Adaptation mechanisms for extreme events in the Capibaribe River Basin, Brazil

Larissa Ferreira David Romão Batista[1], Alfredo Ribeiro Neto[2], Suzana Maria Gico Lima Montenegro[3]

[1, 2, 3]Department of Civil Engineering, Federal University of Pernambuco, Recife, Brazil

ABSTRACT

River basins are impacted by extreme hydrological events (droughts and floods), especially in the face of Climate Change. This paper characterizes the climate spatial variability and mechanisms used to deal with hazards in the Capibaribe River Basin – Brazil. A comparison with similar regions helps identifying the level of climate variability in the CRB, the solutions developed to deal with both shortage and excess of water, and the status of the study area in terms of vulnerability caused by this characteristic. The main strategies identified in the basin for dealing with both drought and flood events are the construction of reservoirs.

1. INTRODUCTION

Many are the challenges proposed by the current climate change tendencies. Natural and anthropogenic actions have been influencing disasters and their dynamics. Even if the causes are still debatable, it is noticeable the increase in the frequency and magnitude of extreme events. In this scenario, floods and droughts play a relevant role, generating countless damages every year. Floods, for example, can be classified as a democratic hazard, hitting areas in all continents, and making no distinction of social or economic status. Whilst droughts can consistently jeopardize livelihoods, leading to migration or lasting frames of poverty. As the human, economic and ecological impacts of climate related hazards increase, proportionally grows the necessity to investigate these events, the risk, and the possible adaptation strategies (Modarres, Sarhadi & Burn, 2016).

The study of the risk and its components, such as hazard, vulnerability, resilience, and adaptation, for instance, corroborates to a more sustainable development. Adaptation strategies are based on the idea that people can learn to cope with hazards, instead of controlling it, which has been proven usually inefficient (Lei & Wang, 2014). Therefore, the focus is to prepare natural and human systems not just to respond after an extreme event strikes, but also to prevent it with actions taken before its occurrence. In this sense, the evaluation of areas exposed to different events contributes to identify the level of relationship between technology, community, and extreme phenomena.

The objective of this paper is to characterize the climate spatial variability and the mechanisms used to deal with extreme events in the Capibaribe River Basin (CRB) – Brazil**.** Due to its historical and touristic importance, huge socioeconomic influence, and especially its geographic attributes, this basin requires specific policies and management plans. The purpose is that the results of the study may contribute to discussion around strategies of adaptation and their availability in the region.

2. STUDY AREA AND CURRENT STRATEGIES FOR COPING WITH HYDROLOGICAL EXTREMS

2.1. Main Characteristics

With a drainage area of approximately 7454 km², the CRB is located in the Pernambuco State – Northeast Brazil. The Capibaribe River runs in the direction west-east to the Atlantic ocean. The basin covers three different geographic areas, which define a heterogeneous environment composed by a high spatial variability of the climate, terrain, vegetation and soil. Figure 1 illustrates the Capibaribe River Basin Location Map.

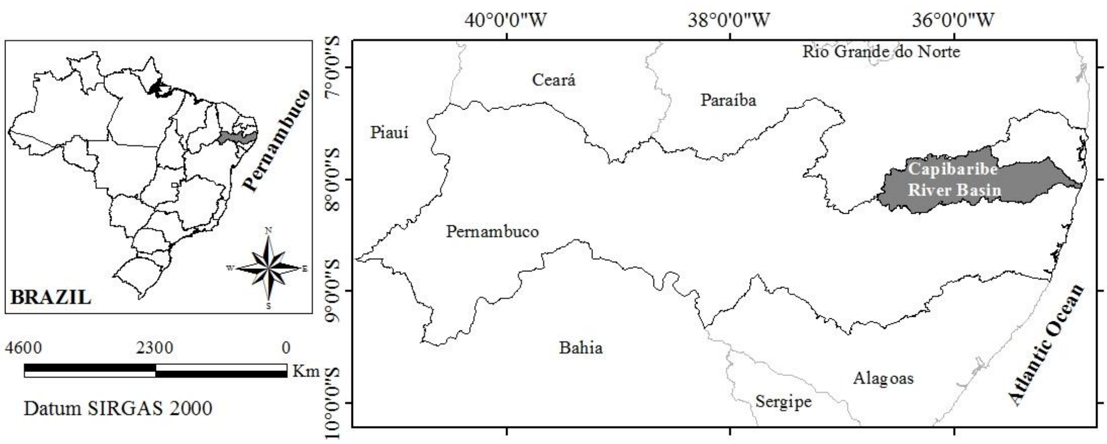

Figure 1. Capibaribe River Basin location.

The west portion is characterized by shallow soils, Caatinga vegetation (thornscrub, cactus, and bunch grasses), and a semiarid climate with 550 mm yr^{-1} of rainfall and mean air temperatures between 20 and 22◦C. Periodically, this region suffers with the consequences of drought events. Whereas the east part of the basin is characterized by deeper soils, Atlantic Forest vegetation, and a humid/sub-humid climate, with 2400 mm yr^{-1} of rainfall and mean air temperature between 25 and 26◦C. During a long time, the cities located in this region were affected by flood events, with emphasis for the city of Recife, the capital of Pernambuco state (Ribeiro Neto et al., 2014). Figure 2 shows the spatial distribution of the precipitation in the basin where it is possible to visualize the climate gradient.

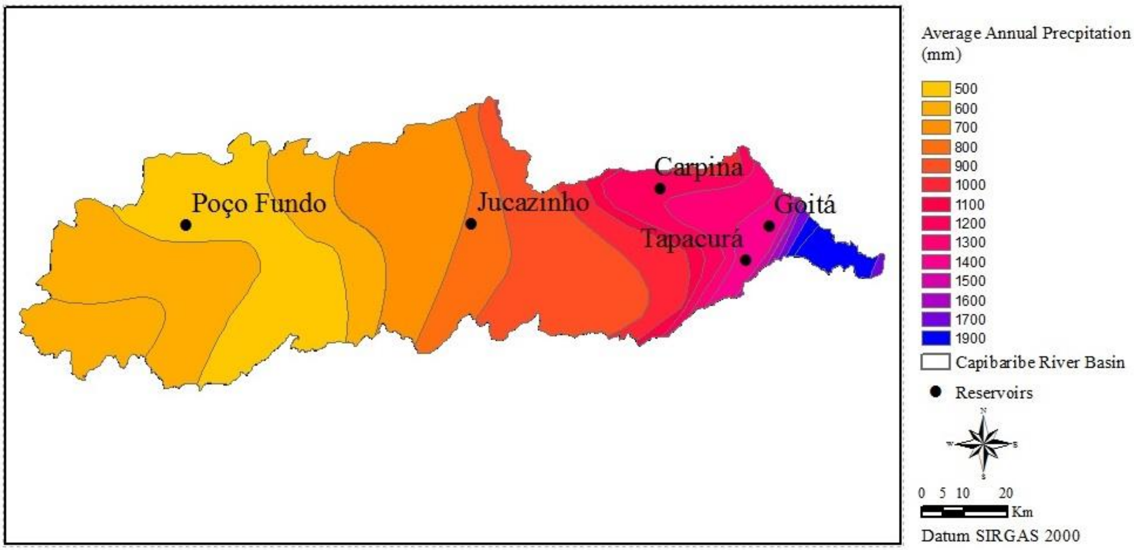

Figure 2. Spatial distribution of the precipitation.

2.2. History of events

After understanding the physical and environmental diversity of the basin, it is now important to comprehend the dynamics regarding extreme events. Even though there is not long term monitoring in the CRB, the recurrence of floods and droughts enabled the construction of a natural phenomenon record that helps identifying hazard behavior in the region. The records are shown on Table 1 (Pernambuco, 2010).

Century	Drought events (years with records)	Flood events (years with records)
17th	1603-1606; 1614-1615; 1652; 1692	1632; 1638
18th	1709-1711; 1720-1724; 1736-1737; 1744-1746; 1748; 1754; 1760; 1772; 1776-1777; 1782; 1784; 1790-1794	No records
19th	1804; 1808-1810; 1816-1817; 1824-1825; 1830-1833; 1844-1845; 1888-1889; 1891; 1898	1824; 1842; 1854; 1862; 1869; 1870; 1884; 1894; 1899
20th	1902-1903; 1907-1908; 1910; 1914-1915; 1919; 1932-1933; 1945; 1951; 1953; 1956; 1958; 1966; 1970; 1979-1981; 1983-1984; 1986-1987; 1991; 1993; 1997-1998;	1914; 1920; 1924; 1960; 1961; 1965; 1966; 1970; 1974; 1975; 1977; 1978; 2000
21st	2001; 2012-2016	2004; 2005; 2010; 2011

Table 1. Floods and droughts History of events.

Concentrated in the west portion of the basin, drought events are a reality of the semiarid climate and its irregular rainfall characteristics. Unlike floods, droughts usually last for cycles of years, hardening livelihoods, and inducing migratory currents. Historically, droughts in the Northeastern region of Brazil led to loss of crops, starvation and death. Initially the shortage of water was an exclusively rural issue, but with time, the consequences turned more extensive as cities downstream the river started to suffer with the lack of supply. Highlights go to 1998 drought; its consequences were still present in the beginning of the 21st century, becoming part of an energy crisis a couple of years later (Pernambuco, 2010). Another point that calls to attention is 2016, marking the sixth year of a harsh drought period. Figure 3 displays the Jucazinho reservoir, which is currently presenting a breakdown and will not be able to supply water for approximately 200 thousand people (TV Asa Branca, 2016).

In what concerns to floods, there is a gap of a century in the information. However, this has a small influence once the first big flood event has only been registered in 1842. In that year, thousands of people became homeless. Another highlight occurred in 1854, when the largest flood of the century was recorded. Lasting 72 hours and hitting especially the capital of the state, that event caused severe damage to houses and urban infrastructure and blocked communication (Goethe, 2016).

The 20th century marks a significant increase in the number of cases with two events being registered in 1970, when the overflow of several rivers led to deaths and destruction in the Metropolitan Region of Recife. In 1975, the greatest flood of that century hit the state, flooding 80% of the capital and another 25 municipalities. Extremely high flood inundation levels were observed in the occasion. The extension of that event is illustrated in Figure 4 (Riachos Urbanos, 2014). The 21st century has already experienced four events in less than a decade, and now other aspects such as massive urbanization tendencies contribute to raise the vulnerability of cities, their properties, infrastructure, and population (Pernambuco, 2010).

Figure 3. Jucazinho Reservoir in 2016.

Figure 4. Flood in Recife in 1975.

2.3. Adopted infrastructure and non- structural policies

Even though the first register of a dam is from 1638, only three centuries later the construction of such infrastructures became widely applied in order to deal with the increasing frequency of floods. Especially after the 1975 major flood event, it was necessary to reinforce flood control measures. The main goal was to avoid another enormous disaster as the one experienced in that year. Still nowadays, dams and reservoirs are the main strategy adopted to cope with inundation.

Containing almost 95% of the total volume accumulated in the basin, Tapacurá, Goitá, Carpina, Poço Fundo and Jucazinho are the main reservoirs on the river. In the

CRB, these dams are the only detected action for flood control, even though this is not their single function, as they are used for water supply purposes as well. The Water and Climate Agency of Pernambuco (APAC) monitors the water level of such large structures. In parallel, a commission made up of federal and state institutions manages the reservoirs and their multiple applications. This solution and arrangement has succeeded so far despite the severe flood events occurred in 2010 and 2011 in Pernambuco state (Pernambuco, 2010). Further details about the reservoirs are listed in Table 2 (Pernambuco, 2010).

Reservoir	Drainage Area (km²)	Total volume ($x10^6$ m³)	Useful volume ($x10^6$ m³)	Average inflow (m³/s)	Inauguration	Purpose
Tapacurá	360	98.7	98.7	2.25	**1973**	Flood control and supply
Goitá	450	52.0	15.6	2.00	**1976**	Flood control and supply
Carpina	5999	270.0	81.0	6.92	**1978**	Flood control, supply and fishery
Poço Fundo	854	27.75	27.75	1.47	**1986**	Supply and irrigation
Jucazinho	4171	327.0	227.0	6.34	**1999**	Supply and pisciculture

Table 2. Major reservoirs and their characteristics in CRB.

In what concern to droughts, the same Tapacurá, Goitá and Carpina dams, designed with the major purpose of flood control, had to adapt their operation, and started supplying water to a constantly growing urban population, mainly in Recife Metropolitan Region. The surface water in CRB (rivers and reservoirs) is responsible for the supply of 5.025 m³/s (human), 1.043 m³/s (industry) and 1.204 m³/s (irrigation), totalizing 7.272 m³/s (Pernambuco, 2010).

There are some Governmental Programs developed to deal with natural and social hazards that enhance population resilience. The ones worth mention are:

- “Bolsa Família” focuses on income distribution to poor and extremely poor families throughout the country, benefitting more than 13.9 million families so far in Brazil (Caixa, 2017).
- “Garantia-Safra” objective is to guarantee minimal conditions to rural households in municipalities that are susceptible to suffer loss of crops due to shortage or excess of water. From 2010 to 2014 this program registered more than 3.6 million farmers (Ministério do Desenvolvimento Agrário, 2015).
- “Chapéu de Palha” is a Program of the Pernambuco State Government created to help unemployed rural workers due to offseason dynamics or natural disasters. Attending 54 municipalities in the state, in 2016 the initiative registered 50 thousand beneficiaries (G1 PE, 2015).

Moreover, in the semiarid region, local households adopted other technologies as alternative sources of water. One of these strategies is the construction of small reservoirs, which is a traditional and largely adopted storage solution in the region. These bodies of water became more popular in the 1960s, but the first ones started to appear in the 19th century. The main uses are for irrigation, human supply and fish-farming. However, high evaporation rates is a major limiting factor of such technique, and also the indiscriminate dissemination of small reservoirs can negatively impact users downstream, interfering with the entire basin management.

In the 1990's, rationing water was a necessity in the coast as well as in the semiarid region. Water trucks became the main emergency measure adopted by governments to provide water to people. This emergencial solution is still applied nowadays, reaffirming the consistency of drought events, and the incomplete extent of other measures. In that same decade, other technique gained momentum. The construction of rural cisterns made rainwater haversting possible with financial incentives from Governmental and Non-Governmental Programs. This technology has been applied as public policy to combat extreme poverty, and to preserve rural yield. Cisterns are relevant mechanisms in the region. They have an accumulation capacity of about 7-15 m^3 represent the availability of 50 L of water per day during 140–300 days (Cirilo et al., 2017).

Besides the aforementioned measures to cope with droughts, another option is the exploitation of groundwater by wells. Naturally protected from high evaporation rates, these resources diminish the main problem found in small reservoirs. Especially in alluvial valleys, wells are very important to human and animal water supply. Despite of its dependence on the seasonality of rainfall, alluvial aquifers present faster replacement and dilution mechanisms than groundwater found in crystalline rock fractures, for example. However, because of the high variability in its soil texture, salinity and hydraulic conductivity, alluvial valleys require mapping and monitoring. Nevertheless, deficiencies in the management and the lack of public incentives increasingly hinders the possibility of a adequate exploitation with small structures and low cost (Montenegro & Montenegro, 2012). Many wells drilled in crystalline produce unsuitable water for human consumption due to the high salinity levels. In these cases, desalination plants of reverse osmosis are used to ensure water with suitable quality for human consumption in small communities. According to information of the Executive Secretariat of Water Resources of Pernambuco State, there are 34 desalination plants in the CRB, which supply water for 6,700 families.

Thus, it is evident that the area presents high vulnerability to climate conditions. The various attempts of adaptation expose the persistent unstable conditions. However, more than natural characteristics, what influences such scenarios are the punctual and discontinued adaptation initiatives that block any structural advances in this area.

Underground dams, for example, have been gaining more and more popularity. This solution consists of waterproofing devices constructed to intercept subsurface flow rates (Montenegro & Montenegro, 2012). Underground dams promote infiltration and storage or rainwater in alluvial deposits, with greater protection from evaporation and salinization. These dams cost approximately R$ 5000 (Brazilian Currency) being considered cheap solutions in the face of surface reservoirs, for instance. It is estimated that there are around 2,240 units throughout the northeastern semiarid region (Maranhão, 2015).

3. EXAMPLES IN OTHER COUNTRIES OF HOW TO COPE WITH HYDROLOGICAL EXTREMS

Like the Capibaribe River Basin, other places around the world have the challenge to adapt to drought and flood events. That is the case of Kanyemba region, in Zimbabwe. Located between Zambezi and Mwazamutanda rivers, the main activity developed in the area is agriculture. Throughout the years, after the recurrence of hazardous events, and consequently many damages gathered, the community resorted to adaptation strategies in a local scale, instead of big infrastructure measures. Farmers had to diversify cropping techniques and types of crops, which proved effective. Therefore, after flood events, certain kinds of seeds were cultivated, exploring the remaining soil moisture, while other more resistant waited for the dry periods (Bola et al., 2014).

Thailand is another rural-based economy that faces both flood and drought hazards. Like the Capibaribe River Basin, the country has adopted the traditional strategy of constructing dams, with various purposes such as electric power generation, irrigation and domestic water supply. However, experience has shown the necessity of a wider approach, integrating surface water and groundwater. Thus, other storage options as Rainwater Harvesting (RWH) and Managed Aquifer Recharge (MAR) have been estimulated for their relative low costs, and wide availability. Off-channel systems that support MAR are beginning to spread nationally. A conjunctive model applied at the basin scale now replaces the historically separated application of technologies as the main risk reduction option. This case importantly stresses the leading role of management in dealing with this dual reality without adopting a mutual exclusive point of view (Pavelic et al., 2012).

Another case worth mention regards the Yangtze River, in China. Comprising three diverse geographic regions, the basin presents a broad rainfall variation, leading to places that face only drought events, or floods alone, or both of them in distinct seasons. The Three Gorges Dam is the largest structure installed in this river. Although its gigantic proportions, and consequently the created controversies in the environmental, political and social spheres, it is undeniable the potential of the dam in what concerns to flood control, drought management strategies, electric power production, and so forth (Deng et al., 2016). This case, more than just the solution proposed, highlights the importance and responsibility of administrators in promoting energy efficiency, economy, and adaptation capabilities of a built intervention like that. For its scale, the possible impact of the Three Gorges on the watershed hydrologic cycle may be enormous, and management errors can lead to a disastrous scenario. (Nakayama & Shankman, 2013).

Literature also references measures not related to infrastructure, such as early warning systems, monitoring techniques, development of conservancy projects, forecast modeling (e.g. Long et al., 2014; Broad et al., 2007). However, regardless the scale, and the strategy applied, droughts and floods together offer a huge challenge to disaster managers who become the essential element on the outcomes of risk reductions policies and actions.

4. DISCUSSION

The state of Pernambuco has experienced the global trend of population growth and consequently the increase in natural resources demand, particularly water. The level of climate variability in the study area is coherent with other regions worldwide, especially places that face both flood and drought events. Evidences show that vulnerability is not only related to natural aspects, but it is also part of political, economic and social processes (Lemos et al., 2016). Risk reduction policies need to have a holistic view of the natural phenomenon, to understand how vulnerable the studied society is, and to elucidate the relationship between those two elements. Only then can technology be effectively applied to the scenario.

The CRB is not an exception; the solutions observed in the region resemble others displayed by the literature, especially in agricultural based communities. Mainly in the semiarid land portion of the basin, local households tend to try to adapt cropping techniques in order to have adequate yield, avoiding migration to other regions of the country. In Zimbabwe and Malawi, crop exchange, shifting planting dates, soil and water conservation techniques are some of the actions taken. The hardening conditions can lead to the search for alternative income generating activities (Bola et al., 2014; Pangapanga et al., 2012).

Other strategies adopted in the CRB are also common in Thailand and Bangladesh. In Thailand, groundwater exploitation and rainwater storage are options, along with dams, but the major initiative is in order to connect technologies through Managed Aquifer Recharge (Pavelic et al., 2012). In Bangladesh, recent study underlines the importance of the interaction between experts and local communities for a better selection of solutions to reduce climate change vulnerability (Xenarios et al., 2016). Both examples illustrate the need of a deeper analysis of each scenario, so that the technologies applied can have a support system, an adequate operation, and a more effective performance. The monitoring of results and the connection with other technologies is a development in the adaptation management policies found around the world.

Aside from all the alternative adaptation strategies, reservoirs play an important role, being the largest most popular structures used to face both drought and flood events. Recent study highlights the second half of the 20th century as the expansion period in the construction of dams for hydropower generation, flood control and water storage for irrigation (Chen et al., 2016). All the main reservoirs found in the CRB began their operation in that same period, fitting in this global trend. The same study also underlines that about one-third of the large dams serve two or more purposes, with a more lately tendency for the construction of multi-purpose dams (Chen et al., 2016). In the CRB this tendency gained strength throughout the years, as the structures had to face different climate conditions. In addition, it is important to consider the negative effects of dams, especially on aquatic biodiversity and ecosystems. These subjects must not be neglected, they have to be part of the entire development of dams, since their plan to their operation.

In what concerns to floods in the Capibaribe River Basin, dams and reservoirs have prevented recurrence of disasters since their construction. These structures have proven efficient in diminishing the vulnerability of riverside communities. Although floods can still occur at the capital city, Recife, the variables involved in this specific case goes beyond the scope of this research, encompassing urban planning, urban drainage, and so forth.

In what regards the droughts in the semiarid land portion of Brazil, the CRB included, the approach has always been based on emergency measures instead of prevention actions. As shown by recent research, when the precipitation rates are low, the drought extends itself, and the volume of water in reservoirs is drastically reduced, emergency measures such as rationing water are the alternatives adopted (Salgueiro et al., 2014). Along with that, there is the temporary use of water trucks, usually hired by local governments, especially in small towns. These scenarios are inefficient for both the population and the public sector, and they contribute to complications in the socioeconomic sphere as well as in the environmental.

There are several Governmental Programs working on reducing poverty and on promoting sustainable water management. However, the majority of the initiatives are still punctual and discontinued, making it difficult to progress in a more lasting manner. The advances are undeniable, but there is still urgency in integration among policies regarding social and environmental spheres (Montenegro & Montenegro, 2012).

5. FINAL REMARKS

The reservoirs are the main option chosen to face drought and flood events in CRB. In general, this solution is suitable for water supply in urban communities, but it is not adequate for small communities in the rural zone. In this case, the population uses alternative techniques such as cisterns for storage of rainwater haversting, groundwater associated with desalinization plants and underground dams. In addition, the assistance programs originally created for income transfer for poor families can currently also be considered as an adaptation measure in Northeast semiarid.

It is evident the relevant strict relationship between natural hazards and infrastructures, which contributes directly to water resources management, disaster risk reduction and adaptation to climate variability in the present and for the possible future climate change. The current needs go beyond the construction; it becomes the planning of such structures, so that they provide more than just electric power and economic products. The idea is that technologies applied to cope with hardening climate conditions can corroborate to an effective risk management and sustainable development, in short and long terms.

It is expected that the results of the study can contribute to discussion around the following issue: are the strategies of adaptation available in the region capable of facing the impacts caused by the climate change? This is especially important in regions subjected to hydrological extremes as CRB. The Capibaribe River Basin Committee and the Water State Agency are the suitable institutions to take this discussion forward.

ACKNOWLEDGEMENTS

This paper is a contribution of the Brazilian Network on Global Climate Change Research funded by Brazilian National Council for Scientific and Technological Development (CNPq) Research Grant Number 550022/2014-7 and FINEP Research Grant Number 01.13.0353.00. The authors also acknowledge the Inter-American Institute for Global Change Research (IAI, project CRN3056, which is supported by the US National Science Foundation grant GEO-1128040), the CNPq for PQ scholarship and Research Grant Number 446254/2015-0 and FINEP Research Grant Number1830 (REHIDRO).

REFERENCES

Bola, G., Mabiza, C., Goldin, J., Kujinga, K., Nhapi, I., Makurira, H., Mashauri, D. (2014) Coping with droughts and floods: A Case study of Kanyemba, Mbire District, Zimbabwe. *Phisics and Chemistry of the Earth.* 67, 180-186.

Broad, K., Pfaff, A., Taddei, R., Sankarasubramanian, A., Lall, U., Souza Filho, F. A. (2007) Climate, stream flow prediction and water management in northeast Brazil: societal trends and forecast value. *Climatic Change.* 84, 217-239.

Caixa. (2017) *Bolsa Família*. Available from: *http://www.caixa.gov.br/programas-sociais/bolsa-familia/Paginas/default.aspx* [Acessed: 5th January 2017].

Chen, J., Shi, H., Sivakumar, B., Peart, M. R. (2016) Population, water, food, anargy and dams. *Renewable and Sustainable Energy Reviews*. 56, 18-28.

Cirilo, J. A., Montenegro, S. M. G. L., Campos, J. N. (2017) The Issue of Water in the Brazilian Semi-Arid Region. In: Bicudo, C. E. M., Tundizi, J. G., Scheuenstuhl, M. C. B. (eds.) *Waters of Brazil – Strategic Analysis*, Cap. 5, Springer, pp. 59-71.

Deng, K., Yang, S., Lian, E., Li, C., Yang, C., Wei, H. (2016) Three Gorges Dam alters the Changjiang (Yangtze) river water cycle in the dry seasons: Evidence from H-O isotopes. *Science of the Total Environment.* 562, 89-97.

G1 PE. (2015) *Em PE, Chapéu de Palha cadastral trabalhadores rurais da Mata Sul.* Available from: http://g1.globo.com/pernambuco/noticia/2015/05/em-pe-chapeu-de-palha-cadastra-trabalhadores-rurais-da-mata-sul.html [Acessed: 5th January 2017].

Goethe, P. (2016) O Recife que vem se inundando por conta própria. Available from: http://blogs.diariodepernambuco.com.br/diretodaredacao/2016/05/30/20687/ [Accessed: 8th October 2016}.Lei, Y., Wang, J. (2014) A preliminary discussion on the opportunities and challenges of linking climate change adaptation with disaster risk reduction. *Natural Hazards*. 71, 1587-1597.

Lemos, M. C., Lo, Y-J., Nelson, D. R., Eakin, H., Bedran-Martins, A. M. (2016) Linking development to climate adaptation: Leveraging generic and specific capacities to reduce vulnerability to drought in NE Brazil. *Global Environmental Change.* 39, 170-179.

Long, D., Shen, Y., Sun, A., Hong, Y., Longuevergne, L., Yang, Y., Li, B., Chen, L. (2014) Drought and flood monitoring for a large karst plateau in Southwest China using extended GRACE data. *Remote Sensing of Environment.* 155, 145-160.

Maranhão, F. (2015) No PI, agricultura familiar sobrevive graças a 'barragens subterrâneas'. Available from: http://noticias.uol.com.br/cotidiano/ultimas-noticias/2015/03/26/no-pi-agricultura-familiar-sobrevive-gracas-a-barragens-subterraneas.htm [Acessed: 10th January 2017].

Ministério do Desenvolvimento Agrário. (2015) *Em 4 anos, 3,7 milhões de agricultores aderiram ao Garantia-Safra*. Available from: http://www.mda.gov.br/sitemda/noticias/em-4-anos-37-milh%C3%B5es-de-agricultores-aderiram-ao-garantia-safra [Acessed: 5th January 2017].

Modarres, R., Sarhadi, A., Burn, D. H. (2016) Changes of extreme drought and flood events in Iran. *Global and Planetary Change.* 144, 67-81.

Montenegro, A. A. A., Montenegro, S. M. G. L. (2012) Olhares sobre as políticas públicas de recursos hídricos para o semiárido. In: Gheyi, H. R., Paz, V. P. S., Medeiros, S. S., Galvão, C. O. (eds.) *Recursos hídricos em regiões semiáridas.* Cruz das Almas, Bahia, Universidade Federal do Recôncavo da Bahia, pp. 2-24.

Nakayama, T., Shankman, D. (2013) Impact of the Three-Gorges Dam and water transfer project on Changjiang floods. *Global and Planetary Change.* 100, 38-50.

Pangapanga, P. I., Jumbe, C. B., Kanyanda, S., Thangalimodzi, L. (2012) Unravelling strategic choices towards droughts and floods' adaptation in Southern Malawi. *International Journal of Disaster Risk Reduction.* 2, 57-66.

Pavelic, P., Srisuk, K., Saraphirom, P., Nadee, S., Pholkern, K., Chusanathas, S., Munyou, S., Tangsutthinon, T., Intarasut, T., Smakhtin, V. (2012) Balancing-out floods and droughts: Opportunities to utilize floodwater harvesting and groundwater storage for agricultural development in Thailand. *Journal of Hydrology.* 470, 55-64.

Pernambuco. (2010) *Plano hidroambiental da bacia hidrográfica do rio Capibaribe: Tomo I – diagnóstico hidroambiental colume 01/03.* Recife, Secretaria de Recursos Hídricos e Energéticos.

Riachos Urbanos. (2014) *5 imagens incríveis da cheia de 1975*. Available from: http://riachosurbanos.blogspot.com.br/2014/07/5-imagens-incriveis-da-cheia-de-1975.html [Accessed: 3rd December 2016].

Ribeiro Neto, A., Scott, C. A., Lima, E. A., Montenegro, S. M. G. L., Cirilo, J. A. (2014) Infrastructure sufficiency in meeting water demand under climate-induced sócio-hydrological transition in the urbanizing Capibaribe River basin – Brazil. *Hydrology and Earth System Sciences.* 18, 3449-3459.

Salgueiro, J., Pinto, E., Montenegro, S., Silva, B. B., Souza, W. (2014) Tendência de índices pluviométricos na bacia do rio Capibaribe – PE e sua influência na gestão dos recursos hídricos. Revista Brasileira de Geografia Física. 7(5), 1002-1014.

TV Asa Branca. (2016) *'Jucazinho' seca e dez cidades terão abastecimento por carro-pipa em PE.* Available from: http://g1.globo.com/pe/caruaru-regiao/noticia/2016/09/jucazinho-entra-em-colapso-e-dez-cidades-terao-agua-por-carro-pipa.html [Accessed: 3rd December 2016].

Xenarios, S. Nemes, A., Sarker, G. W., Sekhar, N. U. (2016) Assessing vulnerability to climate change: Are communities in flood-prone areas in Bangladesh more vulnerable than those in drought-prone areas? *Water resources and rural development.* 7, 1-19.