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Article

Influence of Climate Change on Precipitation and the Formulation of Rain Design in Brazil

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ABSTRACT

This work aims to answer whether climate change is a precursor to updating the rain equations developed in different regions of Brazil. The methodology was based on a Systematic Review of the existing literature, made through the "Periódicos Capes" portal. The results showed that in some cities, there are no rain equations and not enough rain measurements available, so, in these cases it is not possible to study Climate Change and the formulations of Rain Designs. However, in places where data are available, the need to update the Rain Design equations are evaluated using recent historical rainfall data, and it was found that these changes could be explained by climate change.

Keywords: rain design; rain equation; climate change; urban drainage.

RESUMO

O presente trabalho tem o objetivo de responder se as mudanças climáticas são precursoras das atualizações das equações de chuva desenvolvidas em diversas regiões do Brasil. A metodologia baseou-se numa Revisão Sistemática da literatura existente, feita através do portal "Periódicos Capes". Os resultados demostraram que em algumas cidades não existem equações de chuva e não existem medições de chuva suficientemente disponíveis, então, nesses casos, não é possível estudar as Mudanças Climáticas e a formulação das Chuvas de Projeto. Entretanto, nos locais onde existem dados disponíveis, a necessidade de atualizar as equações de Chuva de Projeto é avaliada utilizando dados históricos de chuva recentes, e foi percebido que essas modificações poderiam ser explicadas pela mudança climática.

Palavras-chave: chuva de projeto; equação de chuva; mudança climática; drenagem urbana.

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1. Introduction

The Goal number 06 of the United Nations 2030 Agenda for Sustainable Development is "Clean water and sanitation". Brazil, and the other signatory countries of the 2030 Agenda, take on the challenge of promoting prosperity, combined with the well-being of all the populations living in their territory, in order to contemplate the seventeen objectives of sustainable development.

According to Federal Law Nº 14,026 of July 15, 2020, basic sanitation is compound of water supply, sewage, rainwater management, urban cleaning and solid waste management services, and must be provide considering universal access. and its integration with other sanitation services(BRASIL 2020).

In particular, storm water management is used to known as urban drainage. For the purpose of engineering work, it uses an equation to approximate the rainfall intensities measured over a given time span defined from statistical analysis.

However, the statistic made to calculate the required Rain Design for an urban drainage project must be periodically updated based on the increased information density (Silva & Tucci 1998), as a rainfall is sensitive to Climate Changes. In this case, the rainfall is understood as events of extreme exposure, both in intensity and frequency.

When the formula is updated including the data from recent historical rainfall events, then it is possible to verify whether the urban drainage still meets this new rainfall statistical estimate.

The Climate Change can be characterized by any variation in the climate behavior, caused either naturally or due to human activity. The present work objective is to study these circumstances and their consequences to engineering projects.

The study of rainfall has aroused the interest of several researchers (Oliveira et al. 2005a; 2005b). Some authors have focused on the problem, aiming to update the Rain Design equations for certain cities (Aragão et al. 2013; Bittencourt Silva & Coutinho de Oliveira 2017; Arboit e al. 2018).

These studies have helped to answer the fundamental questions that are addressed in this article: (1) Has Climate Change made such a difference in precipitation?

Due to recent flooding events suffered in different parts of the globe (Bathrellos et al. 2018), it is believed that Climate Change has been so quickly that statistics and/or the researchers could not capture the information.

One hypothesis about the interference of Climate Change is that with each small change in the intense gloves, the average moves slowly to another level, but the old values are still used. With this, a rain with Recurrence Time estimated of five years, would be wrong, and the correct Recurrence Time would be of two years only.

(2) Does updating of the Rain Design motivated by improvement in accuracy and frequency of the measurements collected over time? Or is it caused by Climate Change in precipitation?

The absence of weather stations can result in use of the same station to calculate the Rain Design for more than one city (Campos et al. 2014). Thus, with the presence of new pluviometric station and studies related to this theme, it is possible to improve the rainfall statistics for a given region. This modification in the Rain Design is not due to Climate Change.

In some cases, the station, which previously had measures with greater temporal step, may now have data measured more frequently. In this case, the statistics will be improved and the recurrence of a given rain can be better described (Silva & Tucci 1998).

The longer is the period of observation of the rainfall behavior, the better will be the forecast, and the Recurrence Time of a given event. However, most studies on the estimation of heavy rainfall have series that are shorter than those recommended by the World Meteorological Organization, which is 30 years old (Silva et al. 2002).

What happens, however, due to the absence of long-term data, is the use of adjustments in the Intensity-Duration-Frequency (IDF) curve of the rain, which promote greater uncertainties as the estimated Recurrence Time for it increases (Silva & Tucci 1998). Thus, when there is more data available, the forecasts improves, and this change in the Rain Design would not have anything to do with the Climate Change.

2. Objectives

This work aims to research the literature about the update of Rain Design in order to understand if the Climatic Changes are precursors of such formulations.

This research consisted of answering the following questions:

1. Have Climate Change affect the rainfall?
2. Is recent research on Rain Design based on changes in rainfall or on improvement in the accuracy of measurements over time and on increasement of information density?
3. What is the main scientific interest on this topic and what can be improved?

3.Method

To answer these questions, the work was divided into three sections, with results obtained through a Systematic Review of the existing literature made through the “Periódicos Capes” portal.

The section 4.1 contains some research that demonstrates a link between changes in observed rain and the theme of Climate Change. The section 4.2 presents a list of articles that demonstrate what had been studied for about Rain Design in Brazil. The section 4.3 brings other findings about the impacts of Climate Change. Thus, the work will have support to answer the proposed questions in the final considerations.

4. Results

4.1 Research Relating To Project Rain And Climate Change

In this section, scientific research about the relationship between climate change and the possible change in precipitation will be analyzed, as shown in the summary shown in Table 1.

Andimuthu et al. (2019) estimated rainfall data from the 4 Global Climate Models (GCM) for the 2015-2085 period. It was estimated to project future rainfall trends in the Valachery region of India. The result shows that the intensity of precipitation in the return period of 2 years is 33.57 mm / h. Likewise, for a 10-year return period, the intensity is 57.89 mm / h and the intensity of 88.22 mm / h was estimated for 100-year Recurrence Time for rainfall. The comparison between the observed and projected IDF curves in a changing climate scenario shows that there is a 12% increase in intensity for 2-year Recurrence Time and an 87% increase for 100-year Recurrence Time.

Benini et al. (2016) evaluated five scenarios for the period from 2080 to 2100 in a hydrographic basin on the Italian coast. In summary, three of the five scenarios evaluated suggest a reduction in the annual freshwater rate for the period 2080–2100 for the analyzed basin. All of them predict an increase in the deficit of freshwater in the summer, because of future climate forecasts and the transformation of land use towards vegetated areas and/or air open lakes. Combining the results, the authors claim that the Italian coast basin is sensitive to changes in weather patterns and increases related to saltwater intrusion.

Table 1: Summary of research relating to project rains and climate change

Location	Characteristics	References
Valachery region, India.	The comparison between the observed and projected IDF curves in a changing climate scenario shows that there is an increase in intensity for rains of 2 and 100 years of return period.	Andimuthu et al. (2019).
Watershed of the Italian coast.	Three of the five scenarios evaluated suggest a reduction in the annual freshwater rate for the period 2080–2100 in the analyzed basin.	Benini et al. (2016).
Arizona Region, United States.	The study concludes the presence of extremely dry or humid winters, with a decrease in average climates, and greater challenges in the management of water resources.	Shamir et al. (2015).
Anantapur District, India.	An overall increase in rainfall was observed in all regions of Anantapur.	Kadiyala et al. (2015).
Watersheds of southwest Australia.	Rain decreases in all global warming scenarios with an average decline of 8%.	Silberstein et al. (2012).
Watershed of Canada.	All downscaling methods adopted showed increases in total seasonal precipitation for the 2085 horizon.	Chen, Brissette e Leconte (2011).

Source: Elaborated by the Authors

Shamir et al. (2015) focused on identifying the difference between historical and projected climatic periods in order to guide changes in used rainfall for application in future periods in a region of Arizona, in the United States. The study concludes the presence of extremely dry or humid winters, with a decrease in average climates, and greater challenges in the management of water resources caused by a projected future climate impact of increased water scarcity in the long term, decreased recharge and low subterranean water depth. It is expected that summer will have a higher annual frequency of dry seasons.

Kadiyala et al. (2015) claim that projections of the climate model based on the Intergovernmental Panel on Climate Change (IPCC), Fifth Coupled Model Intercomparison Project (CMIP5), reveal that the temperature of the surface air, including night temperatures, should increase even more compared to what was designed in 2014 by the IPCC. Therefore, it analyzed the spatial variability of the impacts of climate change on peanut production in the Anantapur district, India. Through 72 simulations, an overall increase in rainfall was observed in all regions of Anantapur. The increase in average rainfall will be pronounced in the northern region (19%) followed by the central region (17.4%) southern region (16.8%) and high-level land (16.7%). There will be more heating in the eastern parts of the District. It was concluded that while the northern region will benefit greatly from climate change, which would possibly result in an increase in the peanut harvest. On the other hand, the southern region was considered more vulnerable to it, due to the decrease in the peanut harvest.

Silberstein et al. (2012) based on climate projections of three scenarios, with a temperature increase of 0.7° C, 1.0 ° C and 1.3° C, for 2030, and concluded that rainfall decreases in all scenarios of global warming with an average 8% decline in watersheds in southwest Australia.

Chen et al. (2011) simulated future hydrological regimes (horizon 2070-2099, 2085) with the downscaling method and compared with the reference period 1970 to 1999. All downscaling methods showed increases in total seasonal precipitation for the 2085 horizon for a basin of Canada (province of Quebec). The proportions of increase varied from 6% to 67% in the spring, 1% to 20% in the summer, 3% to 21% for the fall and between 5% and 45% for the winter.

4.2 Review Of Research About Project Rain In Brazil

In this section, Brazilian scientific research about rain prediction equations used in engineering design are analyzed, as shown in the summary shown in Table 2.

Table 2: Summary of research about project rain in Brazil

Location	Characteristics	References
Municipality of Rio de Janeiro.	The Rain Design equation was updated through historical series from 1997 to 2014.	Braga et al. (2018).
Municipality of Iraí.	The existing equation for the Municipality were updated.	Arboit, Mancuso e Fioreze (2018).
Nine municipalities in the Northeast Region.	The Rain Designs were updated using data obtained from the National Water Agency.	Silva e Oliveira (2017).
State of Piauí.	The Rain Designs were obtained for several municipalities.	Campos et al. (2014).
State of Sergipe.	The Rain Designs were obtained for 48 municipalities.	Aragão et al. (2013).
State of Pará.	The Rain Designs were obtained for 74 municipalities.	Souza et al. (2012).
State of Santa Catarina.	The Rain Designs were obtained for 13 municipalities through 13 pluviometric stations.	Back, Oliveira e Henn (2012).
Nine state of Northeast Region.	The temporal variability of rain was analyzed to try to obtain a pattern in its behavior.	Silva et al. (2011).
State of Mato Grosso.	The Rain Designs were obtained for several municipalities through 136 pluviometric stations.	Coutinho et al. (2011).
State of Rio Grande do Sul.	The Rain Designs were obtained for 24 municipalities.	Sampaio, Robaina e Peiter (2011).
Municipality of Pelotas, in Rio Grande do Sul.	The rain Intensity-Duration-Frequency curves were compared with the practical data measured in the municipality to observe the differences.	Damé et al. (2010).
State of Mato Grosso do Sul.	The Rain Designs were obtained for 46 municipalities with 15 years of observation.	Santos et al. (2009).
State of Goiás.	The Rain Designs were obtained in the state through 13 pluviometric stations.	Oliveira et al.(2008).
State of Goiás and Distrito Federal.	The Rain Designs were obtained for 73 locations and adjusted their values for 18 Municipalities.	Oliveira et al. (2005).
Municipality of Jaboticabal, state of São Paulo.	The Rain Designs were obtained for the municipality with the purpose of use in local drainage projects.	Nobukuni, Pereira e André (2005).
State of Minas Gerais.	The Rain Designs were obtained for 22 regions of the State of Minas Gerais.	Mello et al. (2003).
State of Bahia.	The Rain Designs were obtained for 19 municipalities.	Silva et al.(2002).
State of Goiás.	The Rain Designs were obtained for 12 locations in the state of Goias.	Oliveira et al.(2000).

Source: Elaborated by the Authors

Braga et al. (2018) used data from 32 pluviometric stations to update the Rain Design in the city of Rio de Janeiro, Intensity-Duration-Frequency curves were obtained for 32 neighborhoods, using historical data series from 11 to 17 years, between 1997 and 2014.

Arboit et al. (2018) with the objective of showing the current reality of the pluviometric conditions of the Municipality of Iraí, in Rio Grande do Sul, they made an update of the Rain Designs, previously made by Denardin et al. (1980). They used recent data obtained by the Iraí Conventional Meteorological Station, and observed a significant difference in the coefficients present in the equation.

Bittencourt Silva e Coutinho de Oliveira (2017) updated the Rain Designs for 9 municipalities in the Northeast region using updated data from the National Water Agency website.

Campos et al. (2014) analyzed 133 pluviometric stations in the State of Piauí with the objective of obtaining equations that relate Intensity-Duration-Frequency for most municipalities, it was motivated by the fact that only the city of Teresina had these data available within the State.

Aragão et al. (2013) proposed for each of the 48 municipalities in the State of Sergipe a Rain Design, through the historical series of precipitations measured by 74 pluviometric posts selected from those existing in the state. Because of there are not the equations to this municipalities, except for Aracaju, and the presence of long term measurements that would support the calculations. In the case of the Municipality of Aracajú, due to the age of the equation, they updated it. Due to the number of pluviometric observation posts, the Rain Design had a regional scope.

Souza et al. (2012) estimated the Rain Design for 74 municipalities in the State of Pará using the same number of data from rainfall stations in the state, their work was motivated by the lack of information related to the Rain Designs in the State of Pará.

Back et al. (2012) proposed the Intensity-Duration-Frequency curves through 13 pluviometric stations, in order to update the Rain Designs of 13 municipalities in the State of Santa Catarina.

Silva et al. (2011) analyzed the frequency of rain in 9 states in the Northeast, in order to analyze the temporal variability of rain, and concluded that the variability of rainfall is not uniform throughout the Northeast of Brazil. The analysis of the self-correlation coefficients reveals that the precipitation behavior in the Northeast does not follow a pattern.

Coutinho et al. (2011) obtained the Intensity-Duration-Frequency curves of several cities in the State of Mato Grosso based on 136 pluviometric stations, the work was motivated by the absence of Rain Designs, justifying it by the scarcity of pluviometric records, low network density of rain gauges and the short observation period available.

Sampaio at al. (2011) used 34 pluviometric stations to analyze rainfall in 24 municipalities in the State of Rio Grande do Sul in order to estimate the Rain Design. This study is motivated by the lack of stations with long historical series.

Damé et al. (2010) have the objective of verifying if there is gain of pluviometric information for the municipality of Pelotas, in Rio Grande do Sul. They obtained a significant difference between the estimated values and measurements obtained by pluviometers.

Santos et al. (2009) used the observation of 109 stations to obtain the Rain Design for several regions in 46 municipalities in the State of Mato Grosso do Sul. It was possible with at least 15 years of observation.

Due to the lack of information about the critical Rain Design in the State of Goiás, Oliveira et al. (2008) used 13 state rainfall stations in order to obtain the Rain Design equation that would allow identifying the maximum possible rainfall to be equaled or exceeded for a given Recurrence Time.

Oliveira et al. (2005) obtained the Rain Designs for 73 locations in the State of Goiás and in the Federal District, these values were adjusted for 18 municipalities in order to observe changes in the equations, and provide their updates for the one with greater security between the old and the calculated one. There were significant changes both upwards and downwards in the rainfall calculated in the Rain Designs for the municipalities under study, with 25 years of daily observations.

Nobukuni et al. (2005) took the observations of a meteorological station to obtain the Intensity-Duration-Frequency curve of Jaboticabal, in the State of São Paulo, due to the need to use it for local drainage projects.

Mello et al. (2003) used mathematical models to predict rainfall in order to obtain a model of Rain Design for 22 regions of the State of Minas Gerais, claiming that these regions are devoid of pluviometric information.

Silva et al. (2002) used 19 pluviographic stations to obtain the Rain Design for 19 municipalities in the State of Bahia due to the lack of information about the equation for each region studied.

Oliveira et al. (2000) estimated the Rain Design for twelve locations in the State of Goiás.

4.3 Research About Consequences Of Climate Change Or Rain Regime Change

In this section, scientific research about adverse effects of Climate Change is analyzed, as shown in the summary shown in Table 3.

Table 3: Summary of research about consequences of Climate Change or rain regime change

Location	Characteristics	References
French and Western Italian Alps.	Studied that the increased rainfall in spring and autumn can alter the flow activity of water-laden soil masses and fragmented rocks that run downwards mountain slopes.	Stoffel, Tiranti e Huggel (2014).
Ethiopia.	Estimated a relation between increased rainfall and infant stunting and low weight in three agro-ecological zones.	Hagos et al. (2014).
Western Africa.	In the humid regions of the south of the Sahara desert, there would be an increase in the transmission capacity of the malaria vector in all scenarios analyzed.	Yamana e Eltahir (2013).
Coastal areas of southern China.	Indicate that climate change has resulted in rising sea levels and the occurrence and intensity of storms.	Yao-Dong et al. (2013).
Gold Coast Region, Australia.	Studied the increased discharge of pollutants in estuarine and marine waters due to climate change.	Mahbub et al. (2011).
Niger.	Possibility of high losses in agricultural production even with a moderate decline in rainfall due to climate change.	Sivakumar (1992).

Source: Elaborated by the Authors

Stoffel et al. (2014) address about current knowledge of the impacts of climate change on mass debris movement activities in the mountains of the French, Italian and Swiss Alps. The authors believe that increased rainfall in spring and autumn may alter the flow activity of soil masses laden with water and fragmented rocks that run down mountain slopes during March, April, November and December. According to them, it is likely that the frequency of rock slope failures will be increase, however, changes in landslide activity in the French and Western Italian Alps will depend on differences in altitude.

Hagos et al. (2014) studied the variability of rainfall and her connection with short stature and weight in Ethiopia over a time span, and estimated a relationship between increased rainfall and infant stunting and low weight in three agro-ecological zones.

Yamana e Eltahir (2013) assessed the effect of climate change on malaria transmission in West Africa. In addition, their simulation-based estimates suggested that only in the wettest regions of the southern Sahara desert would there be an increase in the vector's transmission capacity in all analyzed scenarios.

Yao-Dong et al. (2013) indicate that climate change has resulted in sea level rise in coastal areas in southern China, increasing storm occurrence and intensity, aggravating the influence of saltwater intrusion, coastal erosion, threatening drainage facilities and coastal infrastructure and flood control, and flooding areas of plains.

Mahbub et al. (2011) describe the effects of climate change on washing volatile organic compounds from urban roads in Australia's Gold Coast region. The researchers believe that the change in the rainfall regime due to climate change in highly urbanized coastal regions will have a significant influence on the discharge of pollutants into estuarine and marine waters

Sivakumar (1992) believes that the pattern presented for the rainfall regime in Niger is likely to continue. This study does not aim to project a future trend, but rather to show that the Niger region has an extremely short rainy season, with a predominance of drought. In addition, the predominance of drought in region denotes high losses in agricultural production even with a moderate decline in rainfall imposed by climate change. The accelerated growth of its population creates pressure on land use, making a future scenario of longer dry seasons more critical.

5. Final Considerations and Conclusion

In some cities there is no rain equation available, so some researchers have focused in developing them. Due to the improvement in the accuracy of measurements over time, some Rain Designs have be modified, and others developed, and this has nothing to do with Climate Change.

Some researchers, starting from previously existing equations, were able to compare with the rainfall data of the region and observe, changes in precipitation that generated changes in these equations, and then, these updates could have been explained by Climate Change.

This research shows how incipient Brazil is in providing rain data and consolidating the Rain Designs. Since the disclosure of certain data is recent, and the formulation of the equations is recent.

The topic has aroused the interest of researchers in different parts of the country, but research is scarce and there is still space for more refining methods. Because they are done, in large part, with Intensity-Duration-Frequency curves and not with the Rain Design.

There is a need for investment to obtain pluviometric data that encompasses more regions, and those recent equations still need future studies for their maintenance or modification. Aiming, in the future, with more data available, it will be possible to have different equations in the same city, which does not occur due to the existence, in many cases, of a single station in each city, when it exists.

The research shows that there are observed changes between the precipitations, and generate significant changes in the Rain Designs, even though both comparative equations are recent.

The application of these results to engineering projects, especially with regard to urban drainage, is to show that these data been not yet consolidated and the use of an equation for the entire city may not represent regional realities. In addition, even with the equation being recent, it may be out of time.

Several other studies have shown that the effects of Climate Change do not only affect the rainfall. However, it can generate agricultural losses, and consequently, hunger in some regions. It changes the temperature, sea level rise (which may or may not been caused by the variation in volume by change in temperature), increased occurrence and intensity of storms, and can increase the influence of saltwater intrusion and coastal erosion, threatening coastal drainage and flood control facilities and infrastructures, and flooding plains.

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