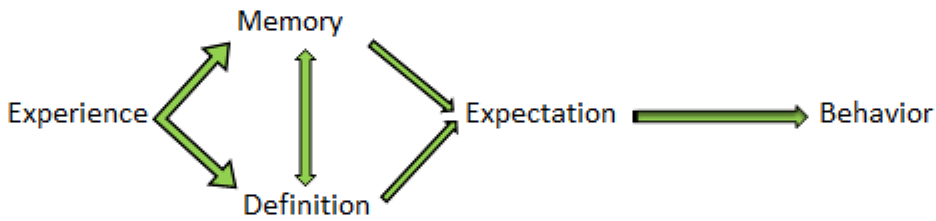


Figure 6. Elements of Drought perception (Taylor et al., 1988)

A Principal Component Analysis (PCA) was carried out to reduce the number of variables that were originally and, with the newly created ones, to explain much of the total variability of the data (Hair *et al*., 1987). Then a varimax rotation and Kaiser's criterion for the PCA selection was used. The number of factors to be used it is under the Kaiser's criterion which specifies the retention of all components with an egeinvalor greater than 1 (Hair *et al*., 1987). This is the most used technique, and it was used for the Social Vulnerability Index (SoVI) by Cutter *et al*., (2003). All those previous analyses from the creation of the z-score to the varimax rotation were undertaken in SPSS 17.0 Software.

The resulting variables and indicators were analysed. Further, it was identified what they roughly represent and in which way they can influence vulnerability, that is, whether they tend to increase or decrease it. Each variable has a value depending on its contribution to vulnerability, with a positive contribution (+) increase of vulnerability and negative (-) decrease.

Previous work has already been done using this method as in Lummen and Yamada (2014), Cutter *et al*., (2003), Ortiz (2012) and, Merlo (2014). Then a table is generated to show the indicators and resulting variables for each vulnerability factor and its contribution to it for each vulnerability factor.

Once the main components to be analysed are known, the scores of each factor were obtained, given to a geographic space determined, in this case, the 92 municipalities that make up the state of Rio de Janeiro in Brazil. Standardisation for scoring was done as follows, depending on how they contributed to vulnerability.

If the contribution is positive:

a) X_i
b) $\bar{X}$
c) $X_i - \bar{X}$
d) $(X_i - \bar{X}) - \min (X_i - \bar{X}) = X$
e) $X \div \max (X)$

If the contribution is negative:

a) X_i
b) $\bar{X}$
c) $X_i - \bar{X}$
d) $(X_i - \bar{X}) - \max (X_i - \bar{X}) = X$
e) $X \div \min (X)$

Where Xi represents each value.

When the scores for each vulnerability factor were obtained, they were added by the additive method, to get a total vulnerability for each geographic space determined and for each factor.

To be able to map the results it was necessary to divide them into a classification, same done in the drought assessment (quintile). To get this, there is a need to obtain the mean and standard deviation of the total vulnerability in order to determine the degree of vulnerability, stating as follows:

Standard deviation <-0.1 = Very low vulnerability

$-1.0 < \sigma < -0.5$ = Low vulnerability

$-0.5 < \sigma < 0.5$ = Medium vulnerability

$0.5 < \sigma < 1.0$ = High vulnerability σ > 1.0 = Very high vulnerability

With the obtained classifications, the vulnerability was represented in maps using ArcGIS, where the colour red represents very high vulnerability, orange high vulnerability, yellow medium vulnerability, light green low vulnerability, and green very low vulnerability.

3.3 Risk Assessment

Risk assessment of drought, according to Singh (2013) needs to involve three components:

1. Hazard assessment which is defined as the product of magnitude and the frequency of the event corresponding to that magnitude.
2. Vulnerability assessment which is a measurement of the sensitivity of the exposed system.
3. Risk assessment incorporating both hazard and vulnerability factors (included in the exposure).

The final step was to integrate the three risk components to generate a Drought Risk Index (DRI). To obtain this, it was necessary to assign risk levels for drought analysis in a quintile scale, where the biggest number has the greatest risk.

If in the above statement either drought or vulnerability scores 0, there will be no risk associated with the place analysed.

3.4 Drought Risk Map

As the WMO (2012) outlines, “it is often in map form that the data best communicate a message based on a geographic context to the decision-maker trying to understand drought severity and spatial extent”. Drought risk was represented using the Inverse Distance Weighting (IDW) algorithm in the ArcGIS software; this is used when the data points are scattered but dense enough to represent local variations, the data then is weighted approaching to balancing the points without information with the nearest points. Both hazard and vulnerability were classified to a common measurement scale of 1 to 5. Each one was assigned with 50 percentage of influence for the final DRI.

Mapping in a scale of categories allows classifying the data from the less likely occurrences to the most likely ones (Figure 7).

Very low
Low
Medium
High
Very high

Figure 7. Scale of categories used in risk map

4. RESULTS

The results were divided into three main subcategories, according to the objectives and methodology: the hazard analysis, vulnerability assessment and finally the integration of both indexes in a Drought Risk Index for the whole state of Rio de Janeiro.

4.1 Index for Drought Hazards

The drought hazard was analysed by its geographical and temporal representation; the results were assessed according to SPI for 3, 6, 12 and 24 months scales using data from 1975-2005 period. For these scales, the longest-lasting events and with more frequency drought records were taken in order to define the most extreme drought occurred in any region of Rio de Janeiro State. Moreover, the moderate drought and the near normal period were considered.

Also, a table was developed (Table 5) with the characteristics of drought events that occurred in Rio de Janeiro state from 1975 to 2005 for each hydrographic region. In Table 5 it can be observed that in the scale of SPI-3, SPI-6 and, SPI-12, the hydrographic region with the longest drought period, were Guandu with 23%, 22% and, 19% , respectively. In SPI-24 the hydrographic region with longest drought period in drought was Baía de Guanabara with 16% of the time in drought, whereas the hydrographic region that was the shortest time in drought was Medio Paraíba do Sul on a scale of analysis of SPI- 24.

The most important drought events for their intensity and average duration were in 1994, but also from the end of 2000 to 2002, there was an increase in drought records in all the SPI analysis.

Table 5 Characteristic of drought events occurring in Rio de Janeiro from 1975-2005.

Hydrographic region	Time scale	Frequency	Average duration (Months)	Time in Drought (%)
Baía de Guanabara	SPI-3	9	3	22
	SPI-6	7	5	20
	SPI-12	4	8	18
	SPI-24	3	13	16
Guandu	SPI-3	9	3	23
	SPI-6	7	5	22
	SPI-12	4	8	19
	SPI-24	2	20	15
Baía da Ilha Grande	SPI-3	8	3	15
	SPI-6	7	4	15
	SPI-12	5	7	14
	SPI-24	3	11	15
Lago São João	SPI-3	11	2	20
	SPI-6	11	3	20
	SPI-12	5	5	17
	SPI-24	2	8	13
Macaé and das Ostras	SPI-3	7	2	15
	SPI-6	5	3	14
	SPI-12	4	5	12
	SPI-24	2	11	10
Médio Paraíba do Sul	SPI-3	6	2	14
	SPI-6	5	2	13
	SPI-12	4	3	10
	SPI-24	2	7	7
Baixo Paraíba do Sul and Itabapoana	SPI-3	7	2	15
	SPI-6	6	2	14
	SPI-12	5	4	13
	SPI-24	3	7	10

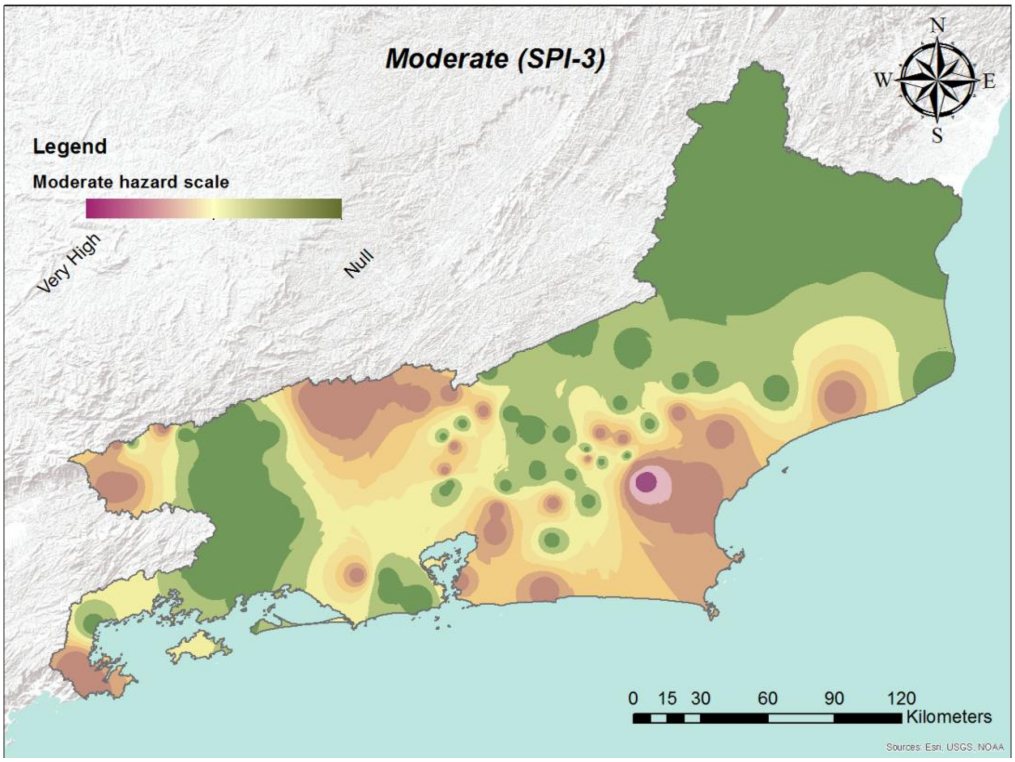
Table 5 Characteristic of drought events occurring in Rio de Janeiro from 1975-2005

Hydrographic region	Time scale	Frequency	Average duration (Months)	Time in Drought (%)
Piabanha	SPI-3	6	2	14
	SPI-6	7	3	14
	SPI-12	4	5	13
	SPI-24	2	9	9
Rio Dois Rios	SPI-3	6	2	15
	SPI-6	7	3	14
	SPI-12	4	5	13
	SPI-24	2	6	9

4.1.1 SPI-3

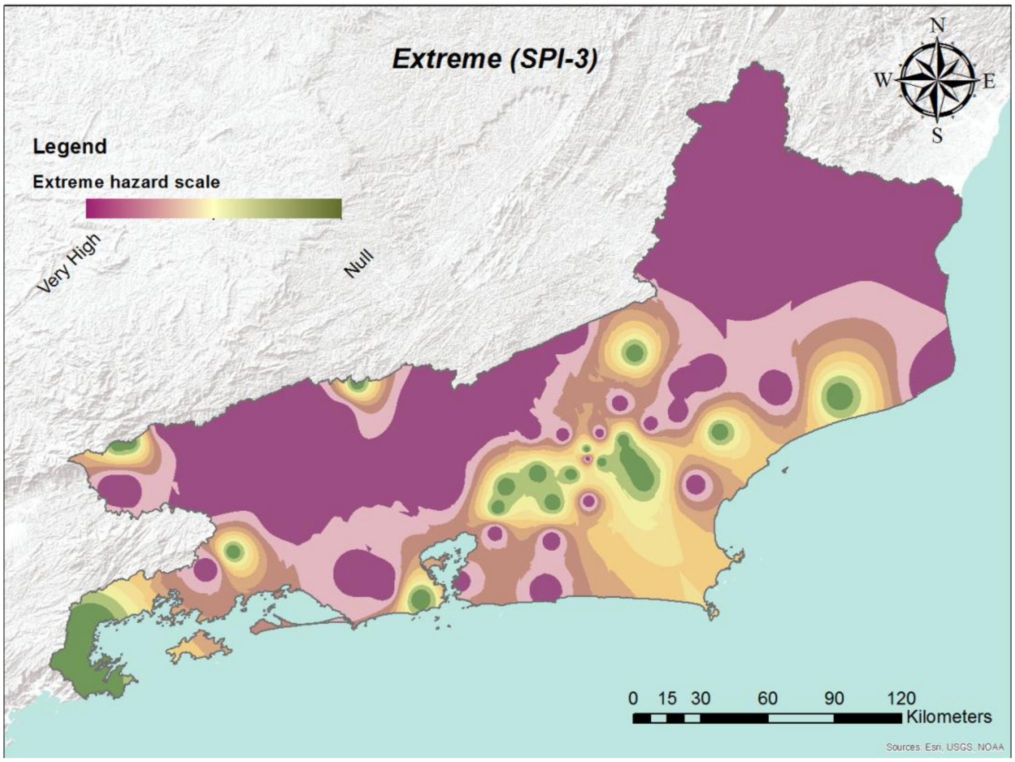
Each category (extreme, moderate and near normal) were mapped to show the spatial distribution of drought hazard. SPI 3 and 6 were not mapped in the near normal scale because all the stations reported periods without drought.

In the SPI-3 analysis scale, it was found that for a moderate hazard to drought scenario (Map 6), while the hydrographic regions of Baixo Paraíba do Sul and Itabapoana and Baía da Ilha Grande had a high hazard score. Only the region of Lagos São João showed a very high hazard zone between the municipalities of Casimiro de Abreu and Silva Jardim and high hazard in the whole hydrographic region.



Map 6 Moderate drought hazard in SPI-3 scale for the state of Rio de Janeiro.

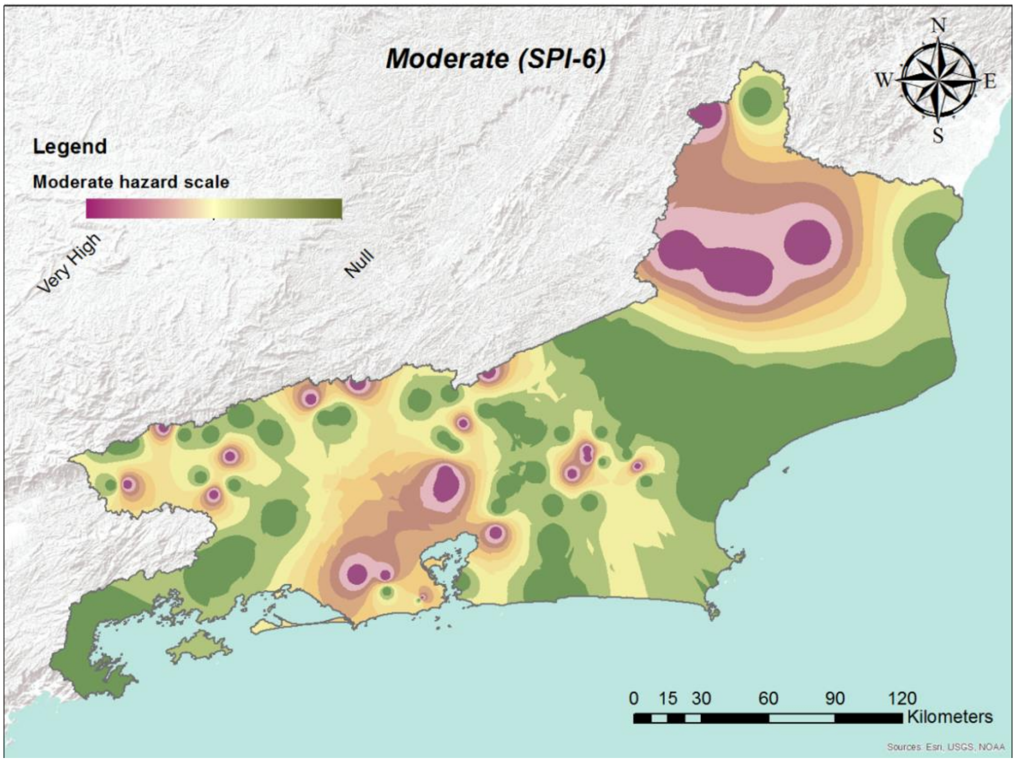
In an extreme drought scenario, the hydrographic regions that came out with the greatest hazard score for an SPI-3 scale analysis (Map 7) were Baixo Paraíba do Sul and Itabapoana and Piabanha; here it can be seen that the regions with very high threat are more extensive than in a moderate case for the same scale of SPI analysis (3).



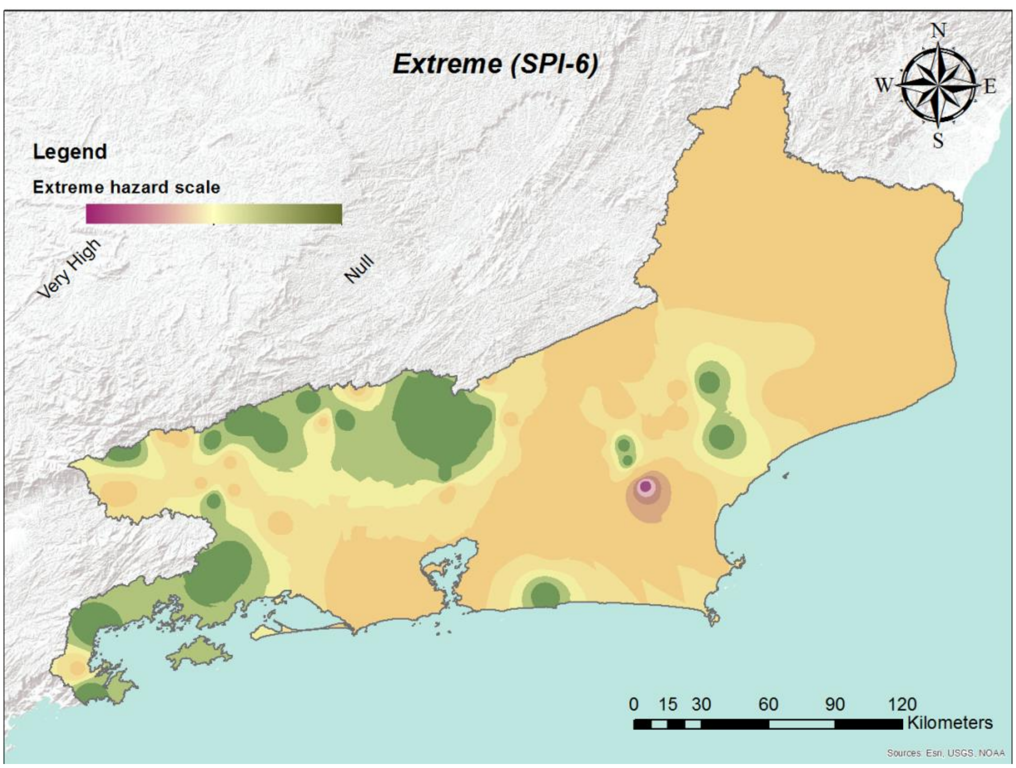
Map 7 Extreme drought hazard in SPI-3 for the state of Rio de Janeiro.

4.1.2 SPI-6

Maps 8 and 9 show the spatial distribution of drought hazard at the extreme and moderate scales for an SPI-6 analysis. In an extreme drought scenario (Map 9), mainly moderate drought hazard in the hydrographic regions of Baixo Paraíba do Sul and Itabapoana, Baía de Guanabara and Lagos São João can be identified, with a very high hazard zone between the municipalities of Casimiro de Abreu and Silva Jardim. In contrast, in a moderate drought scenario (Map 8), there are more regions with very high hazard mostly in the hydrographic regions of Baixo Paraíba do Sul and Itabapoana and Piabanha.



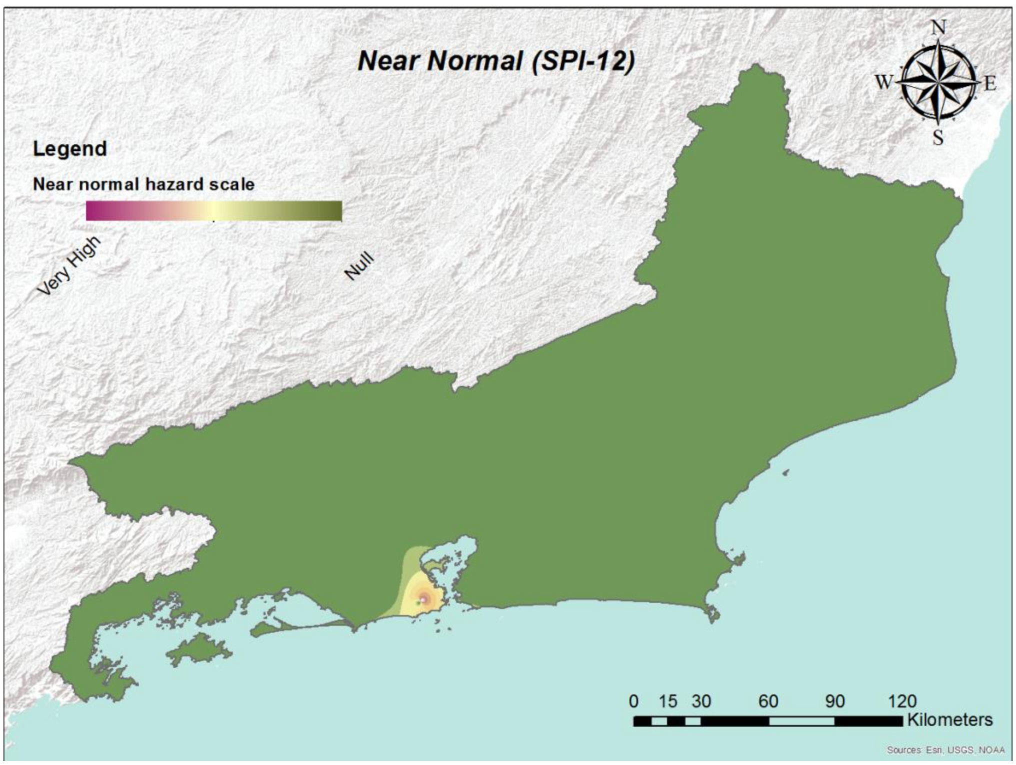
Map 8 Moderate drought hazard in SPI-6 for the state of Rio de Janeiro.



Map 9 Extreme drought hazard in SPI-6 for the state of Rio de Janeiro.

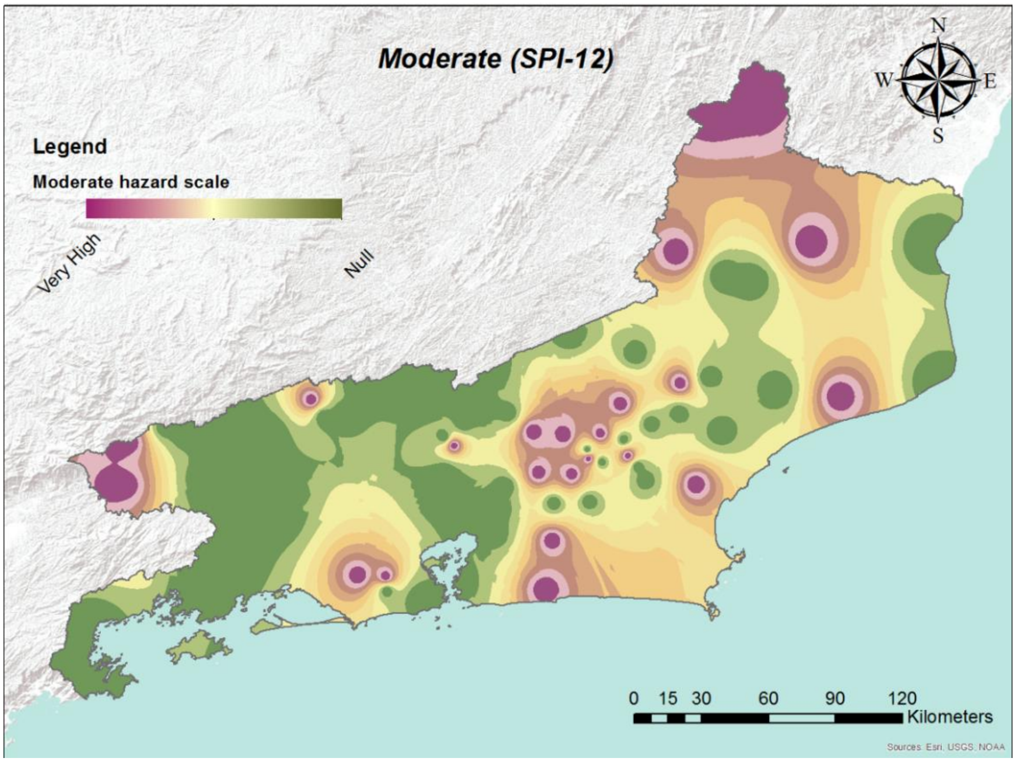
4.1.3 SPI-12

For the SPI-12 scale the near normal, moderate and extreme scales of drought were mapped as well. In a near normal scale (Map 10) almost the entire state came out without threat, except for Baía de Guanabara with a small area of hazard drought in the municipality of Rio de Janeiro.

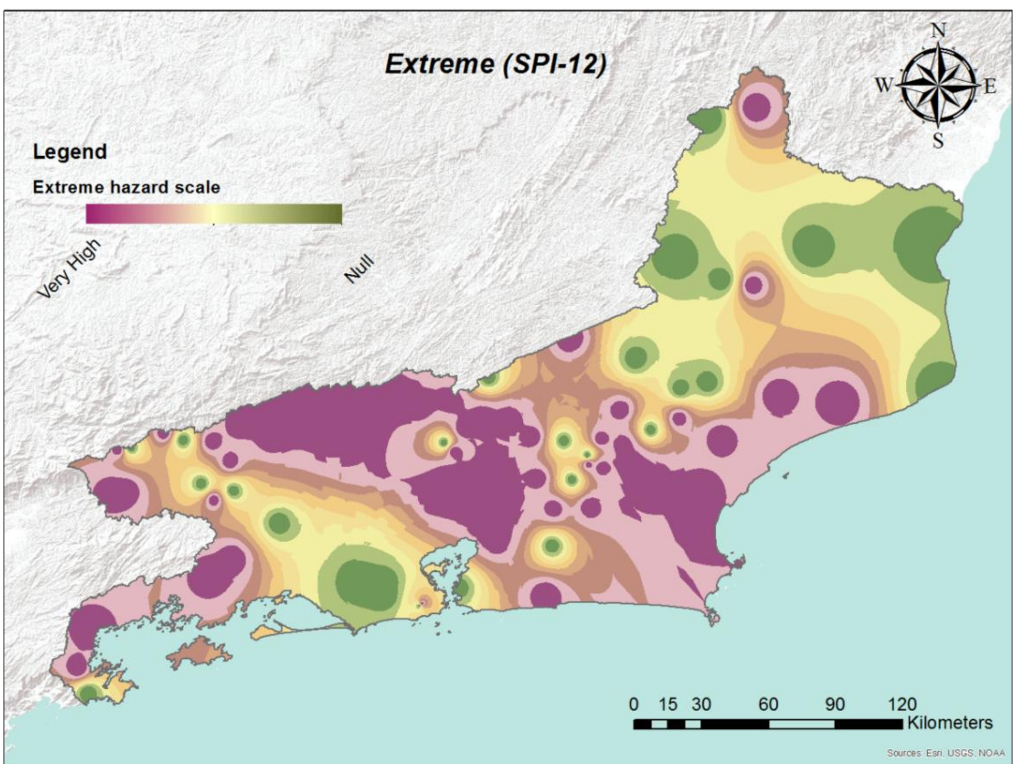


Map 10 Near normal drought hazard in SPI-12 for the state of Rio de Janeiro.

Moderate drought scenarios (Map 11) showed very high drought scenario mostly in Baixo Paraíba do Sul and Itabapoana, and in Medio Paraíba do Sul, with some dots in Piabanha and Baía de Guanabara, being Baía da Ilha Grande the hydrographic region with the majority of its territory in the lowest degrees of hazard. While in an extreme drought scenario (Map 12) four hydrographic regions with very high hazard were identified: Baixo Paraíba do Sul and Itabapoana, Medio Paraíba do Sul, Piabanha, Baía de Guanabara and Lagos São João.



Map 11 Moderate drought hazard in SPI-12 for the state of Rio de Janeiro.



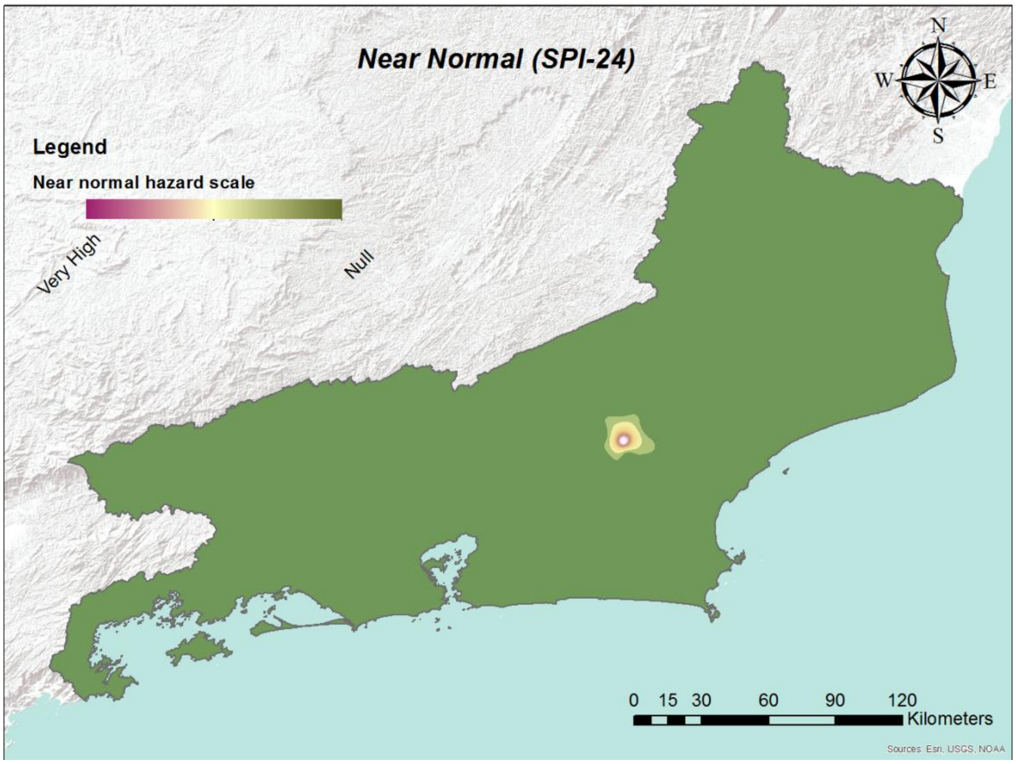
Map 12 Extreme drought hazard in SPI-12 for the state of Rio de Janeiro.

4.1.4 SPI-24

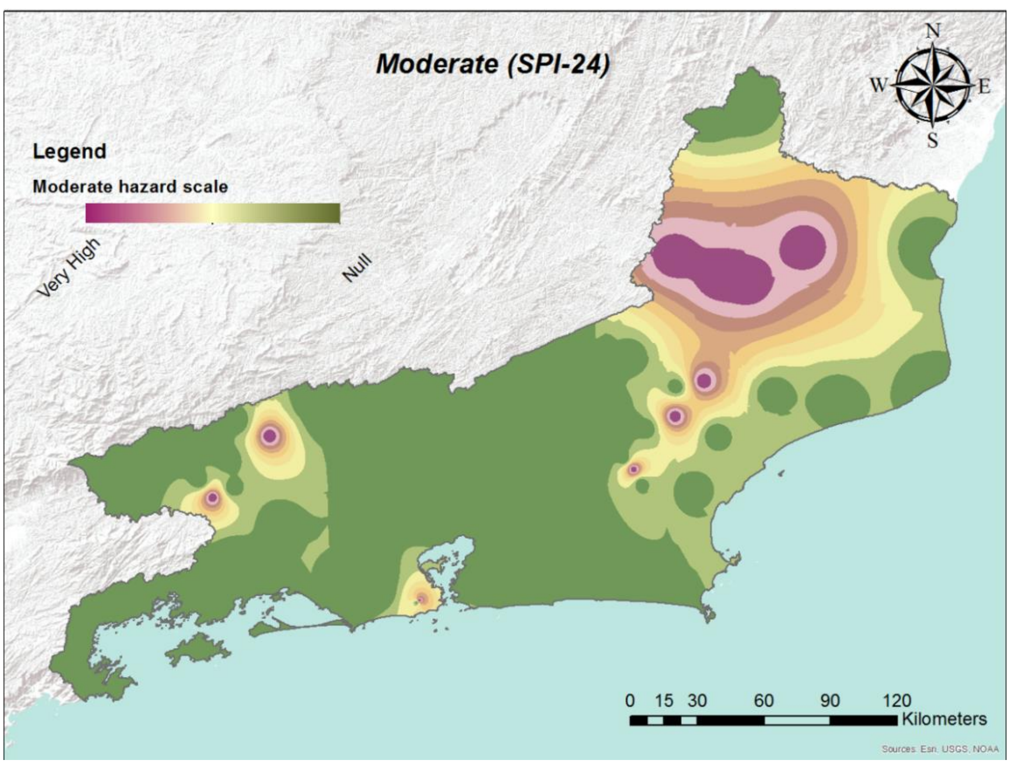
The maps to represent the geographic distribution of drought for SPI-24 at near normal, moderate and extreme scale are as follows: in a near normal scale (Map 13) as in SPI-24 almost the whole state was with null hazard but in this case just the hydrographic region of Rio Dois Rios had a small area from low to high drought hazard.

In Map 14 the moderate drought hazard within the SPI-24 analysis were represented It can be observed that the very high hazard was mostly in Baixo Paraíba do Sul and Itabapoana, and just some dots of very high hazard in Medio Paraíba do Sul. The other hydrographic regions were between medium to very low drought hazard.

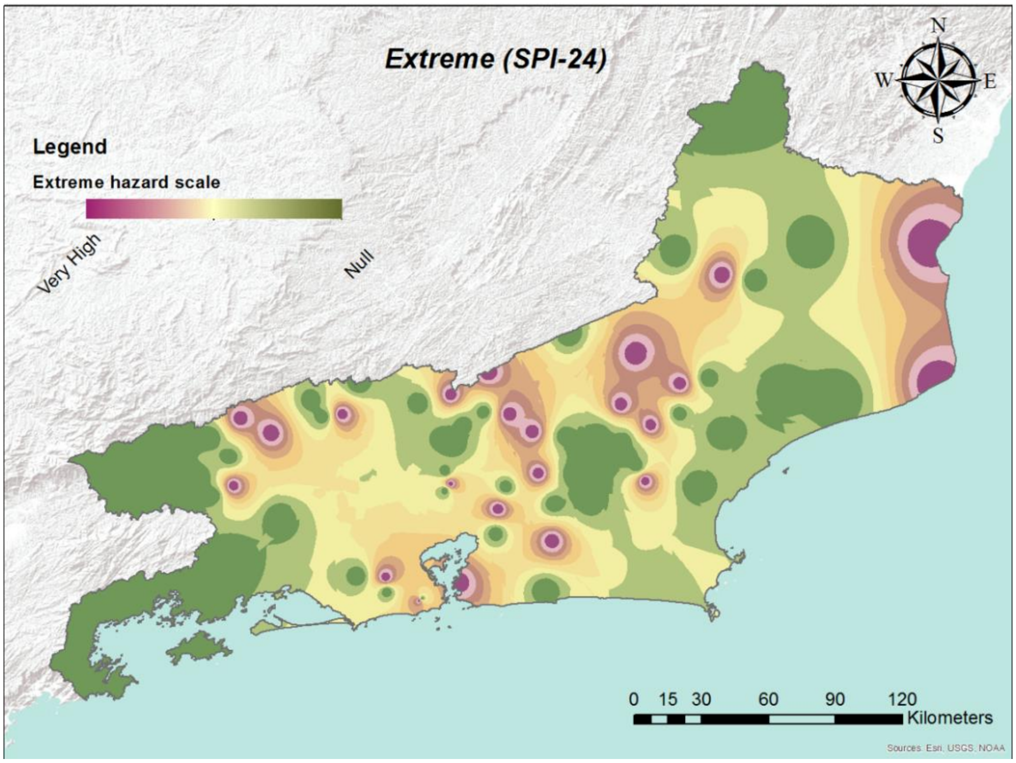
In the case of an extreme drought hazard (Map15), very high hazard was identified in mainly three hydrographic regions: Rio dos Rios, Baixo Paraíba do Sul and Itabapoana, and Medio Paraíba do Sul. Medium hazard was the one that had the largest extension in the entire state.



Map 13 Near normal drought hazard in SPI-24 for the state of Rio de Janeiro.



Map 14 Moderate drought hazard in SPI-24 for the state of Rio de Janeiro.



Map 15 Extreme drought hazard in SPI-24 for the state of Rio de Janeiro

There was one hydrographic region where the hazard to drought in all evaluated scenarios was very low, which is Macaé and Das Ostras. Within this hydrographic region, there are two climatic regions: humid and super humid, where the latter predominates. Also, the prevailing drought conditions for all hydrographic regions were near normal.

4.2 Vulnerability

The vulnerability analysis was undertaken in two steps, one with secondary data and another one adding primary data because only 17 out of 92 municipalities answered the internet survey (compare methodology chapter).

4.2.1 Vulnerability to drought for 92 municipalities based on secondary data

The overall vulnerability index was made of the 72 variables selected in the PCA, which represents 88% of the variance. After analysing each one of the components, the vulnerability score was added by the additive method; and the degree of vulnerability divided into quintiles. The lowest degree of vulnerability was obtained with a score of 11.91 and the highest of 8.73; Table 6 shows the level of vulnerability of each municipality:

Table 6 Degree of vulnerability for the 92 municipalities of Rio de Janeiro

Municipality	Total	Vulnerability Level
Niterói	11.90852	Very low
Rio de Janeiro	12.10017	Very low
São Gonçalo	14.50809	Very low
Volta Redonda	14.51546	Very low
Macaé	14.58041	Very low
Porto Real	14.71009	Very low
Rio das Ostras	14.86359	Very low
Armação dos Búzios	14.8807	Very low
Duque de Caxias	15.15454	Very low
São João de Meriti	15.22135	Very low
Itatiaia	15.25897	Low
Nilópolis	15.30665	Low
Casimiro de Abreu	15.31329	Low
Resende	15.31386	Low
Cabo Frio	15.44699	Low
Petrópolis	15.45228	Low
Quissamã	15.47425	Low
Nova Iguaçu	15.64638	Low
Mesquita	15.67152	Low
Iguaba Grande	15.72912	Low
Comendador Levy Gasparian	15.78312	Low

Table 6 Degree of vulnerability for the 92 municipalities of Rio de Janeiro (continuation)

Municipality	Total	Vulnerability Level
Arraial do Cabo	15.81153	Low
Cordeiro	15.83951	Low
Três Rios	15.89128	Low
São Pedro da Aldeia	15.94405	Medium
Maricá	15.99056	Medium
Miguel Pereira	16.00526	Medium
Barra Mansa	16.03234	Medium
Mendes	16.03335	Medium
Itaguaí	16.04439	Medium
Pinheiral	16.10864	Medium
Piraí	16.11862	Medium
Belford Roxo	16.12401	Medium
Queimados	16.25121	Medium
Itaboraí	16.26987	Medium
Paraty	16.32162	Medium
Angra dos Reis	16.36707	Medium
Mangaratiba	16.36758	Medium
Carapebus	16.37581	Medium
Miracema	16.39161	Medium
Seropédica	16.4305	Medium
Natividade	16.43162	Medium
Aperibé	16.43927	Medium
Areal	16.53788	Medium
Vassouras	16.60487	High
Italva	16.65394	High
Cantagalo	16.67413	High
Guapimirim	16.67443	High
Nova Friburgo	16.68061	High
Quatis	16.68255	High
Japeri	16.73635	High
Sapucaia	16.76054	High
Magé	16.81597	High
Carmo	16.84444	High

Table 6 Degree of vulnerability for the 92 municipalities of Rio de Janeiro (continuation)

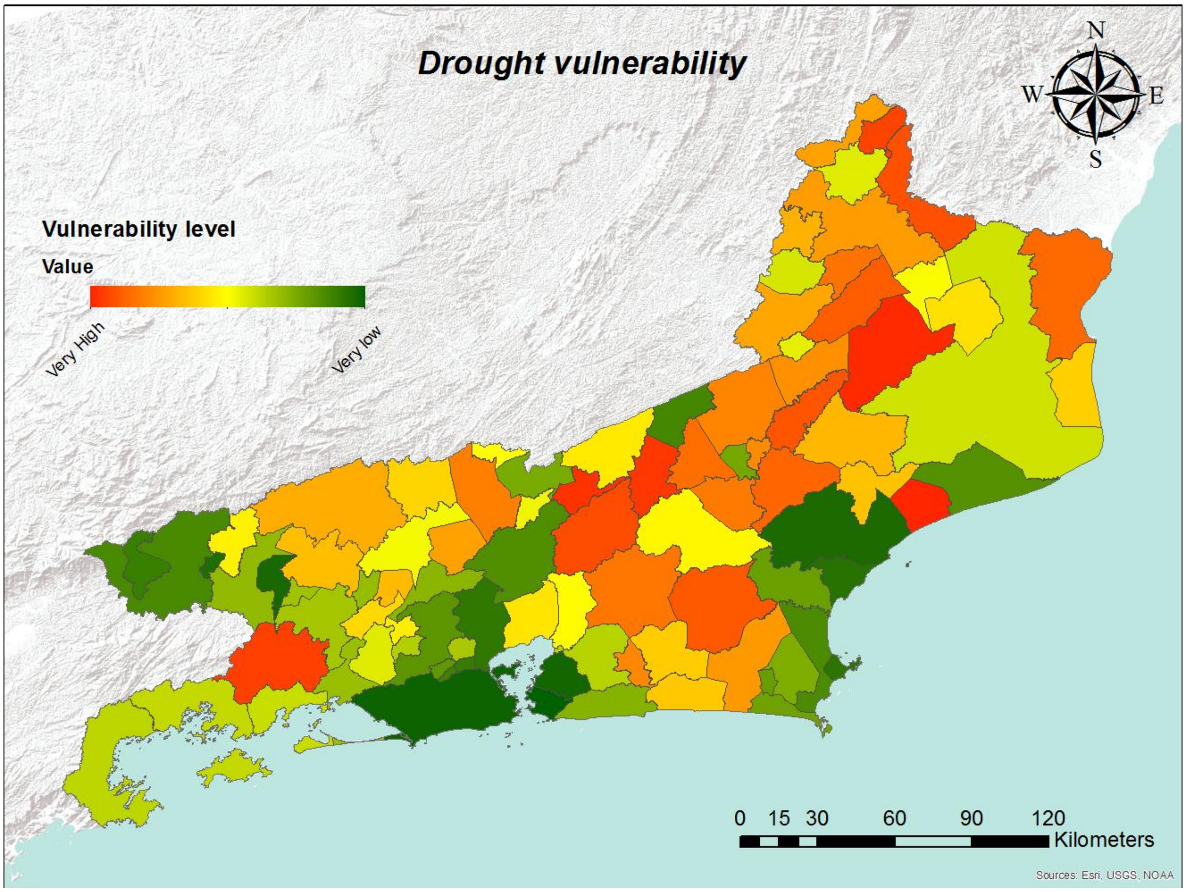
Municipality	Total	Vulnerability Level
Paracambi	16.84564	High
Rio das Flores	16.85518	High
São João da Barra	16.8552	High
Rio Bonito	16.8594	High
Saquarema	16.87699	High
Conceição de Macabu	16.88989	High
Barra do Piraí	16.93645	High
Engenheiro Paulo de Frontin	16.97088	High
Santa Maria Madalena	17.06639	High
Laje do Muriaé	17.0868	High
Valença	17.1953	High
Santo Antônio de Pádua	17.21036	Very High
Porciúncula	17.27358	Very High
Paty do Alferes	17.32581	Very High
Itaperuna	17.36683	Very High
Araruama	17.4547	Very High
Itaocara	17.46878	Very High
Macuco	17.51758	Very High
Tanguá	17.59141	Very High
Cardoso Moreira	17.59171	Very High
Paraíba do Sul	17.60667	Very High
Bom Jardim	17.61166	Very High
Cachoeiras de Macacu	17.63691	Very High
São José de Ubá	17.71824	Very High
Duas Barras	17.73464	Very High
São Fidélis	17.74183	Very High
Trajano de Moraes	17.78192	Very High
Cambuci	17.9328	Very High
Silva Jardim	17.96606	Very High
São Sebastião do Alto	17.98459	Very High
Bom Jesus do Itabapoana	18.00083	Very High
Teresópolis	18.07195	Very High
Varre-Sai	18.14005	Very High

Table 6 Degree of vulnerability for the 92 municipalities of Rio de Janeiro (continuation)

Municipality	Total	Vulnerability Level
Rio Claro	18.23921	Very High
Sumidouro	18.55645	Very High
São José do Vale do Rio Preto	18.6646	Very High
São Francisco de Itabapoana	20.20005	Very High
Campos dos Goytacazes	20.47476	Very High

As shown in Table 6, only ten municipalities have a very low vulnerability, and Niteroi is the municipality with the lowest, while with very high vulnerability resulted in 27 municipalities being the highest Campos dos Goytacazaes, closely followed by São Francisco de Itabapoana; while low vulnerability were scored by 14 municipalities, medium for 20 municipalities and finaly high showed by 21 municipalities. The variables that made the differences between them were the primary economic activity such as livestock, agricultural, health services, adequate water sanitation, and human development index, among others.

In a next step, the vulnerability for each municipality was represented geographically in ArcGIS software:



Map 16 Drought Vulnerability Index based on secondary data

4.2.2 Vulnerability to Drought for 17 municipalities based on primary and secondary data.

To obtain primary data an online interview was conducted. In spite of having been requested to the 92 municipalities, although 63 municipalities opened, the survey was only answered in its entirety by stakeholders from 17 municipalities. Therefore, it was decided to carry out a vulnerability analysis taking into account these 17 municipalities that answered back to the interview; and to see how the variables analysed could affect the overall drought vulnerability considering such important indicators as perception. The scoring and degree of vulnerability results are represented in Table 7 for those 17 municipalities that answered the online survey.

Table 7 Vulnerability score for the 17 municipalities analysed.

Municipality	Total	Vulnerability level
Resende	18.64986	Very low
Niteroi	20.15852	Very low
São Gonçalo	21.31209	Very low
Nova Friburgo	22.53861	Low
Cantagalo	23.30413	Medium
Paraíba do sul	23.58467	Medium
Nova Iguaçu	23.98238	High
Barra do Pirai	24.04445	High
Mesquita	24.42152	High
Porciúncula	24.78358	High
Natividade	25.01762	High
Engenheiro Paulo de Frontin	25.47088	Very High
Paty do Alferes	25.66181	Very High
Trajano de Moraes	25.94703	Very High
Varre-Sai	25.99805	Very High
Cachoeiras de Macacu	26.01691	Very High
Cardoso Moreira	26.42771	Very High

Table 7 shows the resulting vulnerability level, in this case, three municipalities were found with the lowest level, Resende, Niteroi and São Gonçalo, while at the very highest level six municipalities were scored, with Cardoso Moreira as the highest. Comparing these results with those of Table 6 of the previous analysis (all municipalities), it can be observed that the vulnerability level of Resende was changed to very low and the municipality of Engenheiro Paulo de Frontin increased one level of vulnerability to very high. The variables that made the greatest difference in the degree of vulnerability in the analysis with primary data were the main source of income of the municipality, sufficient water reservoirs, drought research, and health services, among others.

Figure 8 shows the resulting vulnerability index scores for each municipality based on the 17 surveys.

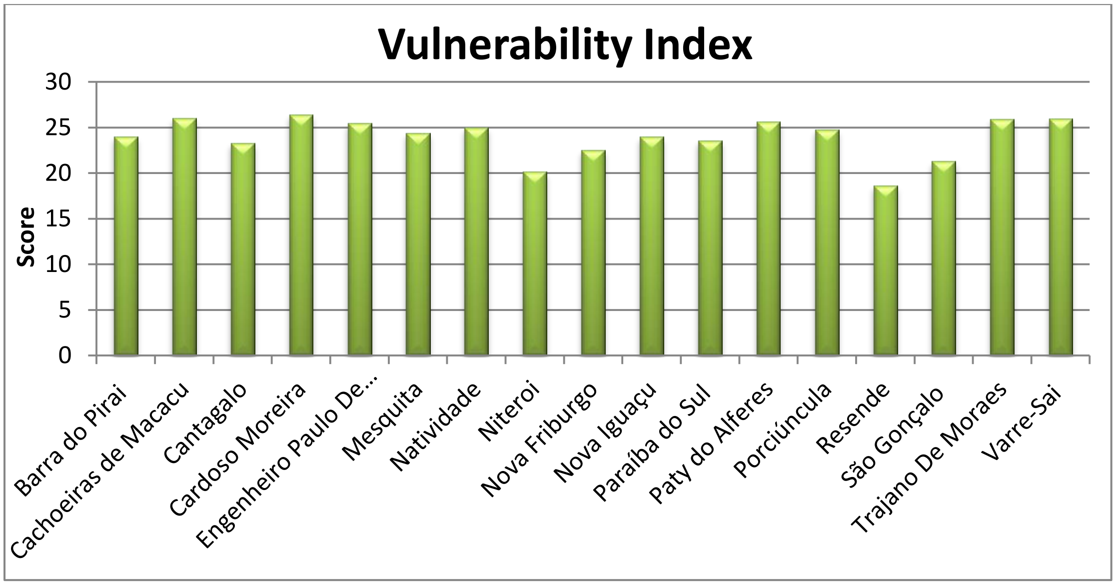
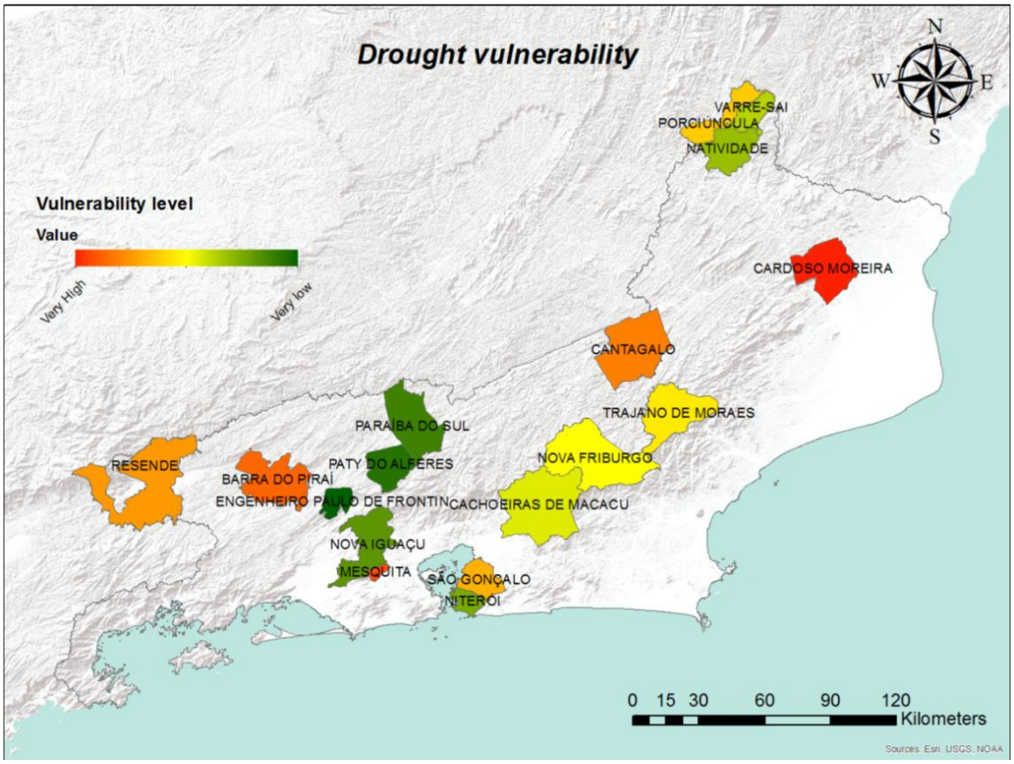


Figure 8 Final scores for the Vulnerability Index at the municipal level

With the respective degree of vulnerability by the municipality, Map 17 was created using the ArcGIS Software to be visually represented:



Map 17 Drought Vulnerability Index with primary and secondary data.

Maps 16 and 17 showed that there is no a geographic pattern of vulnerability to drought and this can change depending on the conditions of each state, municipality, or unit of vulnerability analysis.

4.3 Risk

In order to generate risk maps, maps of hazard and vulnerability to drought were overlaid. Therefore maps were made for each drought scale (near normal, moderate and extreme) in each SPI 3, 6, 12 and 24. Risk maps were divided into two categories:

(a) The risk for the whole state: In which all municipalities are analysed taking into account only secondary data.

(b) The risk for 17 municipalities: This analysis was carried out considering the 17 municipalities which also have primary data.

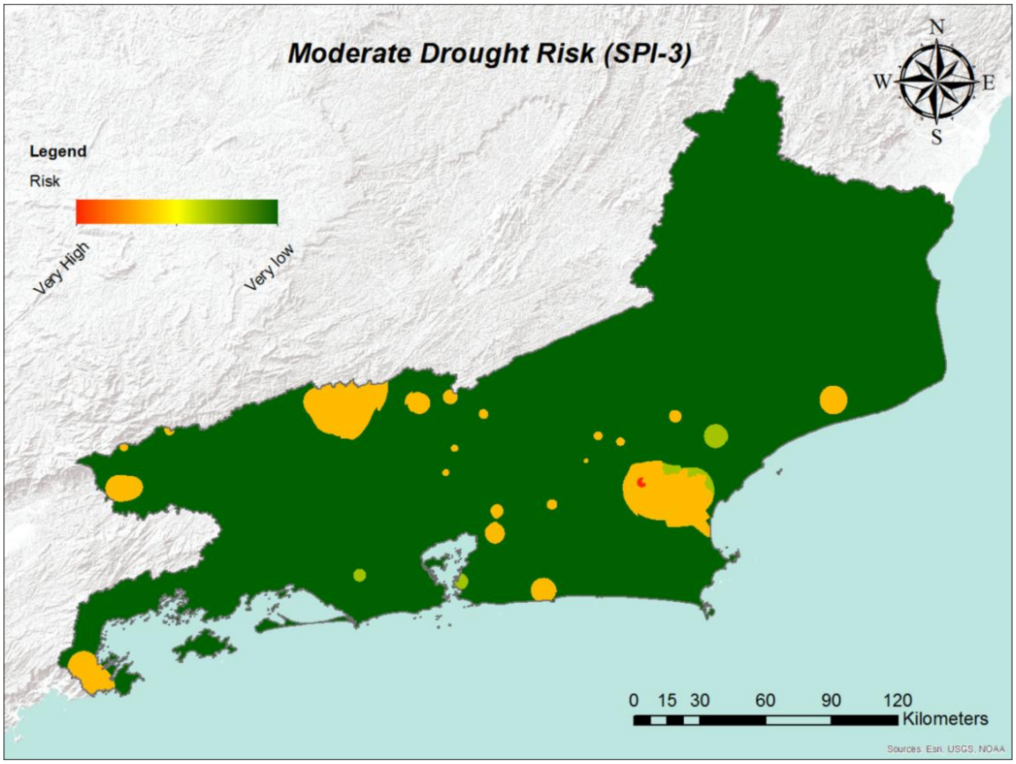
4.3.1 Risk for the whole state

All the hydrographic regions present a very high risk in different SPI scenarios (extreme and moderate risk drought scenario); all the stations for SPI-24 had very high risk. Concerning risk of drought in a near normal scenario, it was found very low risk for all hydrographic regions in all SPI time scales (Annexe 2)

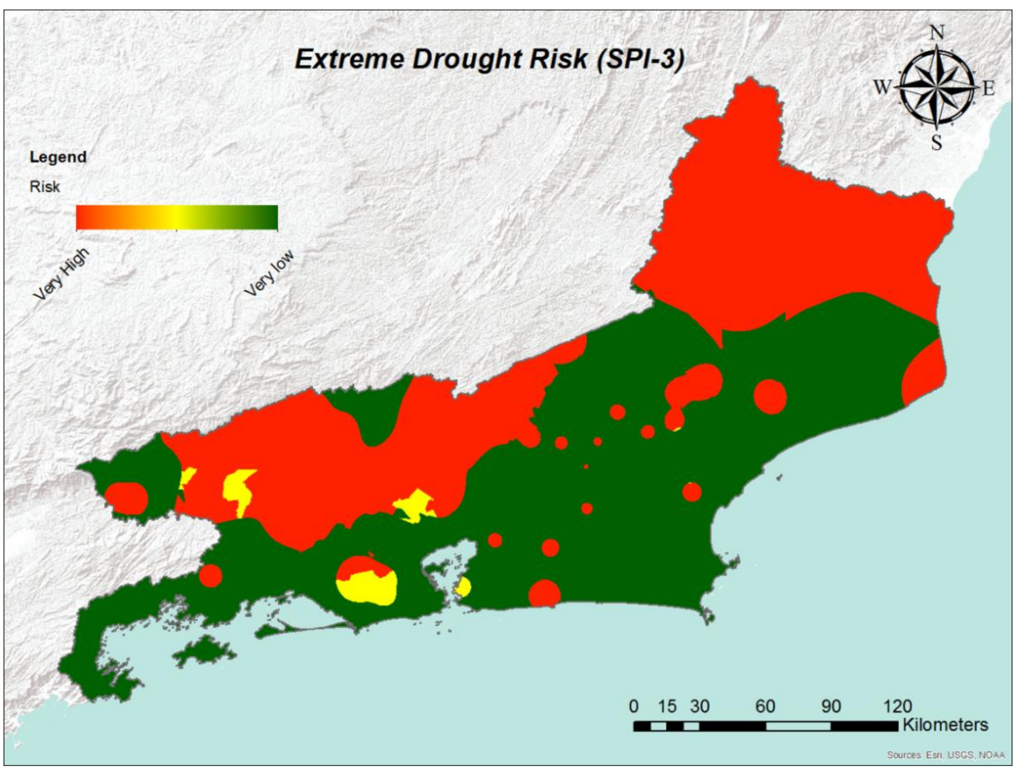
SPI-3

The only hydrographic region with very high risk in a moderate drought risk scenario (Map 18) was Lagos São João with a small dot in a region between two municipalities. Medium levels of risk for a moderate drought risk scenario were presented in six hydrographic regions: Médio Paraíba do Sul, Baía da Ilha Grande, Baía de Guanabara, Piabanha, Lagos São João and a little bit in Macaé and das Ostras. The other parts of the state where mainly in very low drought risk.

Whereas for an extreme drought risk in an SPI-3 scale (Map 19) appeared more regions with very high risk distinguish Baixo Paraíba do Sul and Itabapoana, Médio Paraíba do Sul and Piabanha, while Baía de Guanabara shows only medium drought risk.



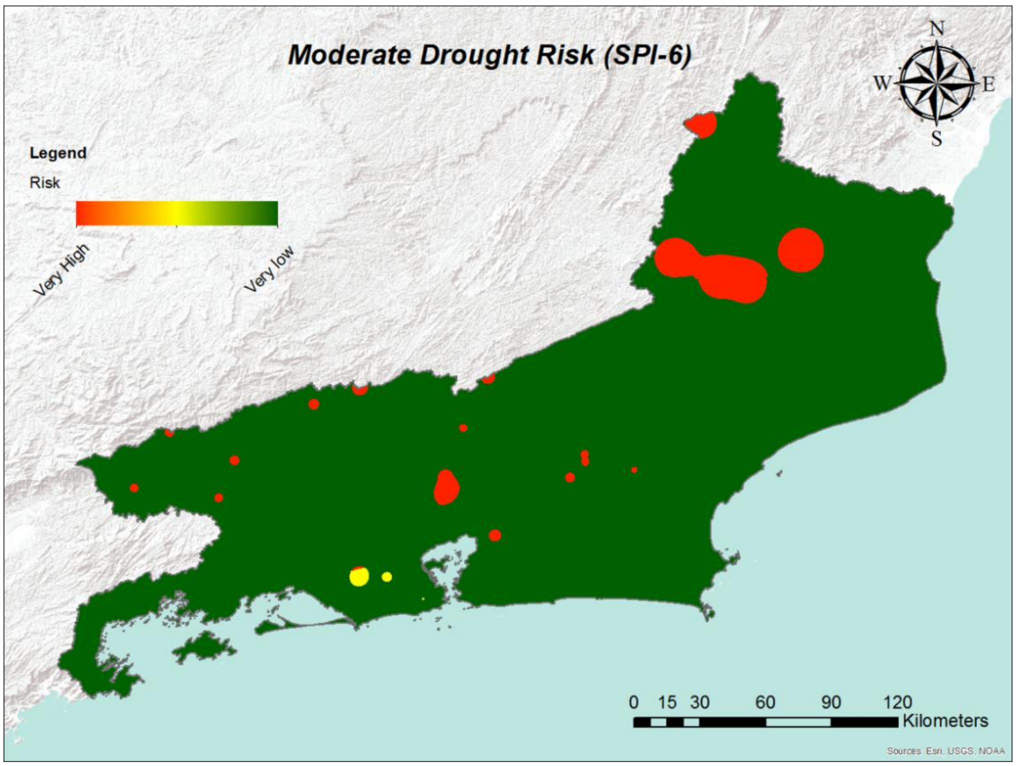
Map 18 Moderate drought risk (SPI-3) for the state of Rio de Janeiro



Map 19 Extreme drought risk (SPI-3) for the state of Rio de Janeiro

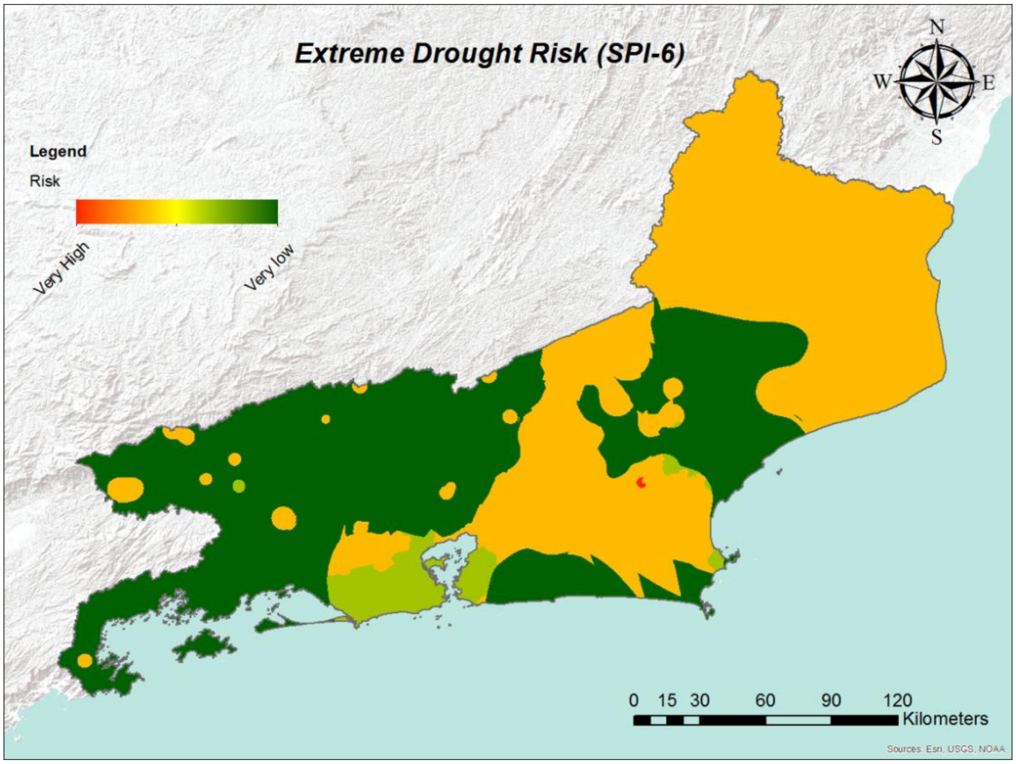
SPI-6

In the moderate drought risk for an SPI-6 (Map 20) the results were very high risk for Baixo Paraíba do Sul and Itabapoana and a few areas from Piabanha, Medio Paraíba do Sul and Baía de Guanabara hydrographic regions, this last one also had some dots in medium drought risk.



Map 20 Moderate drought risk (SPI-6) for the state of Rio de Janeiro

The map for an extreme drought risk show just a little dot of very high risk between the municipalities of Casimiro de Abreu and Silva Jardim, the predominant risk is from medium to very low. The hydrographic regions that had a higher extent of medium risk are Baixo Paraíba do Sul and Itabapoana, Baía de Guanabara, Lagos São João and Rio Dois Rios.

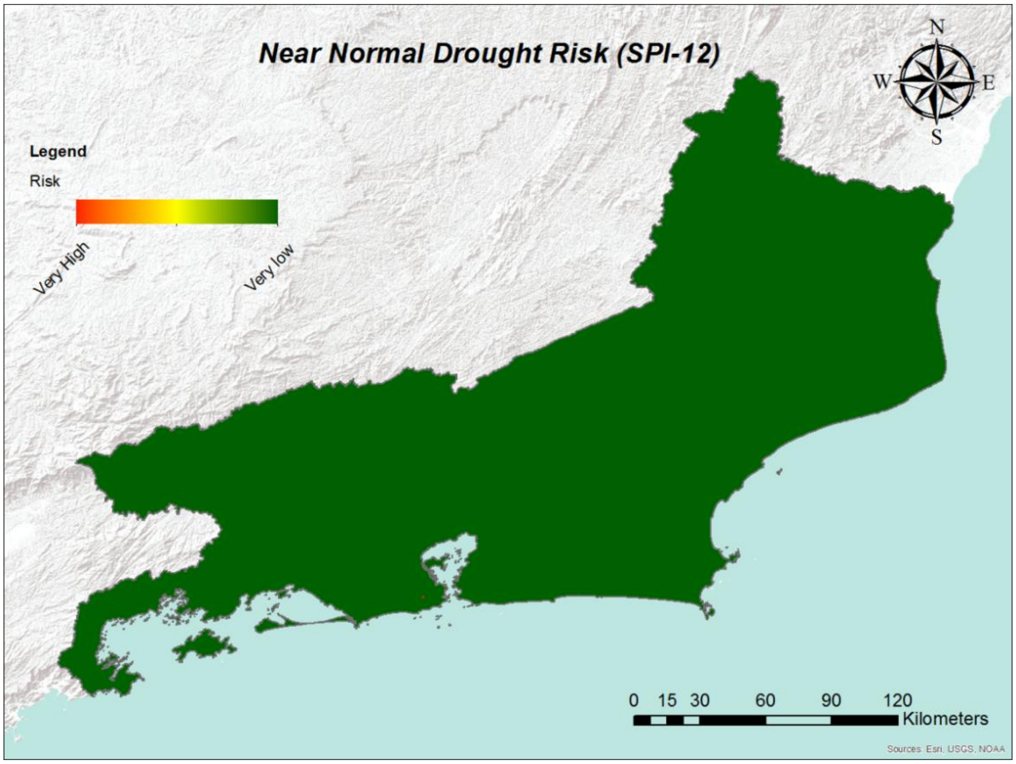


Map 21 Extreme drought risk (SPI-6) for the state of Rio de Janeiro

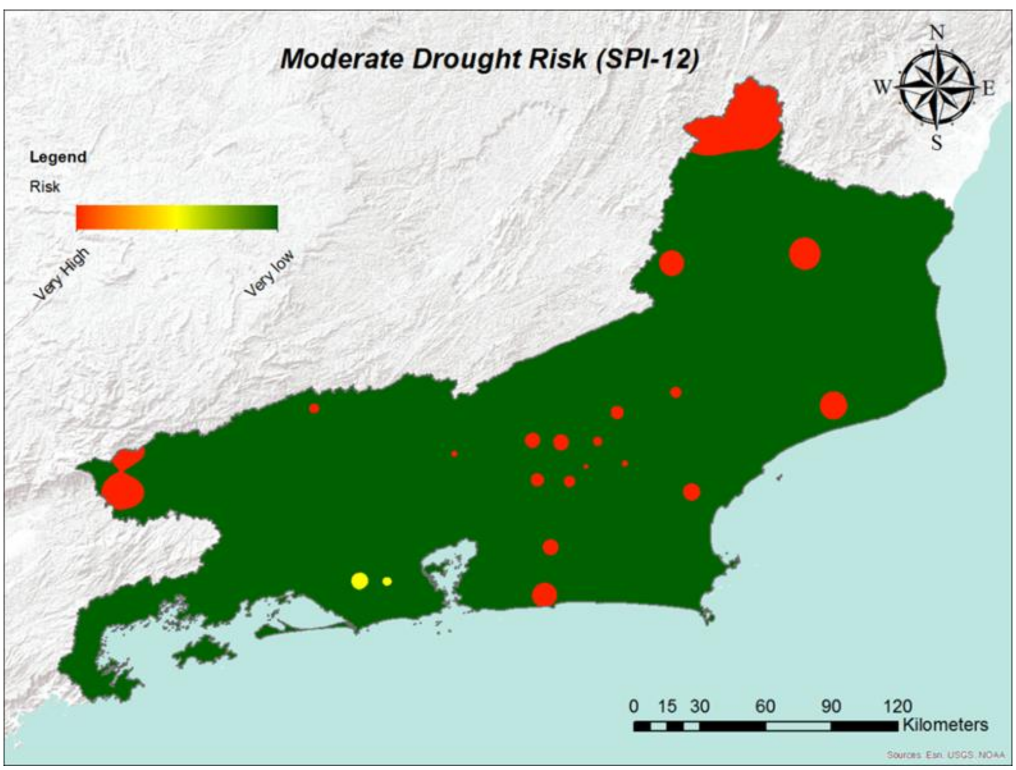
SPI-12

In the analysis of risk for SPI-12, it was possible to determinate risk from near normal drought conditions. In this case (Map 22), very low risk for all hydrographic regions in all SPI time scales was found, only Baía de Guanabara had a small high risk point in the municipality of Rio de Janeiro. While for a moderate drought risk scenario was in high risk the hydrographic regions Paraíba do Sul and Baixo Paraíba Do Sul and Itabapoana and some parts of Baía de Guanabara, in this last one Baía de Guanabara also were detected a small area of medium risk.

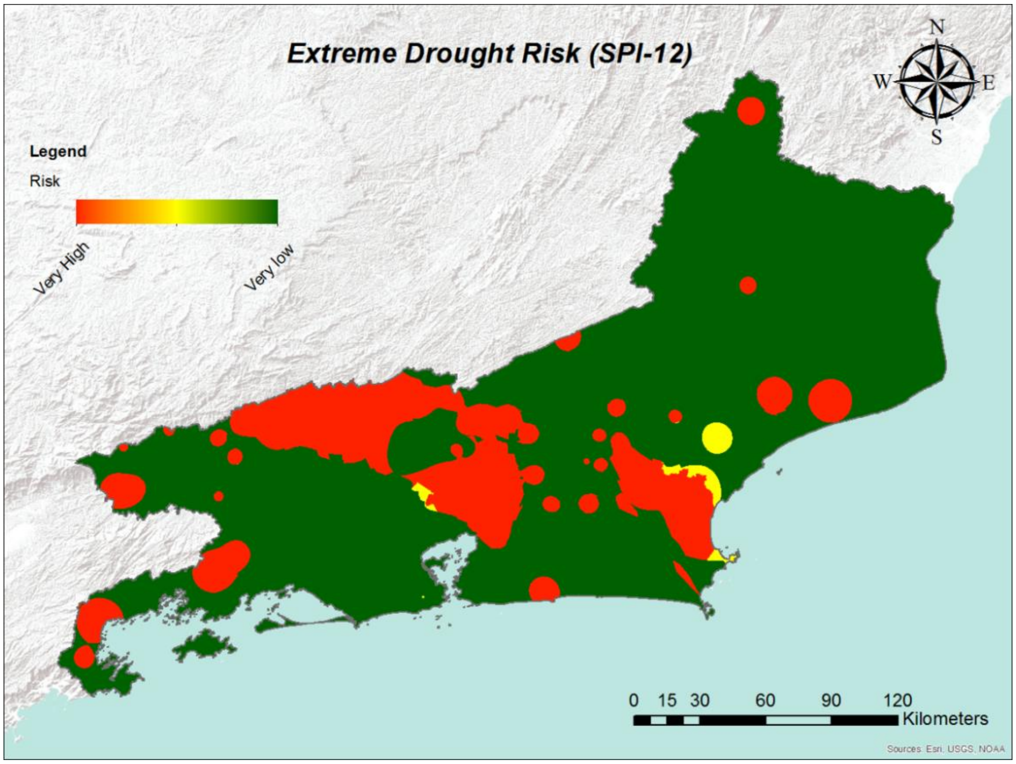
In a case of extreme drought risk, almost all the hydrographic regions have areas of very high risk, but the ones that presented it with more extension are six: Baía da Ilha Grande, Guandu, Médio Paraíba do Sul, Piabanha, Baía de Guanabara and Lagos São João.



Map 22 Near normal drought risk (SPI-12) for the state of Rio de Janeiro



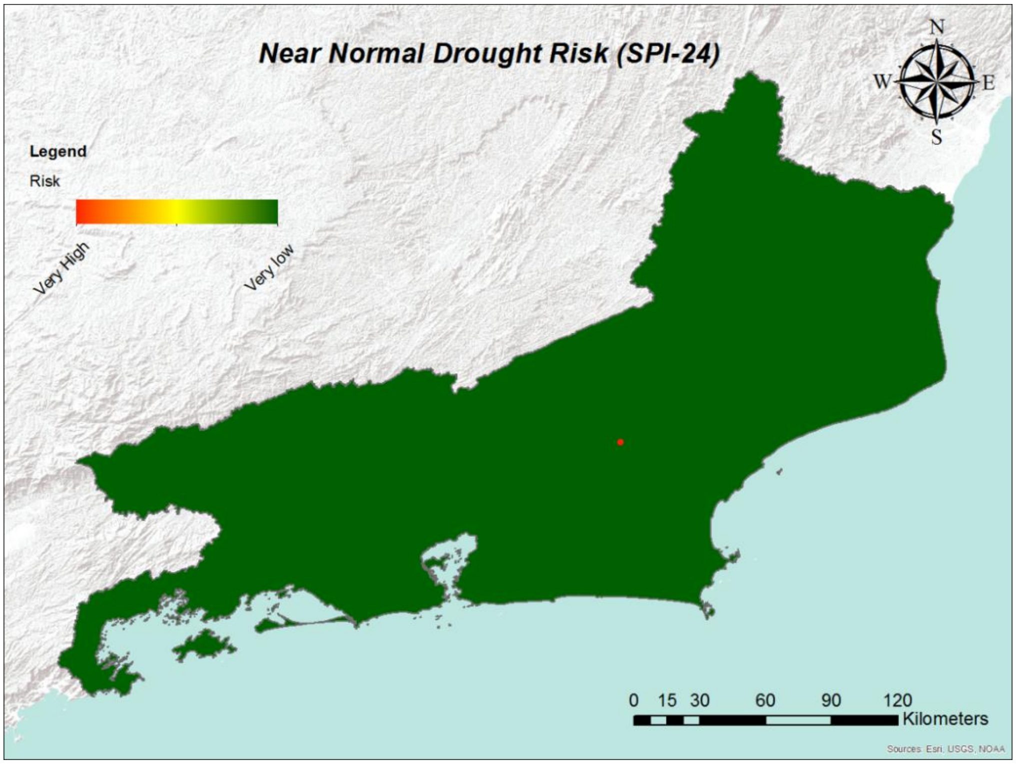
Map 23 Moderate drought risk (SPI-12) for the state of Rio de Janeiro



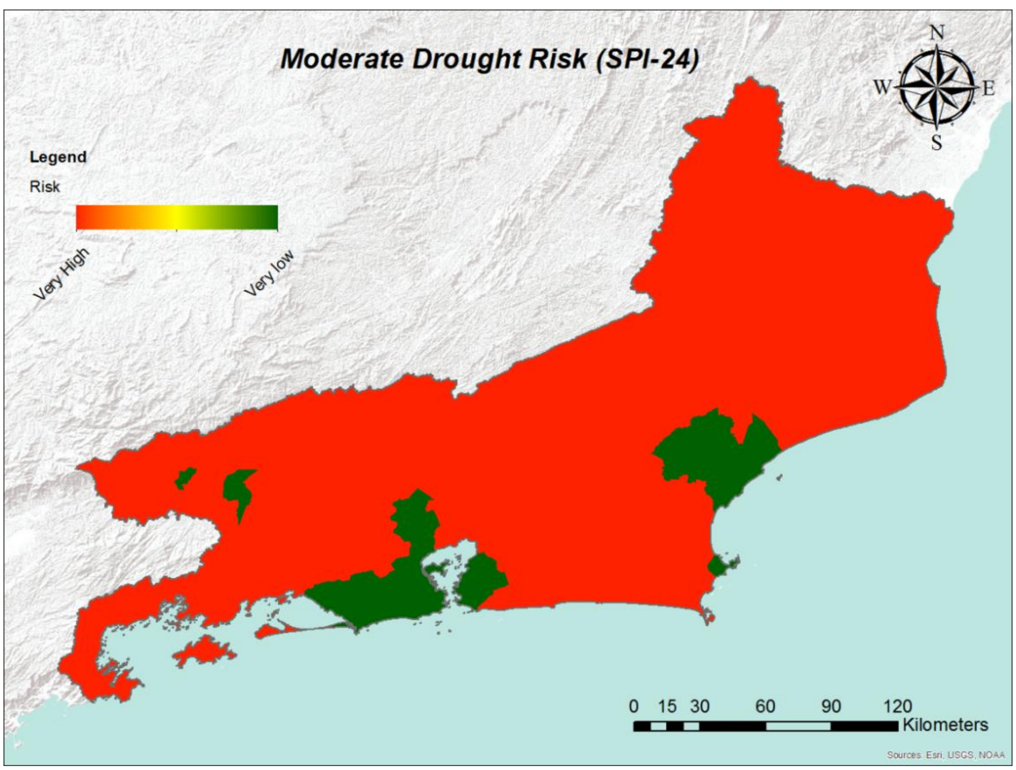
Map 24 Extreme drought risk (SPI-12) for the state of Rio de Janeiro.

SPI-24

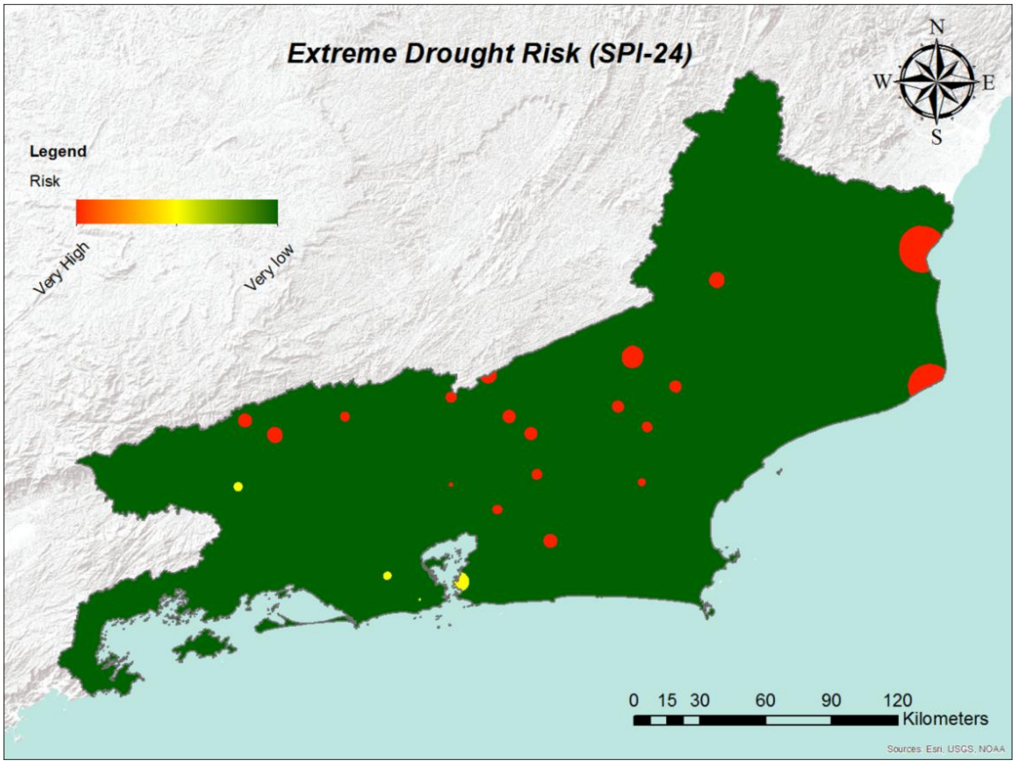
Finally, the maps for SPI-24 risk analysis were made for near normal, moderate and extreme drought risk, in the near normal scenario almost the entire state is in very low risk level, just the region of Rios Dois Rios present a small area of high risk in the municipality of Bom Jardim. In the moderate drought risk scenario, all the stations had very high risk, just three hydrographic regions, Macaé and das Ostras, Baía de Guanabara and Guandu, have some areas with very low risk. In at the extreme drought risk scenario, the very low risk prevail, and some dots of very high and medium risk are barely showed; the hydrographic region that presented more extension of high risk is Baxio Paraíba do Sul and Itabapoana, and for medium risk, Baía de Guanabara had two small areas



Map 25 Near normal drought risk (SPI-24) for the state of Rio de Janeiro



Map 26 Moderate drought risk (SPI-24) for the state of Rio de Janeiro



Map 27Extreme drought risk (SPI-24) for the state of Rio de Janeiro

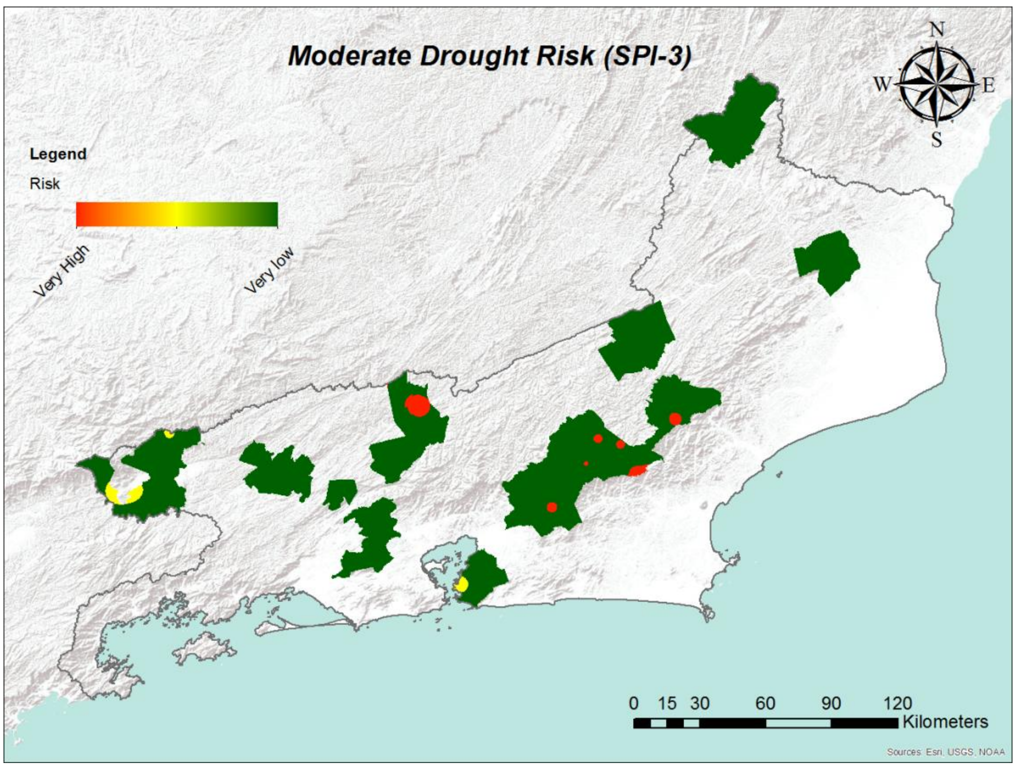
4.3.2 Risk maps for 17 municipalities

Another risk analysis was performed taking into account only the municipalities that participated in the online survey. The interviews made as part of this survey include indicators of perception, knowledge of the threat, the level of management against drought risk, inter alia.

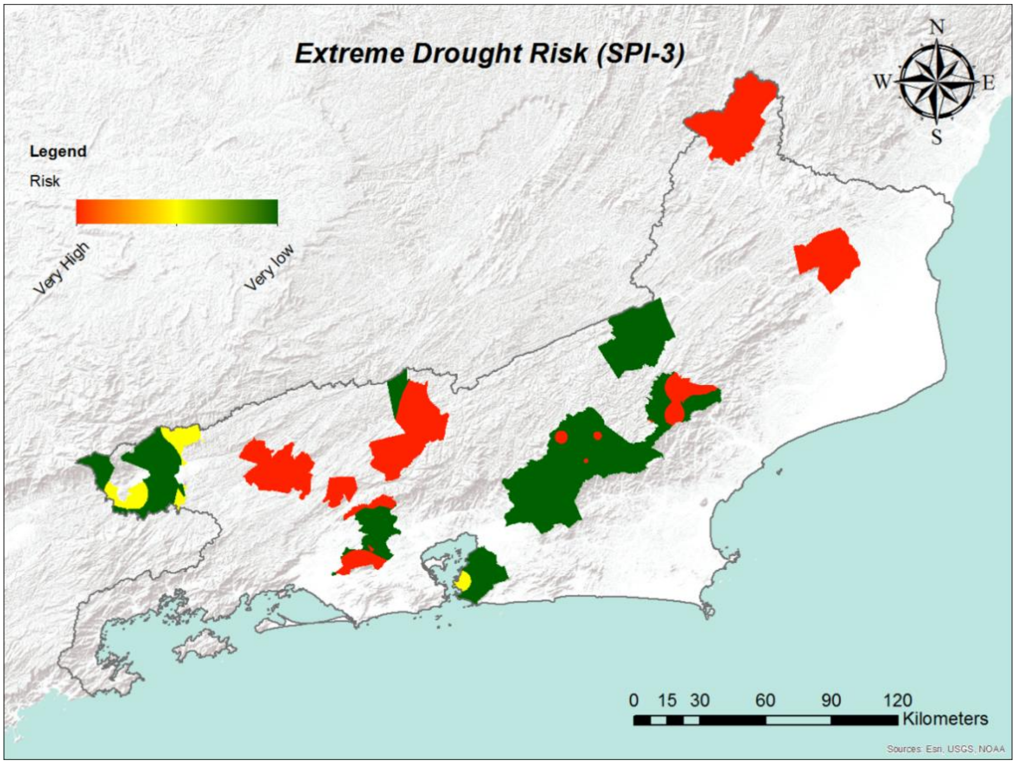
In these results, the risks maps for SPI-3, 6 and 12 for near normal drought were excluded because the analysis showed zero risk.

SPI-3

In a moderate risk scenario for SPI-3 the municipalities with high risk are Cachoeiras de Macacú, Nova Friburgo, Paraíba do Sul and Trajano de Moraes, while at medium risk appeared only Niteroi and Resende. For an extreme drought risk scenario as in the moderate risk the same two municipalities with medium risk turn up, Niteroi and Resende, almost all the other municipalities had an area of very high risk, except for Cantagalo that appears the entire municipality with very low risk.



Map 28 Moderate drought risk (SPI-3) for the 17 municipalities with primary data.

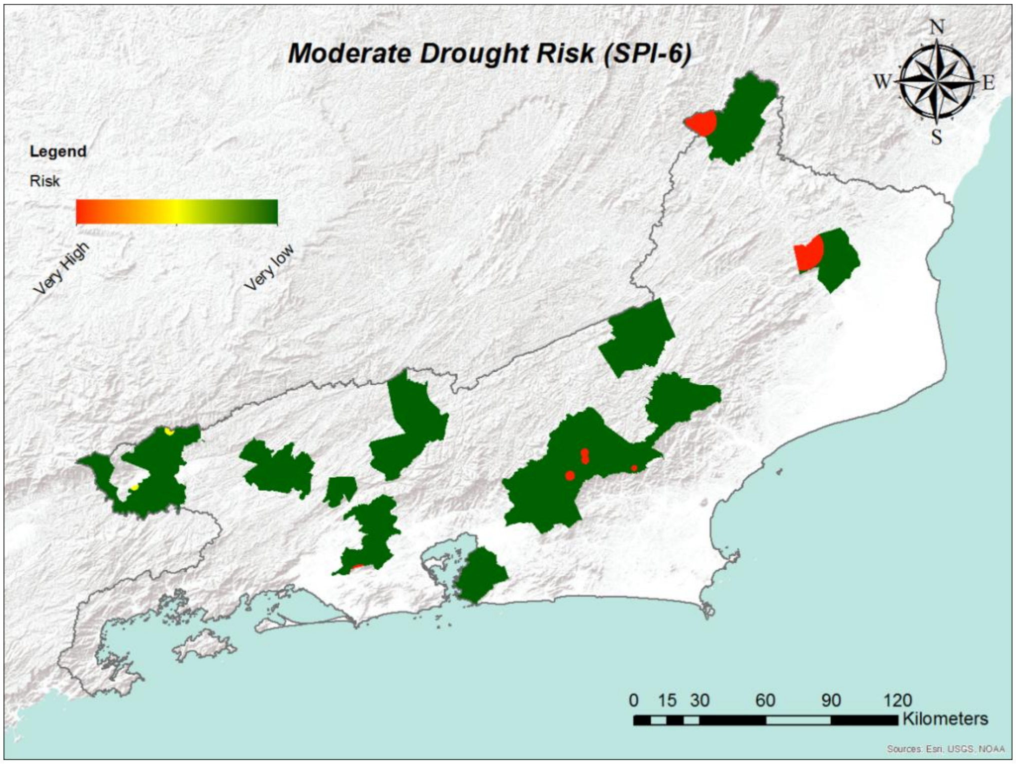


Map 29 Extreme drought risk (SPI-3) for the 17 municipalities with primary data.

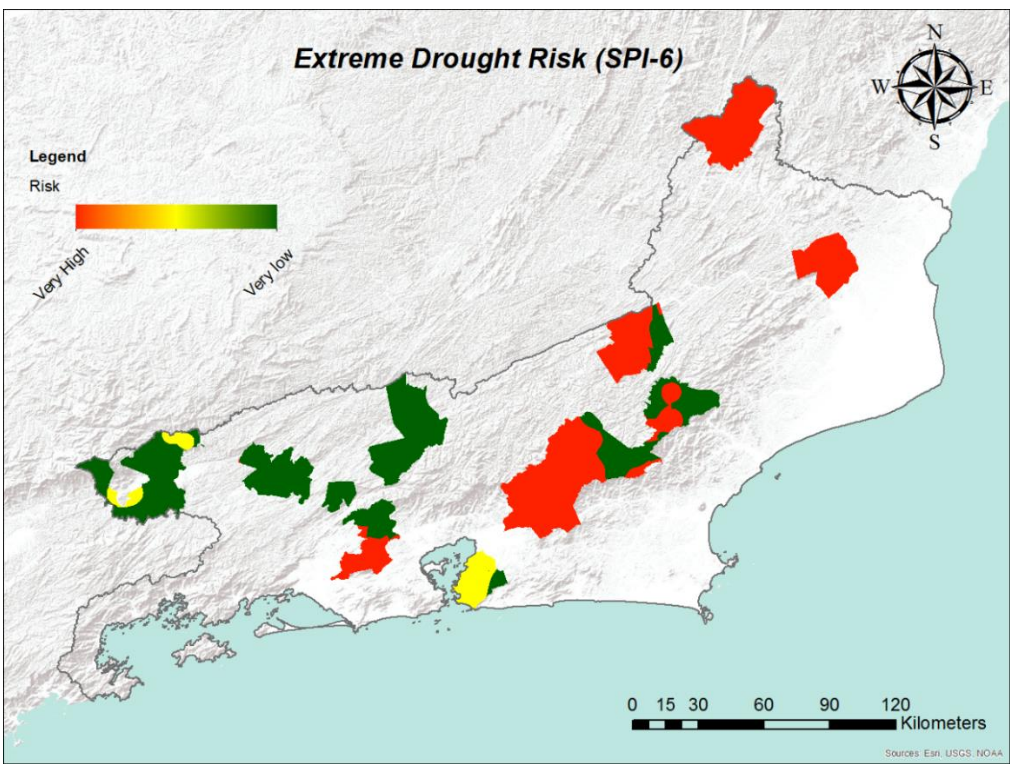
SPI-6

For a moderate drought risk scenario with SPI of 6 months, Porciùncula and Cardoso Moreira are the municipalities with more area in very high risk, and with some dots in very high risk appeared Cachoeiras de Macacú and Nova Friburgo, while the other municipalities are in the range of very low risk.

In an extreme drought risk scenario ten municipalities highlight with very high risk, at medium risk appeared Niteroi with a large area of medium risk and resend with a smaller area, the municipalities in very low risk are Paraíba do Sul, Paty do Alferes, Engenheiro Paulo de Frontin, and Barra do Piraí.



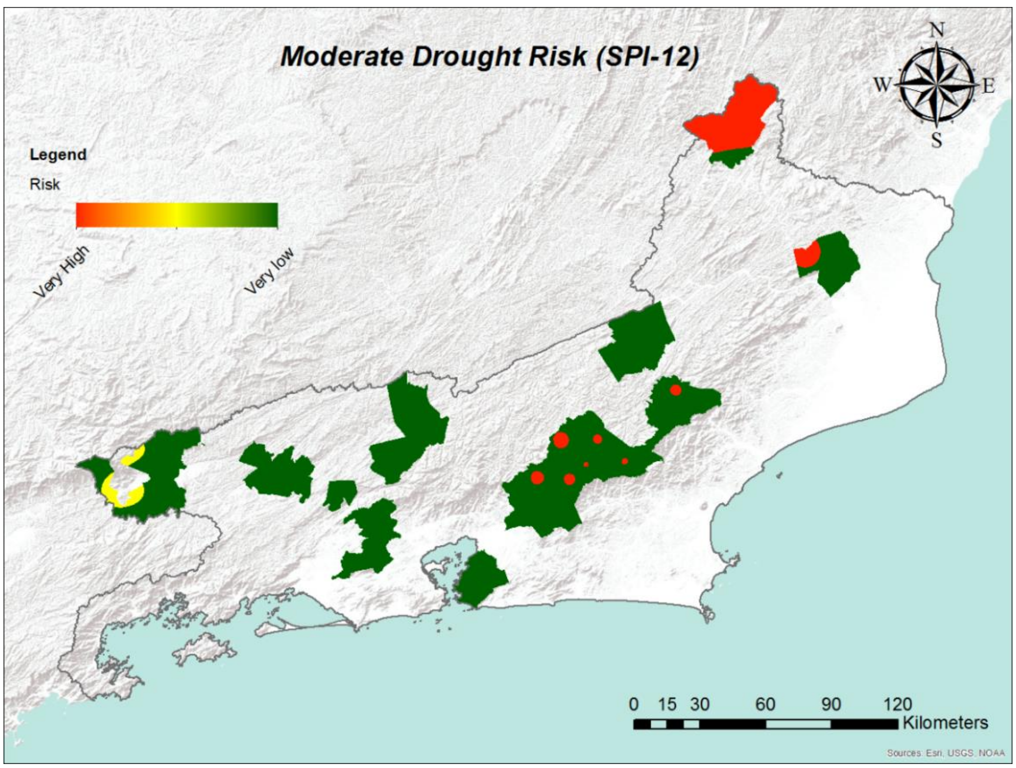
Map 30 Moderate drought risk (SPI-6) for the 17 municipalities with primary data.



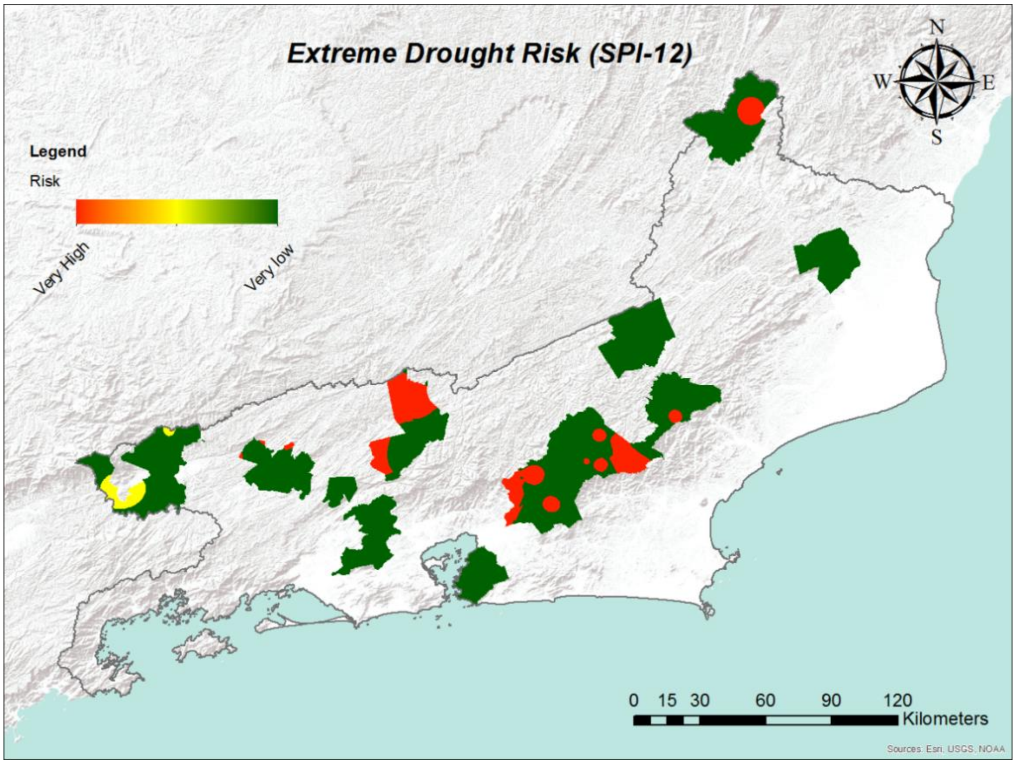
Map 31 Extreme drought risk (SPI-6) for the 17 municipalities with primary data.

SPI-12

In the analysis of drought risk in a moderate scenario with SPI-12, Varre Sai, Porciuncula and Natividade are the ones with higher risk, Resende showed an area of medium risk, and the other municipalities stand out mainly with very low risk. While for an extreme drought risk scenario eight municipalities showed areas with very high risk as Natividade, Nova Friburgo, Cachoeiras de Macacú, Paty do Alferes, etcetera, Resende is the only one with areas in medium risk, and six municipalities presented very low drought risk.



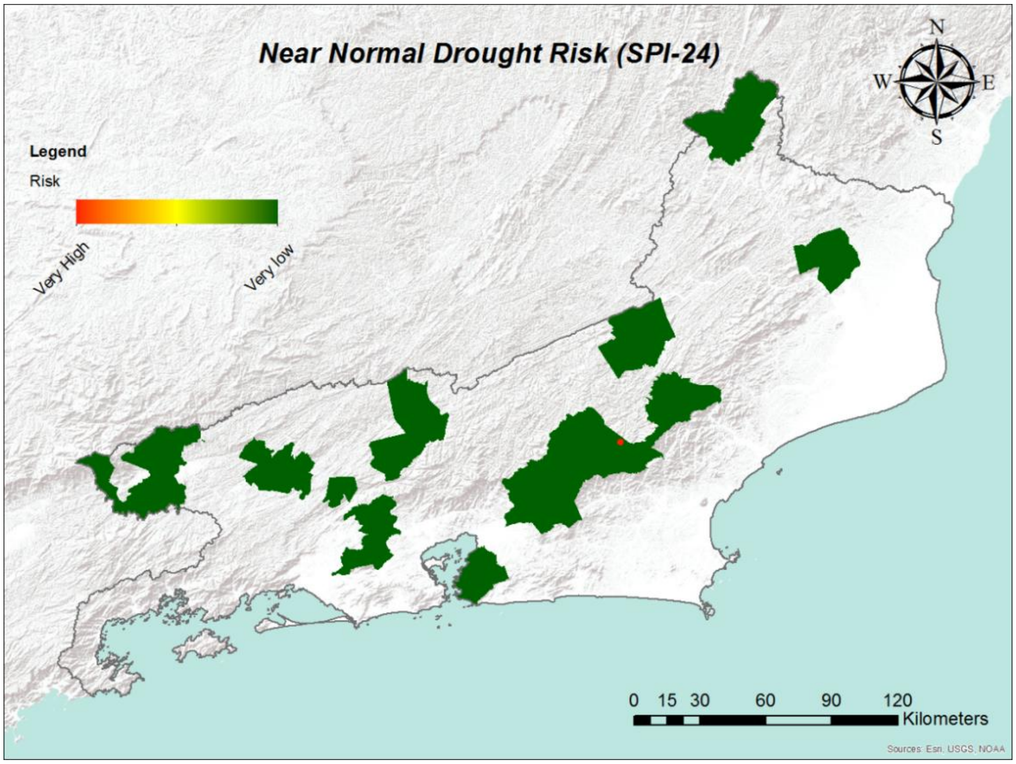
Map 32 Moderate drought risk (SPI-12) for the 17 municipalities with primary data.



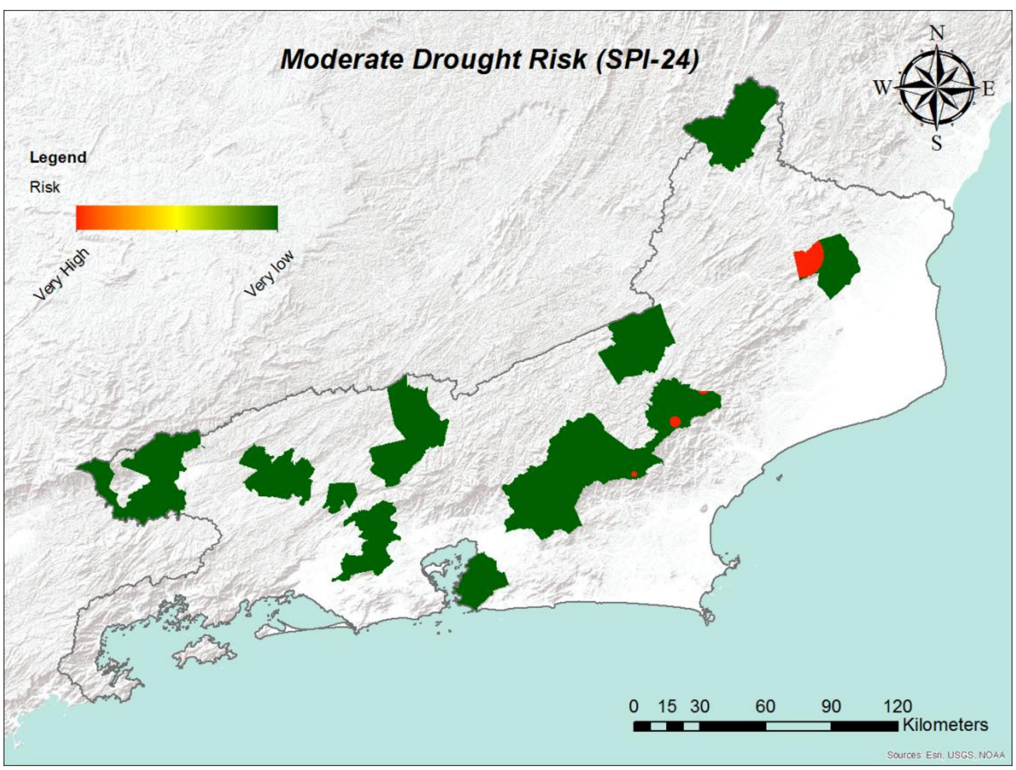
Map 33 Extreme drought risk (SPI-12) for the 17 municipalities with primary data.

SPI-24

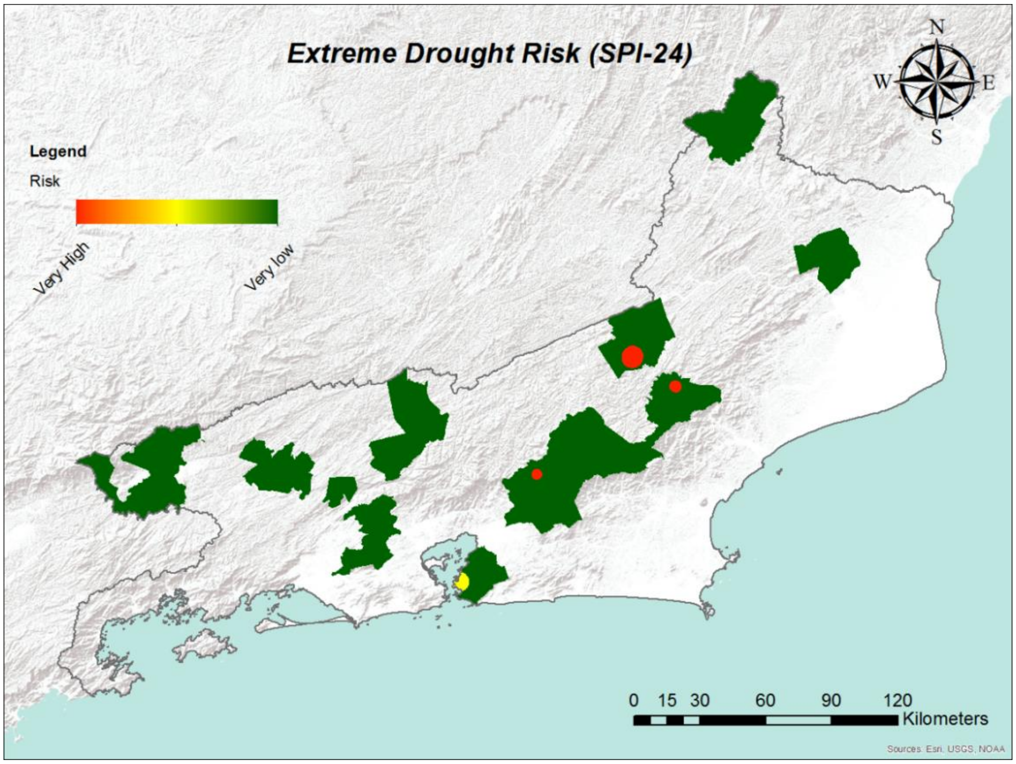
Within the scale of analysis of SPI for 24 months, the risk was found in the three scenarios, near normal, moderate and extreme drought risk. In the case of near normal (Map 34) almost all municipalities appear with very low risk, with the exception of Nova Friburgo that appeared with a small high risk area. In the moderate drought risk scenario, Cardoso Moreira is the municipality with a higher area of drought risk, followed by Trajano de Moraes and Nova Friburgo. For an extreme drought risk Cantagalo, Trajano de Moraes and Cachoeiras de Macacú had some areas in very high risk, in the municipality of Niteroi appeared an area with medium risk, and then all the other municipalities predominate with very low drought risk.



Map 34 Near normal drought risk (SPI-24) for the 17 municipalities with primary data.



Map 35 Moderate drought risk (SPI-24) for the 17 municipalities with primary data.



Map 36 Extreme drought risk (SPI-24) for the 17 municipalities with primary data.

5. DISCUSSION

This chapter is composed of three main sections as throughout the development of this research: drought hazard, drought vulnerability, and drought risk.

5.1 Drought Hazard

The drought hazard was analysed using SPI software for four different periods; three, six, twelve and twenty-four months.

Examining all the SPI results it can be determined that a three month SPI reflects short term cumulative rainfall of three consecutive months of the same period. For all years included in the historical record, the current year is compared historically and statistically to all previous years in the observation record. A six months SPI measures better medium term moisture conditions and provides a seasonal estimate of precipitation; This results coincide with Nuñez *et al*., (2007) and Wu *et al*., (2005) in showing high sensitivity, as were found in the municipality of Bom Jardim where one station showed 49 consecutive months in drought, so in all the SPI-24 analysis this municipality showed up in very high hazard.

On the other hand, SPI 12 and 24 reflect long term precipitation patterns. As for Nuñez *et al*., (2007) found that the values are more stable and can define better the deficit in rainfall. It was verified that the spatial variation of annual rainfall is an important indicator of water and water erosion potential in the state as described by COPPETEC (2014). The SPI for these time scales is usually directly related to flow rates, reservoir levels, and even groundwater levels (World Meteorological Organization, 2012), Also Nehren *et al*., (2017) point out that less precipitation and higher temperatures could therefore further dry up semi-arid and sub-humid regions of the state of Rio de Janeiro.

In total Médio Paraíba do Sul was the hydrographic region with the lowest percentage of time in drought at all the scales of analysis, and the one that had the highest was Guandu having a 35% difference in time in drought compared to the hydrographic region of Médio Paraíba do Sul; this may be due to the relationship between rainfall increase and altimetry elevation in this last hydrographic region. In the study carried out by COPPETEC in 2014, the same result was found. Also in Guandu there is a power system plant that supplies the entire metropolitan area of Rio de Janeiro, which in the last years has been changed their function to water supply for the metropolitan area; added to the fact that part of the drainage area of the Guandu River is in very poor cities, where also the sewage collection and treatment is insufficient (Kelman, 2015). This is why it is very important to keep an eye in the hydrographic region and take proactive measures. Also, the hydrographic region of Guandu has an organism responsible for the correct water management of the Guandu River Basin (Santos, 2016).

It is very interesting to point out that Baixo Paraíba do Sul always appears in any scenario of drought, this corresponds to the climatic region in which it is located. COPPETE (2014) pointed out that in the north and northeast regions of the state, where the Serra do Mar ends and the Serra da Mantiqueria distances itself and loses altitude, the natural barrier effect decreases an extensive area of hot climate with a marked seasonality (four to five dry months in the year) appears, which corresponds to a large part of the hydrographic region of Baixo Paraiba do Sul and Itabapoana. This is consistent with the study carried out in 2016 by Almeida *et al*., where the northern part of the state of Rio de Janeiro has greater exposure to drought, and as it is progresses to the south, this exposure decreases.

In all the SPI analyses from the end of 2000 to 2002, there was an increase in drought records; coinciding with the period of drought described by Cavalcanti and Kousky (2004), for the whole country associating it with atmospheric circulation features. Further literature mentions more recent drought events like in 2005, and

2010 (Marengo *et al.,* (2011), Santos (2016), Kelman (2015)). COPPETEC (2014) also found that the water balance in the region already has a negative trend.

5.2 Drought Vulnerability

The impacts caused by droughts can affect the different social, economic and environmental sectors of the state, therefore it is fundamental to analyse the vulnerability to drought from every municipality.

The vulnerability index was constructed with the available data and according to the quality of these when the informants were less than three in the municipality their data was protected. The analysis shows that the interactions of all the variables within each factor are those that determine the final degree of vulnerability. Each one is weighted equally, and its values from 0 to 1 are determined between the same municipalities studied. Almeida *et al*., (2016) argue that in this way there is a better understanding of the values.

Can be observed in the results that there is no geographic pattern of vulnerability, neither for the analysis at the municipal level of 92 municipalities based on secondary data nor for the 17 municipalities analysed based on online surveys. Research developed by other authors such as Cutter *et al*., (2003), Tate (2011) and, Emrich (2005) also did not show a correlation between the degree of vulnerability and its geographical location.

Some of the municipalities with higher and lower vulnerability coincide with the study conducted in 2016 by Almeida *et al*., which was based on the indicators proposed by the world risk index. In this study, the differences as in this thesis were also highlighted by the index of human development, health services, among others. However, they identify the state of Rio de Janeiro as one of those with the lowest vulnerability compared to the entire country.

It is important to keep an eye out for the vulnerability of municipalities where energy-generating plants are located, or if they are crucial for water supply in the region. As Santos (2016) mentions that water systems are planned to be expanded in the next years, mainly in the municipalities of Magé, Guapirim in part of Duque de Caxias, of which, the first two resulted within the high vulnerability grade.

With the online survey, it was possible to know the perception, the knowledge of the hazard and the preparation of the municipality to any drought event. In this analysis, for example, the municipality of Resende changed its level of vulnerability to very low, but the municipality of Engenheiro Paulo de Frontin increased its vulnerability level. With this it was possible to note how the factors analysed can change the vulnerability of a place. Wilhite *et al*., (2000) and Slovic (1997) discuss the development of communication and management strategies that appropriately deal with uncertainty and the perception of risk, but to deal properly with this, it is important to know their perception and knowledge of the hazard.

The variables that made the greatest difference were the sufficient water reservoirs, if there is drought research and if the municipality is prepared both governmentally and in health services prior to any scenario of drought. It is important to not forget that a community or municipality with a low or very low degree of vulnerability also requires attention, since the results are only a hierarchy of priorities among all municipalities.

This vulnerability study shows what Wilhite and Svoboda, (2000) and Naumann *et al*., (2013) had mentioned, vulnerability to a climatic event such as drought depends on multiple factors such as water uses, economic activities, among others. So far there is not a vulnerability index developed which its results are absolute and completely true, although the developed indexes are getting closer to reality, depending on the context of each community.

5.3 Drought Risk

The risk of drought has been studied for many years in the north, and north-west part of the Brazil; however, Catarina *et al*., (2015) and Almedia and Birkman (2016) have studied the whole country due to the growing episodes of drought affecting it. In the case of Rio de Janeiro, this is the first drought risk study to be carried out in the state. The drought risk index was developed with the combination of vulnerability and risk, through a matrix developed automatically with the weighted overlay of ArcGIS. Was found in the results as Hayes *et al*., (2004) that higher risk areas are the same where both high hazard and high vulnerability coincide.

The analysis was done from cases of near normal to extreme drought, and the results were in line with Welle and Birkmann (2015), who mention that not only extreme events generate a disaster, but also the conditions of societies exposed to the hazard can determine whether a natural phenomenon is going to trigger a disaster or not.

Just a few studies take a holistic approach, integrating exposure, hazard, vulnerability and risk into the analysis (Almeida, 2012 in Almeida 2016). Most studies concentrate on the analysis of the local aspects of disaster risk, but there are few approaches at the state level (Almeida, 2016). Studies like this can help decision-making and risk reduction policies.

Drought Risk in Rio de Janeiro State

With the aim to make easier the observance of drought in the different hydrographic regions a table (annexe 2) was developed. This table shows the most significant risk values in terms of territorial extent for each hydrographic region.

Following this idea in terms of the geographic extent of risk, it was found that all the hydrographic regions present a very high risk in different SPI scenarios for an extreme drought. Nehren *et al*., (2017) carried out a study where they performed a forecast change in water availability in soil 2011-2040 compared to the reference period 1960-2005 in the states of São Paulo, Rio de Janeiro and Minas Gerais. Their result showed that in the state of Rio de Janeiro there is a negative change in water availability from high to medium, with the hydrographic regions of Piabanha and Rio Dois Rios being the most affected. This last hydrographic region also appears with high risk in at least one SPI of all the scenarios analysed.

In all the maps and analyses of risk to drought, the region of Baxio Paraíba do Sul and Itabapoana was present at the highest levels, while for the lowest risk levels Baía da Ilha Grande had the greater extension. The main differences between these two hydrographic regions are that the Baía do Ilha Grande is practically next to the sea and the Serra da Mantiqueira where average annual rains are over 2000 mm/year and can reach up to 2500 mm/year in the highest parts close to the mountain ranges. In contrast, the region of Baixo Paraiba do Sul and Itabapoana is the region with less precipitation in the whole state with an annual average between 750 mm to 1000 mm (André et al., 2008); also Baixo Paraiba do Sul and Itabapoana is situated in a less mountainous area in a higher distance to the Serra da Mantiqueira, leaving an area of the region hot and with less precipitation (COPPETE, 2014).

In map 3 the different climate regions of Rio de Janeiro state are shown. The hydrographic region of Baía da Ilha Grande is in the sub-hot categorie with a subcategory of super humid climate. Near the coast hot and super humid climate is present, further away from the coast the mestothermic soft climate appears also in the category of super humid. And, as COPPETE (2014) mentioned it is also the hydrographical region with the lowest annual rainfall and marked seasonality in a predominantly mild flood (60% of its territory is covered by flatlands and hills), and only 10% is covered by forests.

While Baixo Paraíba do Sul and Itabapoana is in the category of warm climate with humid and semi-humid regions; in addition, it is also the hydrographical region with the lowest annual rainfall and marked seasonality in a predominantly mild flood (60% of its territory is covered by flatlands and hills), and only 10% is covered by forests (COPPETE, 2014). These physical differences make the region more susceptible to drought, which is also reflected in the hazard analysis results.

Baía da Ilha Grande in its territory includes only the municipalities of Paraty and Angra dos Reis, and partially to the municipality of Mangaratiba. The three municipalities show a medium vulnerability scale in the vulnerability index. While the hydrographic region of Baixo Paraiba do Sul and Itabapoana includes in its territory 15 municipalities in its entirety and partially seven municipalities, of which 13 are in a very high degree of vulnerability (60% of municipalities). Furthermore, the main differences between Baía do Ilha Grande and Baixo Paraíba do Sul and Itabapoana were the main economic activity, the amount of temporary crops, the amount of health services that every region has, the gross domestic product and the amount of people working in water services. This also shows the relation between the hazard and the level of vulnerability, because where these two are high also the highest levels of risk is presented and if the vulnerability and hazard are very low or low the lowest levels of risk resulted for the region .

In this study it was found as Nehren *et al*., (2017) that the potential of ecosystem-based measures is not yet exploited and mostly isolated solutions have been implemented in Brazil; this does not ensure the environment management and neither good risk management.

Drought Risk in 17 municipalities of Rio de Janeiro State

The risk analysis performed for the 17 municipalities with primary data showed that in all scenarios of drought risk the municipalities that appeared with less risk are Niteroi, Resende and São Gonçalo.

The most recurrent municipality with high risk in some part of its territory was Trajano de Moraes, meanwhile and the one that appeared with less risk more frequently was Engineer Paulo de Frontin, which belongs to the hydrographic region of Guandu and according to COPPETE (2014) has the largest source of public water supply in the state. Trajano de Moraes shares two hydrographic regions: Baixo Paraiba do Sul and Itabapoana and Rios Dois Rios. As already mentioned, Baixo Paraiba do Sul and Itabapoana is the driest hydrographic region of the state, and Rio Dois Rios which is located next to the Serra do Mar works as a "gateway" to the region; with critical events related to the restrictions imposed by the relief and lack of infrastructure in basic sanitation and with agricultural areas downstream of sewage points (COPPETE, 2014).

The major differences between Trajano de Moraes and Engenheiro Paulo de Frontin in the vulnerability index considering just the primary data were: the main source of income of the municipality, if the drought is seen as a threat, if they are already damaged by drought or alterations have been observed in the municipality due to drought, if there are sufficient water reservoirs and, if the municipalities are prepared for the possibility of drought, among others.

Hayes *et al*., (2004) established mitigation strategies that address hazards like drought, “may be the most cost-effective and successful in reducing the losses caused by droughts and other hazards in the future”. The risk analysis should be based on an adequate assessment of the hazard and identification of the vulnerability factors for each study whether at global, country, municipal or local level, with reliable and complete data. Because of this an analysis with primary data will be more effective and closer to reality; therefore the measures taken will be more easily accepted by the communities.

6. CONCLUSION AND RECOMMENDATIONS

The state of Rio de Janeiro is located in the south-eastern region of the country; this region is the one with the greatest economic development and population density in the whole country. Therefore, it is important to study all the risk factors for the place. This thesis is the first drought risk study to be carried out in the state. The drought in Rio de Janeiro requires detailed studies to characterize it in terms of frequency and intensity at various spatial scales in order to support plans for mitigation and adaptation to drought.

With the SPI analysis, it is possible to determine the potential impacts associated with drought in a function of a scale of time allowing to stablish a relation on different sectors under analysis in a different temporal magnitude. Thus, the 3-month scale reflects the short and medium term moisture conditions and provides a seasonal estimate of precipitation. This is particularly helpful in agricultural regions. On the other hand, a time scale of more than six months reflects long term precipitation patterns; this would allow an assessment of the effect of rainfall on reservoir levels or flow rates.

More drought related studies are needed in the state of Rio de Janeiro, and it is necessary for the meteorological stations to be in constant maintenance and monitored to ensure reliable and complete data. It would be very interesting to conduct a study when precipitation data is complete at least until 2017, as drought episodes have been recurrent in recent years. This study was carried out with selected stations with data from 1975 to 2005, because it is important to capture better the variability in precipitation that has incomplete recent data or not representative data for hydrographic or climatic regions.

The hydrographic region that had the greatest drought hazard at all time and drought category scales is Baixo Paraíba do Sul and Itabapoana, which is the driest and least precipitated region of the state. In contrast, Macaé and das Ostras is the hydrographic region with less drought hazard on all SPI and drought category scales being also the wettest region of the state.

The analysis of vulnerability was adequate to the temporal, cultural and physical situation of the state since always in vulnerability studies changes over time must be considered, so that the different indicators contribute to the overall vulnerability as an attempt to maintain an objective study, all variables were weighted equally, in the analysis of the whole state as in the analysis for the 17 municipalities.

A vulnerability analysis of primary data from all states would make the research stronger. Unfortunately, it was not possible to get primary data from all municipalities, those who responded showed their interest in risk issues despite some not considering drought as a hazard to the municipality. This interest shown in the research automatically reduces vulnerability compared to other municipalities. When the stakeholders have an interest in any hazard issue, it will be easier to take preventive measures against any threat and reduce both physical and vital losses.

In the vulnerability study carried out for all municipalities, Niteroi had the lowest value, in contrast to Campos dos Goytacazes, which has the highest. Niteroi is located in the Baía de Guanabara, and Campos dos Goytacazes is located in Baxio Paraíba do Soul and Itabapoana appearing the driest hydrographic region of the state again. For the exclusive study of the 17 municipalities, it was found again in the lowest levels Niteroi, being the lowest one of all the municipality of Resende, and the highest Cardoso Moreira. Resende is located in the hydrographic region of Medio Paraíba do Sul, and Cardoso Moreira in Baixo Paraíaba do Sul and Itabapoana.

The main differences that defined the level of vulnerability among the municipalities where the perception of drought, the drought exposure or alterations observed in the municipality due to drought, water reservoirs, the index of human development, health services, among others.

The risk analysis, especially for drought in the state of Rio de Janeiro, has a long way to go and it is necessary to solve various doubts and gaps in both practical research and theory, proof of this is the heterogeneity of methodologies, the lack of information to be able to choose the variables and once chosen, the availability of data, as well as the differences between research from the hard sciences and the social sciences. Despite this, progress has been made, seeking to combine drought vulnerability and drought hazard better.

Risk analysis was performed objectively and impartially through matrices that combined hazard and vulnerability, in the risk study for the entire state, the hydrographic region that showed the lowest risk for all the time scales and category of drought was Baía da Ilha Grande, and the one that showed higher risk was Baixo Paraíba do Sul and Itabapoana. This last hydrographic region also obtained the highest values in vulnerability and analysis of the threat through SPI. In the risk analysis of the 17 municipalities, Trajano de Moraes was the highest and Engenhero Paulo de Frontin was the lowest overall in all time scales and drought categories analysed. It is very interesting to note that the municipality of Trajano de Moraes has a part of its territory in the hydrographic region of Baixo de Paraíba do Sul and Itabapoana. This is, therefore, the hydrographic region with the highest risk since it appeared constant in the highest values of all analyses performed in this research.

There is still plenty of work to be done; society, researchers and, stakeholders must work together. This work has to be prospective to make the community aware of the hazards to which it is exposed and how to reduce its vulnerability. The authorities should know the context of the society to be able to include it in the plan development, to reduce risk to any hazard. It is necessary to consider the appropriation that the communities make of the dangerous spaces and how they perceive the risk.

I hope this work will be a watershed to continue research in the state in order to face drought hazard; as it is not possible to change the natural course of drought, it is important to keep investigation about drought duration, intensity and territorial distribution; and concerted action at the political and institutional levels would undoubtedly help to build capacity and reduce people's vulnerability to drought impacts in the most affected regions.

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ANNEXES

ANNEXE 1

Perception Survey.

Drought perception survey
applied to municipal leaders

1. Lideres Pesquisa municipal

1. **Municipio:**

2. **Cargo:**

3. **Sexo**

(●) Feminino (○) Masculino

4. **Faixa Etaria:**

(○) 20-30 anos
(○) 31- 40 anos
(○) 41-50 anos
(○) 51-60 anos
(○) Mais de 60 anos

5. **Nivel de educação**

(○) Fundamental (○) Médio (○) Superior

6. **Que é a principal fonte de renda em seu município?**

(○) Agricultura
(●) Pecuária
(○) Piscicultura
(○) Floresta
(○) Indústria
(○) Empresa de pequeno porte
(○) Projetos de eletricidade

7. **Qual a questão da água mais grave em seu município?**

8. **Para você o que é a seca?**

9. A seca é causada por:

- ○ Natural
- ○ Antropogênica

10. Considera seca como uma ameaça ao seu município?

- ○ Sim
- ○ Não

11. A pesquisa sobre seca é realizada em seu município?

- ○ Sim
- ○ Não

12. A que tipo de seca considera mais vulnerável pelo município?

- ◉ Meteorológica
- ○ Hídrica
- ○ Agrícola
- ○ Econômica e social

13. O seu município sofreu danos de seca?

- ○ Sim
- ○ Não

14. Você notou qualquer uma das seguintes alterações no seu municipio:

	Sim	Não
Doenças dos animais	○	○
Redução das colheitas	○	○
Atividades da vida diária (banhar, regar, cozinhar, etc.)	○	○
Aumento da conta de água	○	○
A escassez de alimentos	○	○
Maiores problemas de saúde	○	○
A escassez de água em corpos d'água superficiais	○	○
Declinio nos niveis de águas subterrâneas	○	○
Qualidade de água deteriorada	○	○
Danos a vida selvagem e habitat do peixe	○	○

Mudança da temperatura média	○	○
Degradação florestal	○	○
Degradação de pastagens	○	○

2. Gestão do governo

15. Quanto esta preparado o seu município à seca?

- ○ Muito alto
- ○ Alto
- ○ Médio
- ○ Baixo
- ○ Muito baixo
- ◉ Não preparado

16. Você acha que o seu município tem reservatórios de abastecimento de água suficientes?

○ Sim ○ Não

17. Tem um sistema de resposta governamental à seca?

- ○ Sim
- ○ Não

18. Há um treinamento nos serviços de saúde para doenças relacionadas com à seca?

○ Sim ○ Não

19. Como o município se prepara durante o ano normal para lidar com qualquer possibilidade de seca?

20. **Indique as atividades que considere que correspondem ao governo estatal, municipal e nacional:**

	Municipal	Estatal	Nacional
Diminuição dos impactos da seca	☐	☐	☐
Prevenir incêndios florestais	☐	☐	☐
Aplicar leis existentes	☐	☐	☐
Educar os usuários de água na comunidade	☐	☐	☐
Punição para os usuários de água que não pagam	☐	☐	☐
Investir dinheiro para reparo e renovação no sistema de água	☐	☐	☐
Aumentar a eficiência do sistema de água	☐	☐	☐
Conservação da água	☐	☐	☐
Construção de infra-estrutura	☐	☐	☐
Crédito anti-seca	☐	☐	☐
Gestão de reservatórios	☐	☐	☐
Investir em novas tecnologias	☐	☐	☐

MUITO OBRIGADA!

ANNEXE 2

Risk Map Analysis Table

Table of Risk Map results, in terms of geographic extension and degree of risk in the nine hydrological regions of Rio de Janeiro State

Hydrographic region	Extreme				Moderate				Near Normal				**Time scale**
Degree of Risk	Very High	Moderate	Low	Very low	Very High	Moderate	Low	Very low	Very High	Moderate	Low	Very low	
Baía de Guanabara		✓					✓					✓	SPI-3
		✓	✓				✓					✓	SPI-6
	✓	✓			✓		✓		✓			✓	SPI-12
	✓	✓			✓							✓	SPI-24
Guandu	✓	✓					✓					✓	SPI-3
			✓				✓					✓	SPI-6
				✓			✓	✓				✓	SPI-12
					✓							✓	SPI-24
Baía da Ilha Grande				✓		✓						✓	SPI-3
								✓				✓	SPI-6
	✓											✓	SPI-12
				✓	✓							✓	SPI-24
Lago São João					✓	✓						✓	SPI-3
	✓	✓						✓				✓	SPI-6
	✓	✓										✓	SPI-12
					✓							✓	SPI-24
Macaé and das Ostras						✓	✓					✓	SPI-3
												✓	SPI-6
		✓										✓	SPI-12

			✓	✓			✓	SPI-24
Médio Paraíba do Sul	✓	✓			✓		✓	SPI-3
				✓			✓	SPI-6
	✓			✓			✓	SPI-12
	✓	✓		✓			✓	SPI-24
Baixo Paraíba do Sul and Itabapoana	✓						✓	SPI-3
	✓	✓		✓			✓	SPI-6
	✓			✓			✓	SPI-12
	✓			✓			✓	SPI-24
Piabanha	✓						✓	SPI-3
		✓		✓			✓	SPI-6
	✓						✓	SPI-12
	✓			✓			✓	SPI-24
Rio Dois Rios							✓	SPI-3
		✓					✓	SPI-6
							✓	SPI-12
	✓			✓		✓	✓	SPI-24