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RESEARCH ARTICLE

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HEAVY RAIN EQUATIONS FOR BRAZIL

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ABSTRACT

The IDF equation is widely used in several engineering areas to estimate rainfall intensities with a specific duration and frequency. These equations can be adjusted based on the series of pluviographic records or by the disaggregation of daily rain in shorter duration rains. In the present study, a survey of the IDF equations published in Brazil was carried out in 118 different types of publications. Until 2010, 634 IDF equations were registered, predominantly (61%) generated by pluviographic data. In the last decade, there was a large increase in the IDF equations, totaling 3096 IDF equations, 19% of which came from pluviographic data and 81% from the disaggregation of daily rain measured in pluviometers. The North region has a lower density of rainfall stations, reflecting the lower density of IDF equations. The rainfall intensities estimated with the IDF equations show variation above 100% in the Brazilian territory, with the highest values occurring mainly in the North and Midwest regions, and southwest of Rio Grande do Sul. The lowest values occurred in the Northeast and Southeast regions. However, even in these regions there are equations that generated high intensities rainfall, which demonstrates the need to update and obtain equations representative of the location.

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INTRODUCTION

The relationships between intensity (I), duration (D) and frequencies (F) of rains can be represented by the IDF curves or by IDF equations. These relationships are crucial for any flood mitigation measures, water engineering project and water resources engineering designs (Ewea *et al.,* 2016). Ewea *et al*. (2018) point out that safe and economic design of any flood mitigation measures, and flood control structures are relying on the IDF curves. Design of culverts and pipes of stormwater networks and flood management are usually dependent on IDF curves. Bara *et al*. (2009) comment that the IDF curves emerged from the studies of Bernard (1932), and after that IDF curves (or equations) have been presented in different regions of the planet (Chow, 1988; Buishand, 1993; Grimaldi *et al.,* 2011; AlHassoun, 2011; Ewea *et al.,* 2018; Puricelli, 2018). With the advancement of information technology applied to engineering, IDF equations gain even more importance, since they allow the implementation of computational routines to obtain rain information according to duration and frequency. Silveira (2016) developed the Chicago Hydrograph method based on the IDF equation coefficients. Pruski *et al*. (1997) developed a method for estimating runoff based on the IDF equation and showed its applications in the design of terraces and erosion control works on rural roads (Griebeler *et al.,* 2005; Fietz *et al.,* 2011; Miranda *et al.,* 2012; Xavier *et al.,* 2014). Chow *et al.* (1988) describe obtaining the IDF equations in three stages. The first step is to adjust a probability distribution for each series of data observed over a given duration. In the second stage, rainfall intensities are estimated for each duration and return periods, usually ranging from 2 to 100 years. In the third stage, the coefficients of the mathematical model of the IDF equation are adjusted. For this procedure, it is necessary to have long series of short-term precipitation data. The first IDF equations were obtained by analyzing the pluviograms, and as these analyzes were made manually and very laborious, many equations were adjusted for durations of up to 120 minutes. Also, the step of adjusting the coefficients of the equation was considered laborious and generally performed through non-linear regressions (Garcia *et al.,* 2011; Bielenki Júnior *et al.,* 2016; Campos *et al.,* 2017). The advancement of information technology has facilitated these procedures, but the process of adjusting the equation still requires optimization routines, being dependent on the optimization method as well as on the assigned objective function. Penner and Lima (2016) discuss different methods used to estimate the IDF equation. The lack of long series of pluviographic data limited the obtaining of IDF equations for locations with a more complete meteorological station, including the pluviographer (Fechine Sobrinho *et al.,* 2014). An alternative adopted to supply the shortage of short-term rain information is to use the technique of disaggregating daily rain in shorter rains. This disaggregation can be made based on observed relationships of rainfall of different durations with the maximum daily rainfall (Svensson *et al.,* 2007; Garcia *et al.,* 2011; Aragão *et al.,* 2013, Rangel and Hartwig, 2017). Other techniques that can be used to obtain the IDF equations cited in the literature are estimates based on satellite or radar observations (Sun *et al.*, 2019; Marra *et al.,* 2017; Ombadi *et al.,* 2018) or stochastic models of disaggregation of daily rain (Gupta and Waymire, 1993; Khaliq and Cunnane, 1996; Koutsoyiannis and Mamassis, 2001; Damé *et al.,* 2008). In Brazil, the most used procedure is the estimation of shorter duration rains by disaggregating the daily rainfall, with the average disaggregation coefficients for Brazil (Cetesb, 1986; Aragão *et al.,* 2013; Campos *et al.,* 2017; Pereira *et al.,* 2017) or the use of the isozone method, which takes into account eight regions in Brazil (Torrico, 1974; Santos, 2015; Basso *et al.,* 2016). It is noticed that in the last decade there has been an evolution in the definition of the IDF equations in Brazil, therefore, this article aims to survey the IDF equations established for Brazil and thereby evaluate the spatial variation of rainfall intensities in Brazil.

MATERIALS AND METHODS

To survey the IDF equations, a bibliographic search was carried out including theses, dissertations, articles published in magazines and works published in events in the areas of Engineering, Environmental Engineering, Sanitary Engineering, Agricultural Engineering, Climatology and Water Resources. A database was organized with the information available in these works, including location of the station (municipality, state, latitude and longitude coordinates), period of data used, type of data (whether pluviometric or pluviographic), author and year of publication. The most used IDF equation model is of the type of equation (1) and in this article only these equations will be considered.

$$i = \frac{KT^m}{(t+b)^n} \quad (1)$$

Where: i is the rainfall intensity (mm h^{-1});
T is the return period (in years);
t is the rainfall duration (in minutes);

K, m, b, n are the coefficients of the equation that must be adjusted according to the observed rain intensity data.

In equation (1) the intensity is usually expressed in mm h^{-1} however some studies have presented the equations with the rain intensity in mm $minh^{-1}$. In this case, the value of the K coefficient was multiplied by 60 to standardize the intensity in mm h^{-1}. With the obtained IDF equations, the intensities of rain were calculated with a return period of 5 and 10 years and durations of 5, 15, 30, 60 and 1440 minutes. For locations where they had more than one IDF equation, the mean of the intensities estimated with each equation was considered. To obtain data in places without information, spatialization of rain intensities obtained by the equations was performed using geostatistical interpolation (kriging). Kriging is considered an excellent estimator for interpolating rainfall data due to its strong spatial dependence (Mello *et al*., 2003; Lundgren *et al*., 2017; Silva and Oliveira, 2017). The software used was ArcGIS 10.6, using the Geostatistical Analyst tool, the Simple Kriging interpolation method being chosen. For locations where they had more than one IDF equation, the mean of the intensities estimated from each equation was considered.

RESULTS AND DISCUSSION

In these study, 3096 intense rain equations were obtained for Brazil, published in 118 papers, of which ten were academic papers, theses and dissertations, 61 papers published in scientific journals, 27 papers in scientific events and 20 papers classified as books and reports technical. It is important to note that several theses and dissertations were later published as articles in journal, and in this case only the journal's article was considered. It is observed that until the end of the 90's, equations generated based on data from pluviographs predominated, and from the 2000's onwards, dozens of studies emerged where the equations obtained by the disaggregation of daily rain from the pluviometers predominate. Of the 3096 registered equations, 592 equations (19%) were obtained with data from pluviographs and 2504 (81%) were obtained with data from pluviometer, using a method of disaggregating the daily rain in shorter durations. The facilities for accessing available data, such as the HidroWeb (ANA, 2020) database of the National Water Agency

Table 1. Number of publications and number of IDF equation in Brazil by decade

Decade	Number of publication	Number of equations		
		Pluviographic data	Pluviometric data	Total
1970-1980	4	5	0	5
1980-1990	5	87	2	89
1990-2000	6	30	2	32
2000-2010	32	389	245	634
2010-2020	71	81	2252	2334
Total	118	592	2504	3096

(ANA – Agência Nacional de Águas), combined with computational tools, facilitate the analysis of these series, justifying the increase in the number of studies and the large number of equations. It is important to note that in many weather stations, traditional rain gauges have been replaced by electronic rain gauges. This change should imply a reduction in the number of equations with traditional pluviogram data. On the other hand, the large number of automatic stations may be generating data for a new way of obtaining IDF equations, in addition to enabling the review and updating of the relationships between rainfall durations.

Figure 1 shows the spatial variation of the locations where the IDF equation obtained in this study. Among the IDF equations based on pluviographs, a greater concentration was observed in the Southeast region, where the states of Minas Gerais, Rio de Janeiro and Espirito Santo stand out. In the South region, the pluviographic stations are in greater numberin Paraná. In the Midwest region, IDF equations with rainfall data occur in greater numbers in the state of Goiás. Some states such as Santa Catarina, in the South and Ceará, Paraíba and Piauí in the Northeast, have higher density of equationsbased on pluviometricdata. In the Northern Region of Brazil, a small number of IDF equations are observed based on pluviographic data, as well as a reduced number of equations derived from pluviometric data. This distribution is directly related to the existence of pluviometric stations with long series of data. Figure 2 shows the intensity of rain lasting 5 minutes and the return period of 5 and 10 years. A variation above 100% in these intensities is observed in Brazilian territory. The highest values are observed in the southwest region of Rio Grande do Sul, but values of higher intensity also occur in the Midwest region, especially in the states of Mato Grosso do Sul and Mato Grosso, and in the North region. In the state of Ceará, places with high intensity of rain lasting 5 min also were observed. In general, the lowest values are observed in the Southeast and Northeast regions.

The intensity of the rain lasting 5 minutes is indicated for the dimensioning of the gutter. NBR 10844 (ABNT, 1989) recommends using the intensity of the rain lasting 5 minutes and the return period of 5 years, and in the absence of this information, it recommends using the intensity of 150 mm h^{-1}. Based on Brazil's IDF equations, it is observed that this value underestimates most of the intensities obtained with the IDF equations. However, it is important to note that the duration of 5 minutes is in general the shortest duration used, since most of the pluviographs used had daily graphs with hourly divisions and subdivisions of ten minutes, thus, in the visual analysis the duration of 5 minutes is considered the shortest viable duration for obtaining information from the pluviograms. Gutierrez-Lopez *et al*. (2019) point out the 5-minute rain as critical in the IDF equation studies. In the method of disaggregating the daily rainfall by the method of relationships between durations (Cetesb, 1986) the shortest duration is of 5 minutes. In the isozone method, the shortest duration was considered to beof 6 minutes (Torrico, 1974). Another point to consider is that in the stage of adjusting the coefficients of the IDF equations, in general the intensities estimated with the shortest durations, in particular the duration of 5 minutes, presents a greater estimate error. This error can be minimized, depending on the objective function used, but in general it is considered as an objective function to minimize the sum of the squares of the deviations between the observed and estimated intensities. As the intensity decreases with duration, there is a tendency for errors to be greater in the shortest duration, where the intensity is greater. Some authors exclude the duration of 5 minutes and present IDF equations valid for ten or

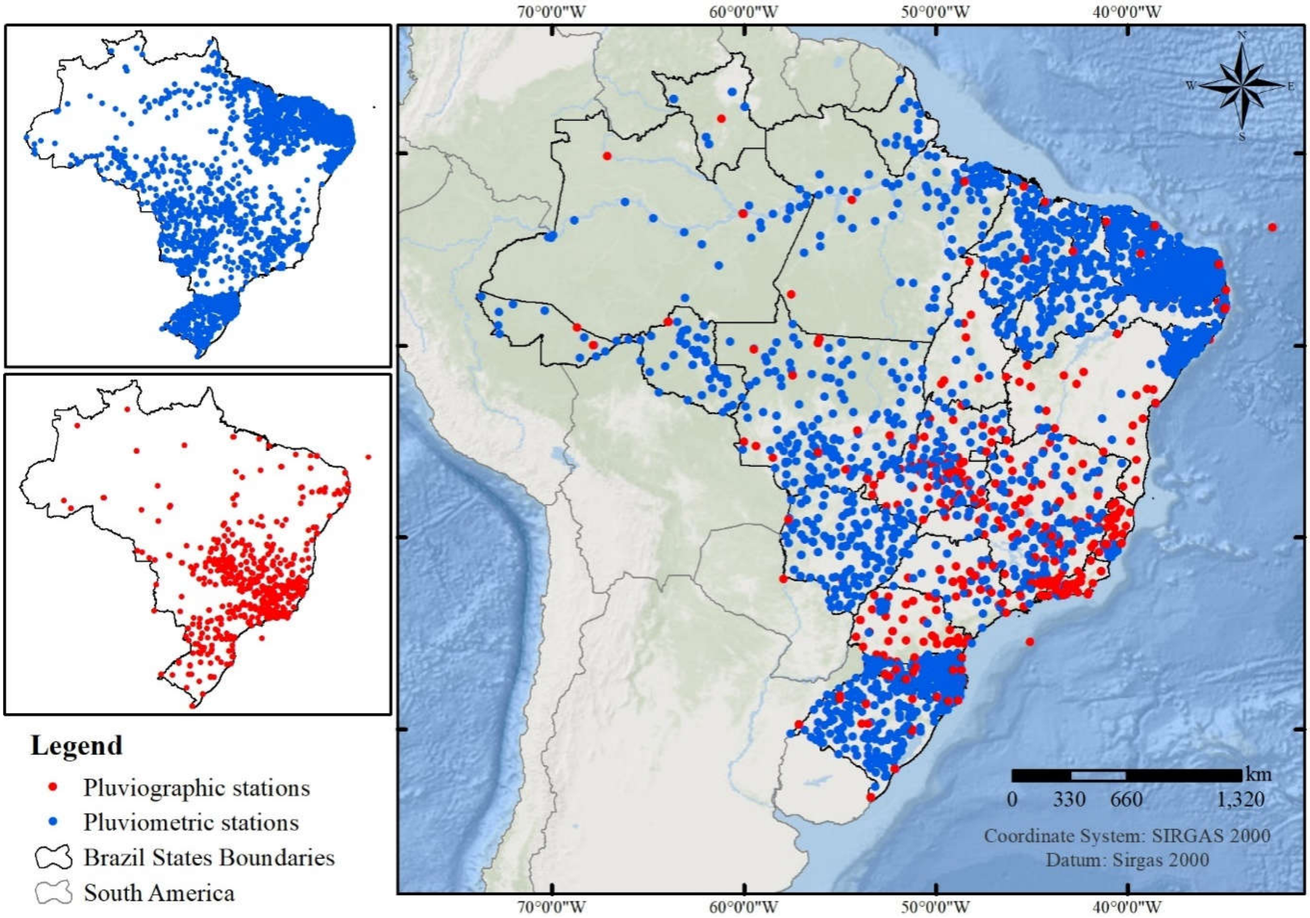

Figure 1. Spatial distribution of the IDF equations generated from data from pluviographic stations (in red) and pluviometric stations (in blue).

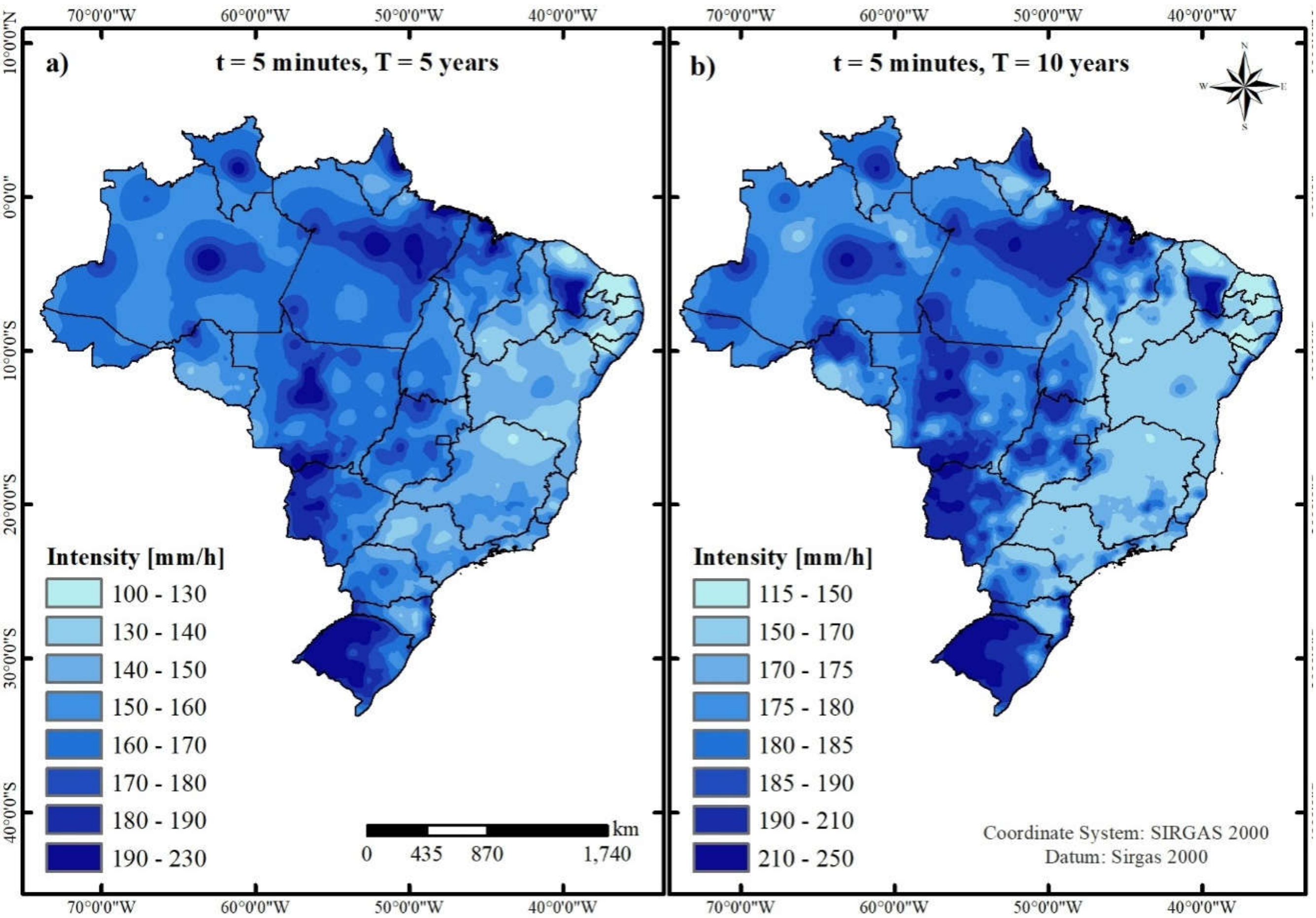

Figure 2. Maximum rain intensity with duration of 5 min and return periodof 5and 10 years

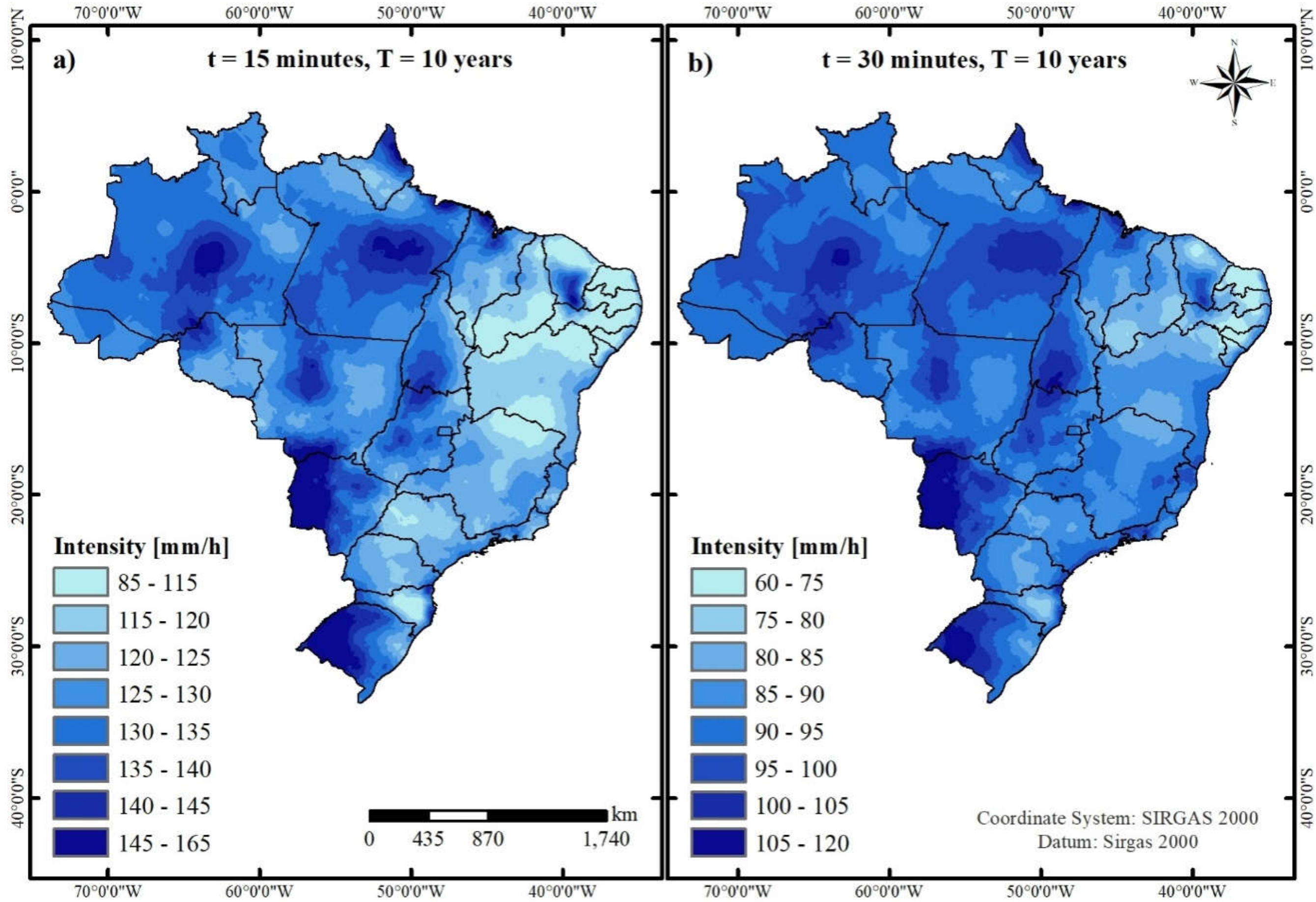

Figure 3. Maximum rain intensity with duration of 15 min and 30 min and 10-year return period

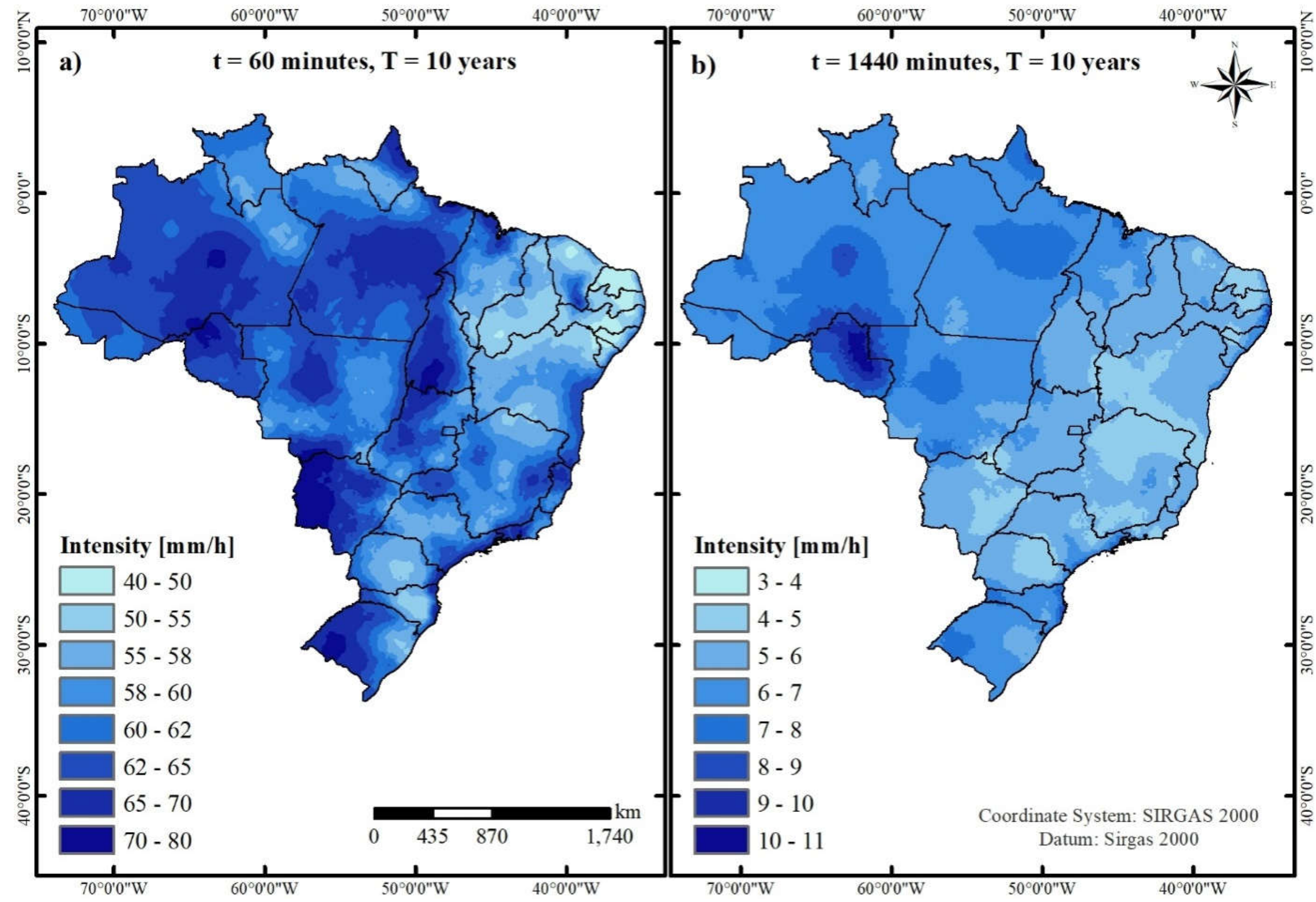

Figure 4. Maximum rainfall intensity with duration of 60 and 1440 min and a 10-year return period

more minutes (Freitas *et al.,* 2001; Silva *et al.,* 2002; Pereira *et al.,* 2007; Nascimento *et al.,* 2020; Sabino *et al.,* 2020). Figure 3 shows the rainfall intensities for 15 and 30 minutes and a 10-year return period. The intensity of the rain with duration of 15 minutes and the return period of ten years varies in Brazilian territory from 85 to 165 mm h^{-1}. The highest values occur in the North and Midwest, and also in Rio Grande do Sul, and the lowest values in the Southeast and Northeast. However, it is possible to observe that there are stations in these regions in which the values of intensity of rain with duration of 15 minutes are greater than 125 mm h^{-1}. For the duration of 30 min the intensity varies from 60 to 120 mm h^{-1}, where a more homogeneous distribution is observed in the Brazilian territory. Rainfall lasting 15 minutes and a return period of 10 years is an important parameter in the area of soil conservation, being used in the dimensioning of terraces in gradients, aiming to control surface erosion (Lombardi Neto *et al*., 1994). The intensity of the rain with duration of 30 minutes is an input parameter in the SWAT model (Soil and Water Assessment Tool)), which allows modeling of runoff, soil and waterlosses (Gassman *et al.,* 2007). Also, for urban drainage, many micro-drainage works with gutters, sewer gratesand pluvial galleries use the intensity of the rain with duration between 15 and 30 minutes.

Figure 4 shows the intensities of the rain with duration of 60 and 1440 minutes (1 and 24 hours). It is observed that the spatial variation follows the patterns described for shorter rainfall. This is explained by the fact that most of the IDF equations have been adjusted based on the relationships between rainfall durations, and thus maintain the ratio between durations. In the 1440-minute rain estimated with the IDF equation, because it is the longest, there is also a greater estimation error, which depends on the objective function used in adjusting the coefficients of the IDF equation, as discussed for the 5-minute duration. The maximum rainfall with duration of 24 hours is an important parameter for Rural Engineering, being used in soil conservation projects, as in the dimensioning of terraces in level (Cruciani, 1988). These results confirm that the IDF of rainfall is directly linked to its spatial distribution (Santos *et al.,* 2009; Campos *et al.,* 2017), corroborating the need to determine these parameters for each specific rainfall station.

Conclusions

Based on the research on the adjusted IDF equations for the pluviometric stations in Brazil, in which 3096 equations were registered, from 118 publications, the following conclusions can be drawn:

- The IDF equations generated from the disaggregation of daily rain data recorded in pluviometers predominate (81%) over the equations generated from data recorded in pluviographs (19%);
- In the last decades, there has been a large number of papers and IDF equations published, with predominance of IDF equations obtained by disaggregating daily rain;
- Some Brazilian states have a large number of IDF equations, however there are regions with low density, especially in the Northern region of Brazil;
- The rainfall intensities estimated by the IDF equations show spatial variation above 100% in the Brazilian territory, showing the importance of updating and using the local IDF equation.

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