Chapter 2
Impacts of Climate Change: A Case in Watersheds in South of Brazil

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Introduction

The 21st century is the century of cities, as people are increasingly living in urban areas and there has been greater impact in the natural resources. However, with increased pressure on the environment, the risks are inevitable, with extreme events causing severe consequences including damage to infrastructure, properties and even loss of life. In this sense, identify risks and vulnerability before the disaster to occur is essential to effective risk reduction in long-term periods (Birkmann 2007). It seems that enhancing the resilience of the urban environment is indispensable for the sustainability of cities.

The increase in population density, traffic, waterproofing of roads and various other needs of modern cities greatly contribute to the risk of natural disasters. These anthropological actions on the environment tend to lead to climate change and stimulate global warming. Despite the availability of water resources being also affected by intense urbanization, land use, occupation and deforestation, climate events certainly emphasize all these problems, causing floods that bring great economic damage and loss of life, and also droughts that damage agriculture, human consumption and the generation of hydroelectric power (Marengo 2006).

In this context, water is an important factor for the development of any community and there is no doubt that climate change threatens the security of this resource. Thus, growth and development resilient to climate change is essential. Strategies, plans and investments that promote good water management are alternatives to promote climate resilience and better management of water resources benefits many sectors (health, energy and agriculture) and also contributes to the goals of sustainable development (AMCOW 2012).

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According to the Intergovernmental Panel on Climate Change (IPCC 2007a), the impacts of climate change on water resources will be through changes in the hydrologic cycle, increased extreme events, change in the average flow of the watercourse, longer drought events, rise in sea levels and increased frequency of floods. The increase in the intensity of precipitation will also result in increased erosion and new watershed models. Trenberth (2011) also states that precipitation varies from year to year and over decades, and changes in amount, intensity and frequency affect the environment and society, especially when it potentiates extreme events.

Additionally, limitations on measurements and records of rainfall are difficulties that concern researchers, because the frequency and reliability of the records of regional and global rainfall do not have scales to secure regard to control and record the data. This is because in situ measurements in areas of steep and complex topography does not occur due to numerous limitations (Adam et al. 2006).

The impact scenario on water resources will vary according to the region in Brazil. For example, the tendency is that the precipitation increase in the South and decrease in the North and Northeast (Marengo 2006). This will result in a change in river flows in these regions. The occurrence of floods is due to changes in the watershed and precipitation patterns, and this problem is often seen in urban areas. Therefore, it is necessary to develop new concepts and practices in management and public governance processes to improve coexistence with this phenomenon and minimize the impacts to the affected communities (Kobiyama et al. 2006).

Considering all the impacts to be caused in a watershed, it is impossible to guarantee 100% security and the risk culture is needed. Taking into account, it is particularly important that communities develop the ability to deal with the uncertainties in three main aspects: preparation, response and recovery (Federal Office for Civil Protection 2013). Thus, they are connected to the concept of resilience, that can be understood as "the ability of a country or city to respond to and evade the consequences brought about by global warming and to adapt to them." The construction of a society based on the principles of resilience requires new commitments and cooperation of all (Mateus 2004).

According to Randhir (2014), it is important to renew the understanding of resiliency, adaptability, and transformability of watersheds through social and ecological research. Its management to climate change requires a thorough understanding of state and dynamics and the result must be information dissemination and decision support systems related to a watershed to enhance resilience to handle adverse impacts of climate change. Urban planning needs to incorporate knowledge of the vulnerability and risk, to propose measures to mitigate potential impacts and to aim the adaptation to increase urban resilience; for that, it is required multidisciplinary approach and integration of researchers from different areas of knowledge (IPCC 2007b; Frank and Sevegnani 2009).

Farwell et al. (2012) point out that quantifying the anticipated changes allows water managers to match adaptive strategies with expected impacts to improve watershed resiliency to potential impacts. Some of the potential impacts include changes in precipitation patterns and temperature changes. In this context, the present study addresses the potential impacts of climate change on patterns of maximum monthly precipitation in Passo Fundo River and Várzea River Watersheds, located in south of Brazil, relating to temperature data. The results can enforce the need of operational management and urban resilience.

Method

Study Area

This research focus on two watersheds and they are show in the Fig. 2.1. The Passo Fundo River and Várzea River Watersheds are located in north region in Rio Grande do Sul State, and belong to the Hydrographic Region of Uruguay.

The climate in the region researched is characteristic of southern of Brazil, the humid Subtropical type. The seasons are well defined, with hot and humid summer and cool winters. The winds affect the climate, and in summer the trade winds blowing, coming from the southeast, causing high temperatures and heavy rains.

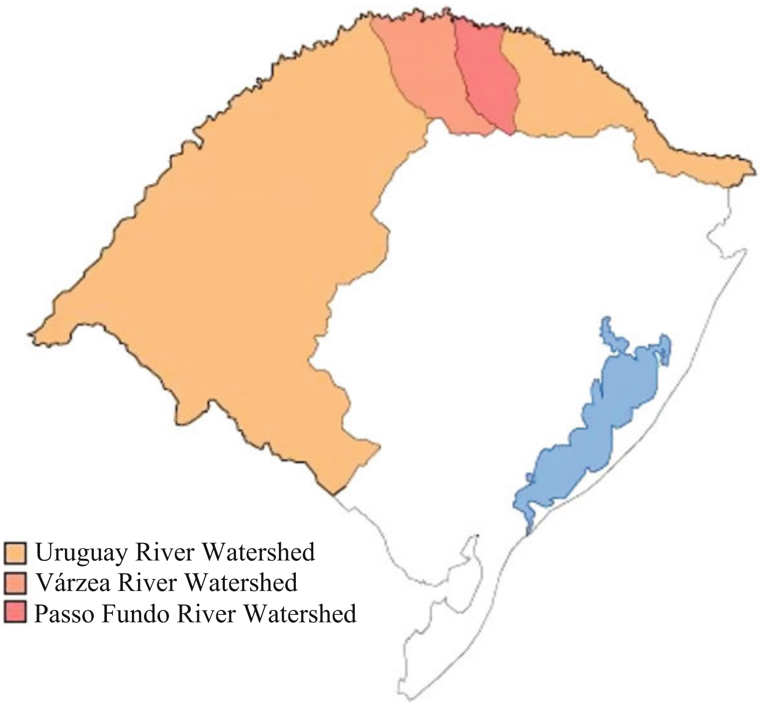

Fig. 2.1 Location of watersheds researched

In the winter, there is occurrence of cold front followed generally of air masses from the South Pole (Rossato 2011).

The Table 2.1 shows the characteristics of watersheds researched (SEMA 2010; FEPAM 2016a, b).

Data Collection

The precipitation data were obtained from the software Hidro 1.2, in website Hidroweb (ANA 2014), with a database from pluviometric stations (Table 2.2). In the study area, there are 26 pluviometric stations with precipitation data, but only 9 contain representative historical series with data for the analysis period. According

Table 2.1 Watershed's characteristics

	Passo Fundo River Watershed	Várzea River Watershed
Latitude and longitude	27° 04′–28° 19′ S 52° 13′–52° 51′ W	27° 00′–28° 20′ S 52° 30′–53° 50′ W
Main waterways	Passo Fundo River and Timbó Stream	Várzea, Porã, Guarita, Ogaratim Rivers and the Sarandi and Goizinho Streams
Main uses	Animal watering, irrigation, industrial use and human consumption	Animal watering, irrigation and human consumption
Drainage area	4785.7 km^2	9.324 km^2
Municipalities covered by watershed	30 municipalities	55 municipalities
Watershed population	168.370 inhabitants	328.057 inhabitants

Table 2.2 Pluviometric stations

Watershed	Codigo	Location/City	Latitude	Longitude	Altitude (m)
Várzea River Watershed	2753004	Sarandi	27:48:42	53:01:40	350
	2753014	Liberato Salzano	27:35:57	53:04:17	378
	2852006	Carazinho	28:17:36	52:43:27	570
	2753015	Palmeira das Missões	27:54:48	53:18:39	610
	2852007	Distrito Xadrez	28:11:21	52:44:45	593
	2753002	Frederico Westphalen	27:21:40	53:23:51	530
	2853026	Chapada	28:03:31	53:03:58	450
Passo Fundo River Watershed	2752017	Itatiba do Sul	27:23:20	52:27:16	350
	2752006	Erebango	27:51:15	52:18:17	763

to Tucci (2002), for analysis of historical precipitation series, they shall contain data for at least 30 years. For this reason, only this 9 were included in the analyses.

The temperature data were obtained from National Institute of Meteorology (INMET), which have a database with maximum monthly temperatures for each station (http://www.inmet.gov.br/portal/index.php?r=home2/index). Since there was no availability of temperature data for the exact locations of pluviometric stations studied, the temperature was estimated based on concepts of meteorology, and for every 180 m higher in altitude has been a decrease in temperature of the order of 1 °C (Dury 1972).

Analysis

To show the potential impacts of climate change on patterns of maximum monthly precipitation in the area studied, the analysis looked evidence about extreme events like of drought, floods and windstorms. For this, thermo-pluviometric diagrams are presented for each pluviometric station, using the maximum monthly precipitation and temperatures. The thermo-pluviometric diagram represents the precipitation data in blocks and temperature data in lines. Besides that, the average maximum precipitation is also presented, in order to support the analysis. Thus, is possible to verify the interference of temperature on precipitation, qualitatively, since the statistic was not used in this study.

Results and Discussion

Figures 2.2 and 2.3 show the average maximum temperatures of two pluviometric stations: Sarandi, in the Várzea River Wathershed and Erebango, in the Passo

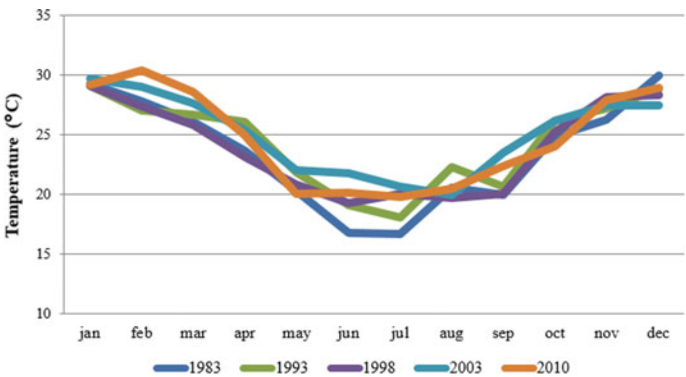

Fig. 2.2 Average maximum temperatures in Sarandi pluviometric station

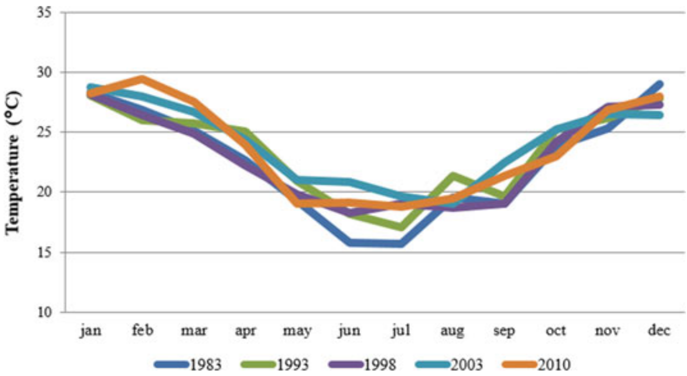

Fig. 2.3 Average maximum temperatures in Erebango pluviometric station

Fundo River Wathershed, respectively. After analysis of all periods, it is possible to notice a tendency of increase in maximum temperatures in recent years.

Increase in Earth's average temperature has been mainly evidenced by studies conducted by the Intergovernmental Panel on Climate Change, which, in a more optimistic scenario, forecasts an increase of about 2 °C (IPCC 2007b). However, observing the figures above, it can be seen that the temperature in June and July, which are the months with lower temperatures, already showed an increase of about 4 °C between 1983 and 2010.

Várzea River Watershed

Seven stations were studied in Watershed Várzea River. In 1983, the initial year of the study, there is no evidence of droughts or floods, as shown in Fig. 2.4, which illustrates the situation using the Sarandi pluviometric station, but the same is observed in Xadrez District and Chapada.

Between 1983 and 1994 most stations did not have evidences of extreme events, except for a few. One example is Frederico Westphalen pluviometric station, as shown in Fig. 2.5, which in February of 1991 had maximum precipitation of less than 10 mm, well below the average maximum. In 1991 and in a similar situation, Xadrez District station's maximum precipitation was less than 5 mm in March. These results are combined with the observation of high temperatures in these months in comparison with the temperature observed in previous years (equal or above 30 °C).

In 1995, Chapada pluviometric station had an average maximum precipitation of about 40 mm, below the average observed in the previous periods, which were between 50 and 60 mm. Furthermore, there was extreme precipitation in October, as shown in Fig. 2.6.

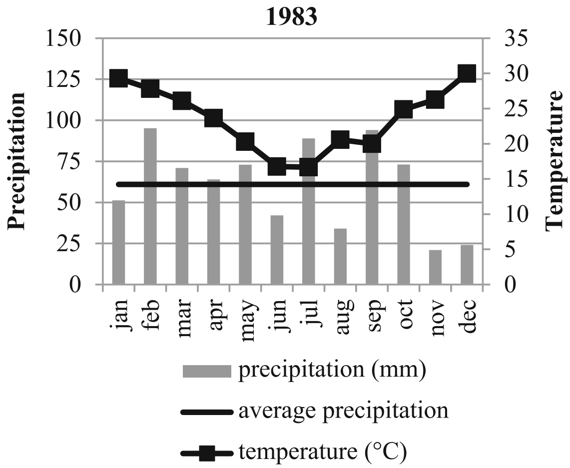

Fig. 2.4 Termopluviometric diagram of Sarandi (1983)

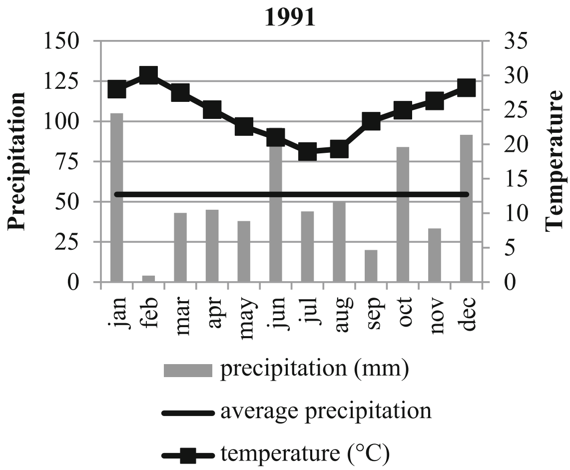

Fig. 2.5 Termopluviometric diagram of Frederico Westphalen (1991)

In the following years there were some extreme events in Chapada, such as the low maximum precipitation in February of 2005 and the high ones in September and October 2012. Such situations can be seen in Fig. 2.7.

From these diagrams obtained, it is observed that for the Várzea River Watershed, the temperature rise may be influencing the hydrological series, causing extreme events of drought and floods with greater frequency and magnitude than in the past. It can also be noted that the periods between January and May and November and December are more prone to droughts, while the months from June to October are more prone to floods.

Regarding the maximum monthly temperature data, it is observed that in the months of June and July, in the earlier years of study, the value was close to 15 °C, and in recent years the result is closer to 20 °C or even above it.

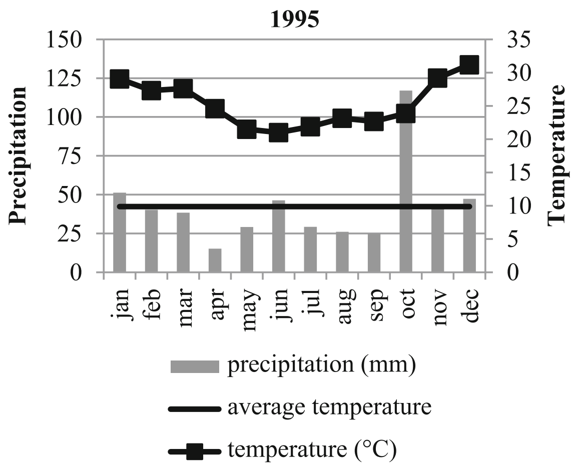

Fig. 2.6 Termopluviometric diagram of Chapada (1995)

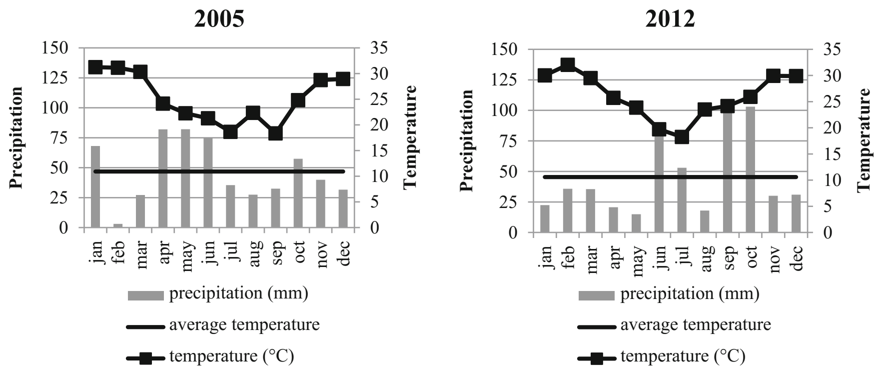

Fig. 2.7 Termopluviometric diagram of Chapada (2005–2012)

It is known that natural disasters such as droughts, floods and windstorms are occurring more frequently and with greater intensity in recent years in Rio Grande do Sul (Reis et al. 2012; Junior et al. 2012; Albuquerque and Mendes 2009). According to the Civil Defense of Rio Grande do Sul, approximately 400 drought events were recorded during the years 2002, 2005, 2009 and 2012. Also, flash floods were recorded in the years 2009, 2010 and 2011 with higher frequency than the annual average (CEPED UFSC 2013). However, not only climate change affects the increase in occurrence of extreme events, but it also affect the use and occupation of land, deforestation and population growth.

Passo Fundo River Watershed

Two pluviometric stations were studied in Passo Fundo River Watershed. The identified behavior is similar to the observed in Várzea River Watershed, with a greater tendency to extreme events. Additionally, this watershed also has higher precipitations in some months and intensified droughts in others.

In 1983 both stations showed a different behavior, as observed in Fig. 2.8. In terms of maximum monthly temperature, they are similar, but when it comes to precipitation, Itatiba do Sul has values higher than 40 mm in each month (except for December) and maximum of over 140 mm in July and September. Erebango has several months with precipitation around 30 mm, and maximum of around 90 mm in May and July. This can be explained by the difference in altitude between these stations, since Itatiba do Sul station is located 350 m above the sea and Erebango station is 763 m above the sea.

Figure 2.9 shows extreme precipitation in 1985 in Itatiba do Sul, in the same month that there was higher maximum temperature if compared to 1983. In 1991, the same city had extreme low precipitations, especially during southern hemisphere's summer. This episode may be related to the increase of 1–2 °C in temperature during these months, in comparasion to previous years.

Erebango, as shown in Fig. 2.10 for 1991, when compared to the beginning of the study data, presented an increase in the maximum monthly temperature and precipitation higher than expected in January and lower in February and March, which are also characterized as extremes events because of the variation in relation to the average of the year.

In 2002, both stations showed low levels of maximum precipitation, coinciding with the increase in the maximum monthly temperature in relation to the early years of the study and in relation to its annual average. This situation is shown in Fig. 2.11. Qi et al. (2016) in their study of watershed systems, also observed there is a decline in precipitation in recent years in relation to the past ones, along with continuous increases in temperatures, from 1980 to 2005.

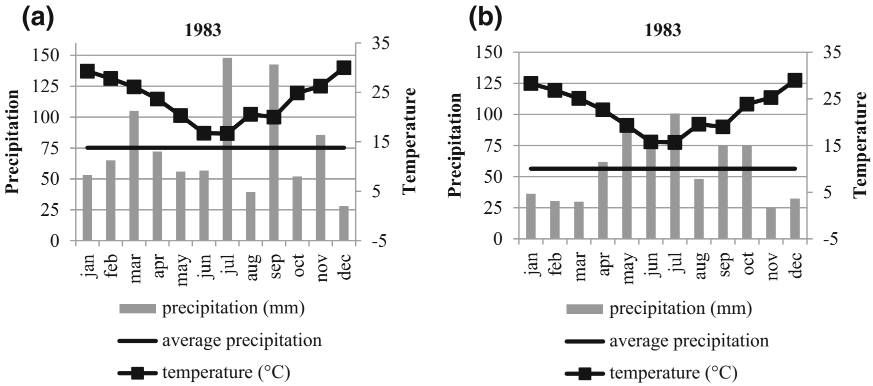

Fig. 2.8 Termopluviometric diagram of Itatiba do Sul (**a**) and Erebango (**b**) (1983)

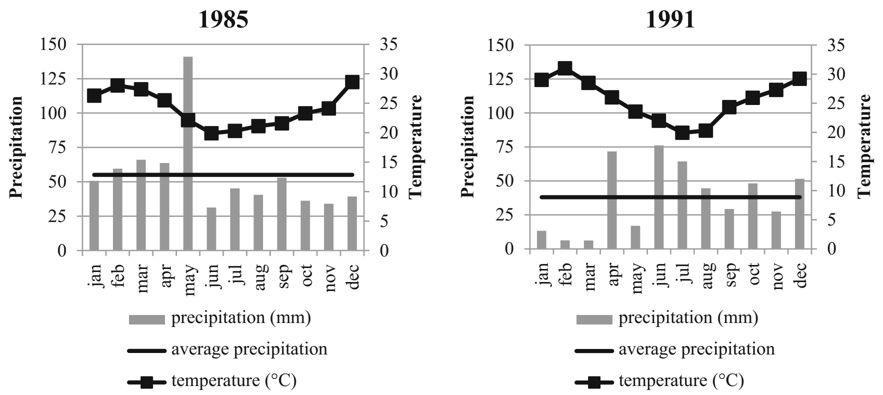

Fig. 2.9 Termopluviometric diagram of Itatiba do Sul (1985–1991)

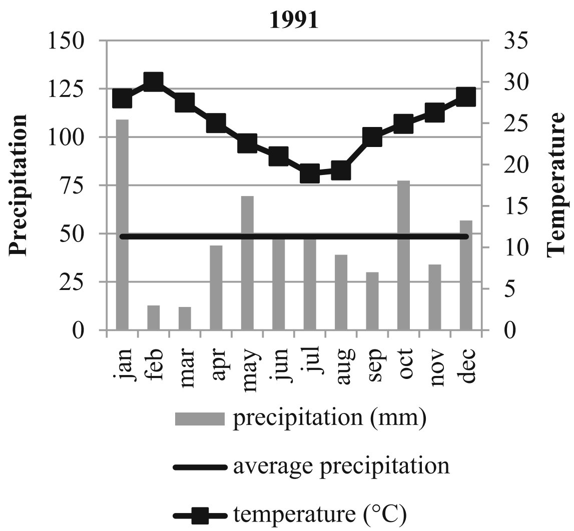

Fig. 2.10 Termopluviometric diagram of Erebango (1991)

It is noticed that Itatiba do Sul station shows a more intense drought than Erebango's, with maximum monthly precipitation around 15 mm in the first three months of the year. According to the Civil Defense of Rio Grande do Sul, 413 cases of droughts were registered in this watershed in 2002, the third year most affected by this phenomenon, in a study of the years 1991–2012 (CEPED UFSC 2013).

In the years 2009 and 2012 both stations showed similar behavior, with a reduction of the maximum average precipitation in relation to initial years of study and precipitation below the average. Then, Erebango presents the most critical values, with maximum precipitation lower than 5 mm in April and May. Figures 2.12 and 2.13 show the behavior of the stations for these years.

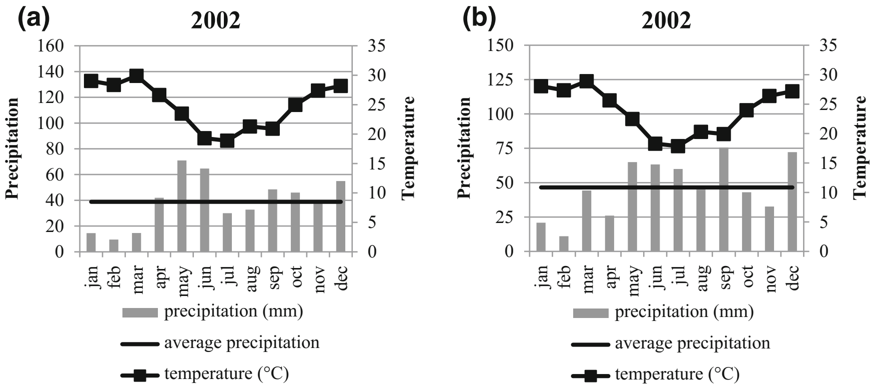

Fig. 2.11 Termopluviometric diagram of Itatiba do Sul (**a**) and Erebango (**b**) (2002)

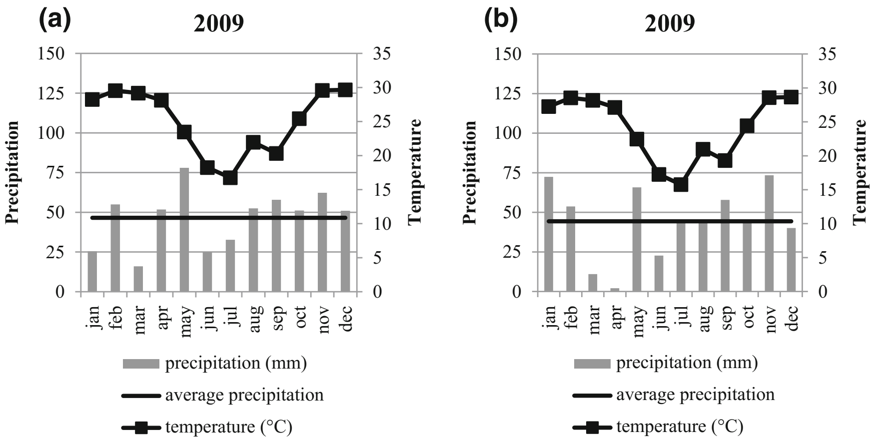

Fig. 2.12 Termopluviometric diagram of Itatiba do Sul (**a**) and Erebango (**b**) (2009)

In 2012, Erebango also presented an extreme event characterized by high precipitation in October, well above the annual average. Itatiba do Sul, on the other hand, draws more attention to the reduction of the maximum precipitation over the years under study and presents maximum precipitation below the annual average.

For this watershed, it can be seen that the results are similar to the previous one, just showing some extreme events in the previous years. This can be explained by the difference in altitude and also land use and occupation.

So, it is possible to highlight some extreme events in both watersheds, related to droughts or floods, as well as an increase in temperature, which may be related to climate changes. The results show the same as Alexander et al. (2006) and indicates the precipitation indices have tendencies toward different conditions but not all show statistically significant changes.

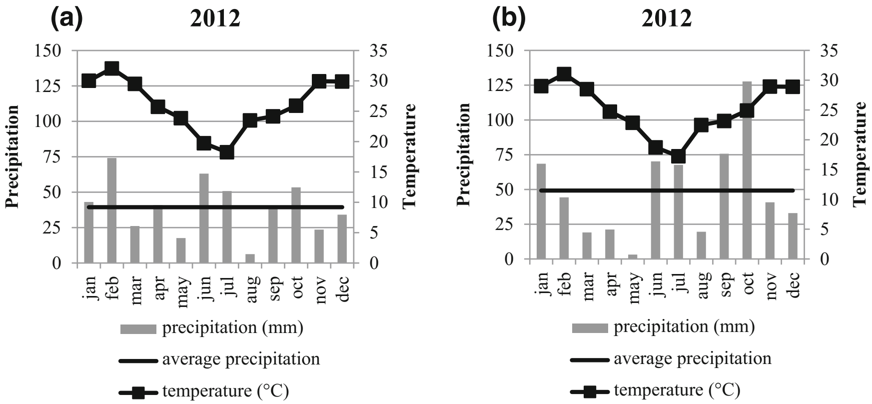

Fig. 2.13 Termopluviometric diagram of Itatiba do Sul (**a**) and Erebango (**b**) (2012)

Even though, studies regarding changing in patterns and potential impacts of climate change must be encouraged to verify the tendency through the years and to provide subsidies for implementation of control measures (see Solomon et al. 2007). Mainly because measuring the watershed impacts becomes more complex as its interventions consider how hydrogeological aspects affect livelihoods. In this context, integrated assessments of watersheds must have resilience as an important attribute, especially in the context of climate change impacts (Reddy and Syme 2014).

The Resource Innovation Group (2012) reinforce that changes in precipitation and the increase in frequency of extreme weather events are related to climate change, leading to negative consequences as drying of wetland areas, shifts in vegetation conditions, higher concentrations of pollutants. Considering that, studies on watershed's conditions and its effective planning to resilience can reduce long term costs, identify opportunities for immediate local benefits, increase in local economic and community security by reducing the risks of damage from major floods or droughts, and identification of new economic, social, and ecological opportunities that may arise with changing climate conditions.

Conclusions

In this study we sought to evaluate the consequences in precipitation series caused by the increase of temperature, which is one of the main impacts of climate change. The evaluations were made between the years 1983 and 2013, however presents some flaws due to lack of data, especially temperature, then an analysis of 25 years was made.

It is noticed that there was an increase in the frequency and intensity of extreme events such as droughts and floods, and that the maximum temperature has increased over the years, especially in the winter (June and July), showing the occurrence of milder winters than before.

Thus, it is observed that climate changes tend to be interfering in the hydrologic series of precipitation for the Passo Fundo River and Várzea River Watersheds, mainly in the form of increasingly frequent extreme events. Some stations have suffered more severe effects than others, but all are being affected. Therefore, the two watersheds have been presenting consequences probably due to the increase in the average temperature on Earth.

Climate change is placing cities at the risk of being increasingly hit by extreme weather phenomena and there is a need to review the current patterns of consumption of natural resources, in order to continue enjoying the benefits of community life and minimize the impact of urban agglomerations. The preparation for the occurrence of disasters is also essential, both for civil society and for the government, and resilience is essential for communities.

These results point to the need for greater planning regarding watersheds, incorporating resilience fundaments. According to The Resource Innovation Group (2012), some entities such as watershed councils and formal and informal governance agreements have vital importance to this subject.

Urban resilience also depends on the awareness of individuals about the possibilities of occurrence of environmental disasters, and coping ability when necessary, with adaptation measures; and, if possible, to minimize them by mitigation methods. The form of planning and management of cities, their infrastructure, services and institutions should be planned and managed in the best possible performance before, during and after the occurrence of extreme weather events.

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