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Evaluation of the Rio de Janeiro State Flood Warning System: A Case Study for the Hydrographic Region of the Médio Paraíba do Sul (RJ), Brazil

Avaliação do Sistema de Alerta de Cheias do Estado do Rio de Janeiro: um Estudo de Caso para a Região Hidrográfica do Médio Paraíba do Sul (RJ), Brasil

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Abstract

This work is a case study for the Hydrographic Region of the Médio Paraíba do Sul located in the State of Rio de Janeiro (Brazil), which has natural disasters, such as floods, as the most recurrent. Due to the social, economic and environmental impacts that these disasters cause, this research aim to analyze the history of alerts issued by the Flood Warning System (FWS) and to assess its efficiency. Through the retro-analysis of Alert Trigger Events (ATE) that occurred in the monitored rivers, investigations were also carried out in the hydrological and meteorological scope. The results identified that the Attention stage belonging to the operational protocol significantly reduces the efficiency of the FWS about sending alerts, causing high false alarm rate. Regarding the influence that variation in the type of data transmission has on the Operational Protocol in RH-III, it is considered that the time interval between data transmission and their availability on the State Environmental Institute (SEI) server generates a false alarm, however the FWS is still efficient. Barra Mansa River is the only one that has flood events, which raises questions about the representativeness of the other stations spread across RH-III. In addition, 60% of alerts issued for RH-III were related to episodes of Cold Fronts and South Atlantic Convergence Zones. These information helps improve the description of the flood events in the region. Rainfall Anomaly Index (RAI) identified periods that the rainfall rate was below the climatological average, indicating a drier environment, but with alerts issued.

Keywords: Natural disasters; Overflow; Barra Mansa

Resumo

Este trabalho é um estudo de caso para a Região Hidrográfica do Médio Paraíba do Sul localizada no Estado do Rio de Janeiro (Brasil), a qual possui os desastres naturais do tipo inundações como os mais recorrentes. Devido aos impactos sociais, econômicos e ambientais que esses desastres causam, esta pesquisa tem como objetivo analisar o histórico de alertas emitidos pelo Sistema de Alerta de Cheias (SAC) e avaliar sua eficiência. Por meio da retroanálise dos eventos desencadeadores de alertas (EDA) que ocorreram nos rios monitorados, também foram realizados estudos no âmbito hidrológico e meteorológico. Os resultados identificaram que o estágio Atenção pertencente ao protocolo operacional reduz significativamente a eficiência do SAC no envio de alertas, ocasionando alta taxa de alarme falso. Quanto à influência que a variação do tipo de transmissão de dados tem sobre o Protocolo Operacional na RH-III, considera-se que o intervalo de tempo entre a transmissão dos dados e sua disponibilização no servidor do Instituto Estadual do Ambiente (INEA) gera alarme falso, porém o SAC ainda é eficiente. O Rio Barra Mansa é o único que possui eventos de inundação, o que levanta dúvidas sobre a representatividade das demais estações espalhadas pela RH-III. Além disso, 60% dos alertas emitidos para a RH-III estiveram relacionados com episódios de Frentes Frias e Zonas de Convergência do Atlântico Sul. Essas informações ajudam a melhorar a descrição dos eventos de inundação na região. O Índice de Anomalia de Chuva (IAC) identificou períodos em que o índice pluviométrico ficou abaixo da média climatológica, indicando um ambiente mais seco, mas com alertas emitidos.

Palavras-chave: Desastres naturais; Inundação; Barra Mansa

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1 Introduction

Floods are considered one of the most destructive natural disasters in the world, covering a third of all risks considered geophysical on a global scale (Saharia et al. 2017). This type of natural event generates damage not only at the time of occurrence but also in the long term, due to its consequences that, when impacting society, can be defined as natural disasters (Alcántara-Ayala 2002).

The increase in the occurrence of floods is associated with population growth and rapid urban growth within river basins (Abdo 2020). Climate change, land use changes, and increased waterproofing of surfaces influenced by to urban areas are also factors that lead to increased flooding (Nasiri, Yusof & Ali 2016).

The Southeast region of Brazil is the region that exhibits one of the highest rates of urban growth and changes in the precipitation regime that can impact the population's vulnerability to rain-related disasters such as floods and landslides. Although there are uncertainties regarding the change in precipitation levels over this region, there are indications of a tendency for an increase in precipitation rates for the states of Rio de Janeiro and São Paulo (Zilli et al. 2017).

Monitoring of natural disasters in Brazil is carried out by several State Agencies like the ANA (National Water Agency), CPRM (Geological Survey of Brazil), CEMADEN (National Center for Monitoring and Early Warning of Natural Disasters), and CENAD (National Center for Risk Management and Disaster). Some states and municipalities also have this type of monitoring, having their systems, as is the case of Alert - ES – Disaster Prevention in the state of Espírito Santo, of the SAISP (Flood Warning System of São Paulo) and the Flood Warning System (FWS) in the state of Rio de Janeiro, the latter two being specialized in flood monitoring.

Due to the concern of the State Institute for the Environment (INEA) with the frequent problems caused by floods in different regions of the Rio de Janeiro State, causing human and material losses, the FWS was started to operate in 2007, aiming monitoring weather conditions nonstop detecting therefore possible alert situations and informing state authorities (Viana, Farias Júnior & De Oliveira 2009). In a scenario of possible overflowing of rivers in the monitored regions, alerts are sent to the authorities and the population based on an Operational Protocol that emits five types of alerts, namely: Attention, Alert, Maximum Alert, Overflow, and Surveillance.

This work aims to analyze the performance of the FWS to contribute to the identification of possible characteristics that still limit its use in the state of Rio de Janeiro. Among the monitored regions, the Hydrographic Region of the Médio Paraíba do Sul (RH-III) was chosen for this work, as it is a region that plays an important economic role in the state (IBGE 2021a), and because it presents flooding as the type of natural disaster with the highest incidence in the region (COPPETEC 2014).

1.1 Description of the Flood Warning System (FWS)

The FWS started operating in October 2007, installing 10 telemetric stations in the Baixada Fluminense region, and later, it was expanded to other regions of the state. The FWS was created to monitor weather conditions uninterruptedly, detecting possible alert situations and informing competent authorities. The system is operated by a team of professionals who monitor weather conditions through a monitoring network (Viana, Farias Júnior & De Oliveira 2009).

The system has a network of telemetric stations that transmit rainfall and river level data with an interval of 15 minutes to GSM/GPRS (Global System for Mobile Communication/ General Packet Radio Service) type stations, which is safe and stable for data transmission. However, in places where there is no telecommunications infrastructure, satellite transmission is used. The FWS uses the technology available from the GOES/NOAA (Geostationary Operational Environmental Satellite/ National Oceanic and Atmospheric Administration), which transmits rainfall and river level data at hourly intervals.

In 2015, the FWS also started to have two weather radars that were financed with funding from the World Bank, with the purpose of promoting the monitoring of rainfall over the hydrographic basins that make up the state of Rio de Janeiro. Thus, the Operational Protocol was improved to include radars in decision-making as of 2015.

The alerts issued by the System are based on an Operational Protocol described in Table 1. The Attention stage is issued when there is a forecast of rain that could trigger the overflow of a monitored river. If there is a rise in the level of a monitored river, the Alert stage is issued, which can be associated with local rainfall or in the contribution basin. If the river level reaches a value equal to or greater than the Maximum Alert river level, the Maximum Alert stage is issued. If the rise in the river level reaches the overflow level value, the Overflow stage is issued. It is important to emphasize that both the Maximum Alert and the Overflow river levels are previously defined by the knowledge from the Civil Defense and the FWS. When there is no longer a forecast of rain that could trigger elevations in the monitored rivers or when these rivers' levels return to a value close to their average behavior, the Surveillance stage is issued.

Table 1 Definition of the stages belonging to the FWS Operational Protocol. Source: Adapted from Alerta de Cheias (2020).

Stages	Situation
Surveillance	No significant rain forecast that could cause river levels to rise.
Attention	Possible rise in river levels due to rainfall.
Alert	A rise above the normal level of a monitored river, with a forecast of elevation.
Maximum Alert	Imminence of overflow of a monitored river, with forecast of elevation.
Overflow	Record of the level of a monitored river above the overflow quota.

This Operational Protocol follows a sequence of alert stages with a maximum duration of up to 12 hours for the Attention, Alert, Maximum Alert, and Overflow stages. It is necessary to renew the alert or terminate it after this time interval has elapsed. If a new stage is issued to the river during this time interval, the previous one is revoked, and a new 12-hour count begins.

To better understand the dynamics of issuing alerts, it is necessary to define the concept of Alert Trigger Events (ATE). An ATE is defined as a situation that refers to the need to send alerts on account of the possibility of flooding due to local rain or in the contribution basin. Thus, an ATE starts from the first alert issued, which can be an Attention, Alert, Maximum Alert, or Overflow stage. It is important to emphasize that the Attention stage is issued at the municipal level; that is, all rivers monitored in a municipality enter the Attention stage when this type of alert is issued. However, the Alert, Maximum Alert, and Overflow stages are explicitly issued for rivers with elevations in their levels. In addition, the Maximum Alert and Overflow stages have reference thresholds (river level) to be issued.

It is worth noting that the dynamics of sending alerts depends on the behavior of the river in rainfall events, which makes the evolution of alerts present different behaviors in each ATE. So, the evolution of the stages may not follow the same sequence proposed by the Operational Protocol. A river can move, for example, from an Alert stage to a Maximum Alert stage, or it may return from an Alert stage to an Attention stage. It is also possible to repeat the stages, that is, an Alert stage can be issued repeatedly throughout the ATE, depending on the behavior of river levels. For an ATE to be terminated, it is necessary to send the Surveillance stage. With this, it is understood that the river level has returned to its usuais stage or is no longer at risk of new elevations.

1.2 Study Area

The area of interest for this research corresponds to the Hydrographic Region of the Médio Paraíba do Sul (RH-III), as seen in Figure 1. This is one of the nine hydrographic regions of the State of Rio de Janeiro, according to the Committee of Médio Paraíba do Sul Hydrographic Region Basin – CBH – Médio Paraíba do Sul (CBH – Médio Paraíba 2020).

Among the regions monitored by the FWS, the Hydrographic Region of the Médio Paraíba do Sul was chosen for this study, as it is a region that plays an essential economic role in the state. It is the fourth most industrialized hydrographic region in the state of Rio de Janeiro, with emphasis on the municipality of Volta Redonda, which is the 7th most industrialized within the Rio de Janeiro state. More than 50% of the GDP of this hydrographic region is made up of industrial production (IBGE 2021a). The steel, metalworking, and automotive sectors are some of the most relevant activities. However, cement, food, and energy industries sectors, as well as activities focused on agriculture, production of horticultural products, and retail trade, are also among the main economic activities in this hydrographic region (INEA 2021).

The RH-III is divided into two sub-basins, the Preto Basin and the Upper Middle Course Basins of Paraíba do Sul, the latter being used for hydroelectric and industrial use, mainly by the Barra Mansa and Volta Redonda steel plants. In addition, the Paraíba do Sul River also significantly contributes to the water supply for the Metropolitan Region of Rio de Janeiro (INEA 2021).

Regarding the history of natural disasters in this region, in a survey carried out by COPPETEC (2014), it was identified that between 1979 and 2012, there were 96 natural disasters. In a more careful assessment of the period 2000 to 2012, there were 37 floods, the most recurrent natural disaster type in the region. These events affect approximately 157.000 people. 12 of events were declared as Emergency Situations and one as a State of Public Calamity. In addition, concerning the region most vulnerable to floods, 13 points was identified in the RH-III, all located close to the Paraíba do Sul River. Among these regions of higher vulnerability, the municipalities of Barra Mansa and Volta Redonda have five identified vulnerability points, which are also the ones with the highest population concentration (IBGE 2021b). These data indicate the need for more in-depth studies regarding the efficiency of the FWS to increase its quality and respond with greater precision to possible future natural disasters.

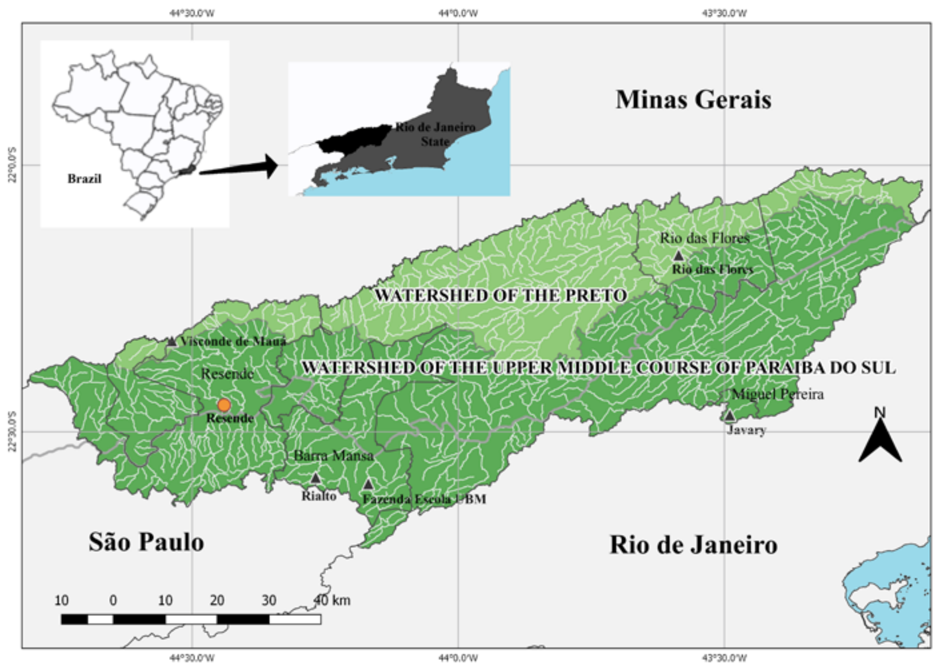

Figure 1 Hydrographic grid of the Médio Paraíba do Sul region with the municipalities and hydrometeorological stations used for monitoring by the FWS – RJ.

2 Methodology and Data

2.1 Data

In this work, precipitation data provided by the FWS and by the National Institute of Meteorology (INMET) were used, in addition to the river level data and the alerts issued, made available by the FWS as observed in Table 2. Synoptic charts, hydrometeorological bulletins from the Hydrographic Center of the Brazilian Navy (CHM), the Center for Weather Forecasting and Climate Studies (CPTEC), and the FWS are also used.

2.2 Methodology

The methodology used was divided into different steps, as shown in the flowchart (Figure 2) below.

2.2.1. Alert History

Initially, a survey and evaluation of the evolution of all alerts issued to the stations of the FWS for the Hydrographic Region of the Médio Paraíba do have been carried out from May 2014 until March 2020.

For a more careful assessment of the processes in which the alerts involved, an individual ATE-by-ATE event analysis was carried out, following or not the order of the Operational Protocol, except for the Surveillance and Attention stages that depend on the analyst's interpretation or which presupposes a high degree of subjectivity. Furthermore, the consideration of an ATE for this case study was defined as a situation that refers to the need to send alerts due to the possibility of flooding caused by local rain or in the contribution basin. Thus, an ATE starts from the first alert issued, which can be an Attention, Alert, Maximum Alert, or Overflow stage. The end of the ATE was also considered when the Surveillance stage was sent. So, it is understood that the river level has returned to its normality stage or that it no longer represents risks for new increases in the levels of the monitored rivers. It is important to emphasize that the ATE were different by municipality and that it was possible to observe more than one monitored river presenting elevations in its levels in some ATE, as is the case of the municipality of Barra Mansa, which has two monitored rivers (Barra Mansa and Bananal rivers).

In Table 3, it is possible to observe two examples of identified ATE. Note that on 02/15/2016, the stage that started the ATE was the Alert. Subsequently, the ATE was closed with the issuance of the Surveillance stage. For days 17 and 02/18/2016, the ATE began with the Attention stage, later evolving to the Alert and Overflow stages. This ATE lasted until 02/18/2016 when the level of the overflowing river returned to alert, as it was still high or at risk for new elevations. Afterward, the ATE was closed with the submission of the Surveillance stage.

Table 2 Information about stations and data characteristics.

City monitored	Station	Institute	Period	Monitored river	Type*	Overflow quote	Transmission
Resende	Visconde de Mauá	INEA	2014 a 2020 (15 minutes)	Preto	Plu/Flu	2.75 m	GSM/GPRS
Barra Mansa	Rialto	INEA	2014 a 2020 (15 minutes)	Bananal	Plu/Flu	6.70 m	GOES/NOAA
Barra Mansa	Fazenda Escola UBM	INEA	2014 a 2020 (15 minutes)	Barra Mansa	Plu/Flu	2.00 m	GOES/NOAA
Miguel Pereira	Javary	INEA	2018 a 2020 (15 minutes)	Saco	Plu/Flu	2.04 m	GSM/GPRS
Rio das Flores	Rio das Flores	INEA	2014 a 2020 (15 minutes)	Ribeirão Manoel Pereira	Plu/Flu	3.55 m	GSM/GPRS
Resende	Resende	INMET	1961 a 2019 (monthly)	-	Plu	-	-

*Type = Pluviometric (Plu) and Fluviometric (Flu).

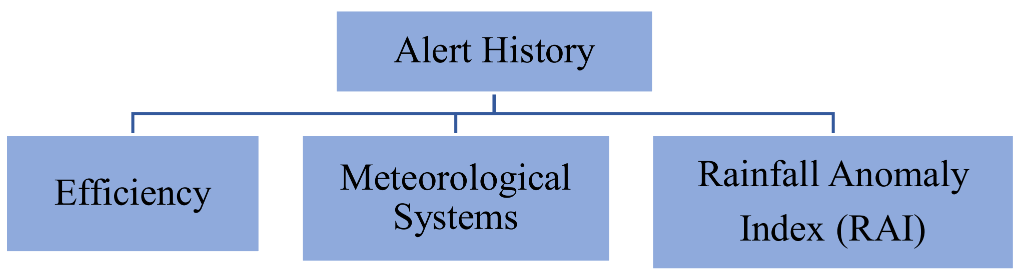

Figure 2 Flowchart referring to the subdivisions that make up the methodology for this case study.

Table 3 Examples of alert trigger events considered in this research.

Date	City	Station	Attention	Alert	Maximum Alert	Overflow	Surveillance
15/02/2016	Barra Mansa	Fazenda Escola UBM		X			X
17/02/2016	Barra Mansa	Fazenda Escola UBM	X	X		X	
18/02/2016	Barra Mansa	Fazenda Escola UBM		X			X

2.2.2. Efficiency

The efficiency of the FWS was evaluated through the variation of alerts in relation to the evolution of the Operational Protocol and to the variation in the type of data transmission (GSM/GPRS and GOES/NOAA). The methodology used follows the steps represented in the flowchart (Figure 3).

In order to calculate the efficiency of the system in relation to the evolution of the Operational Protocol, contingency tables were prepared according to the model presented in Table 4, considering all the ATE identified in item 2.2.1. Two contingency tables were created: in the first, all ATE were considered; in the second, only those that evolved to the Alert, Maximum Alert, and Overflow stages, disregarding the ATE in which only the Attention stages were emitted.

Two criteria were created to calculate the efficiency in relation to the variation in the type of data transmission: cases of success and cases of error. In the case of success, it was considered that the maximum level reached by the river in an ATE was consistent with the maximum stage emitted. As for the error cases, it was considered that the maximum stage emitted in an ATE did not correspond to the maximum level reached by the river. Thus, river level thresholds were constructed for each ATE that evolved to the Alert, Maximum Alert, and Overflow stages, using precipitation data (mm), river level threshold (m), and the values of the overflow river level made available by the FWS. The information obtained from the analysis of the water level measurements was used in the contingency table in relation to the variation in the type of data transmission. In this way, it was possible to visualize whether the maximum stage emitted in an alert trigger event was or was not consistent with the maximum reached river level, both for GOES/NOAA stations and GSM/GPRS stations.

To calculate the efficiency through the variation of alerts in relation to the evolution of the Operational Protocol, the contingency table was constructed as follows:

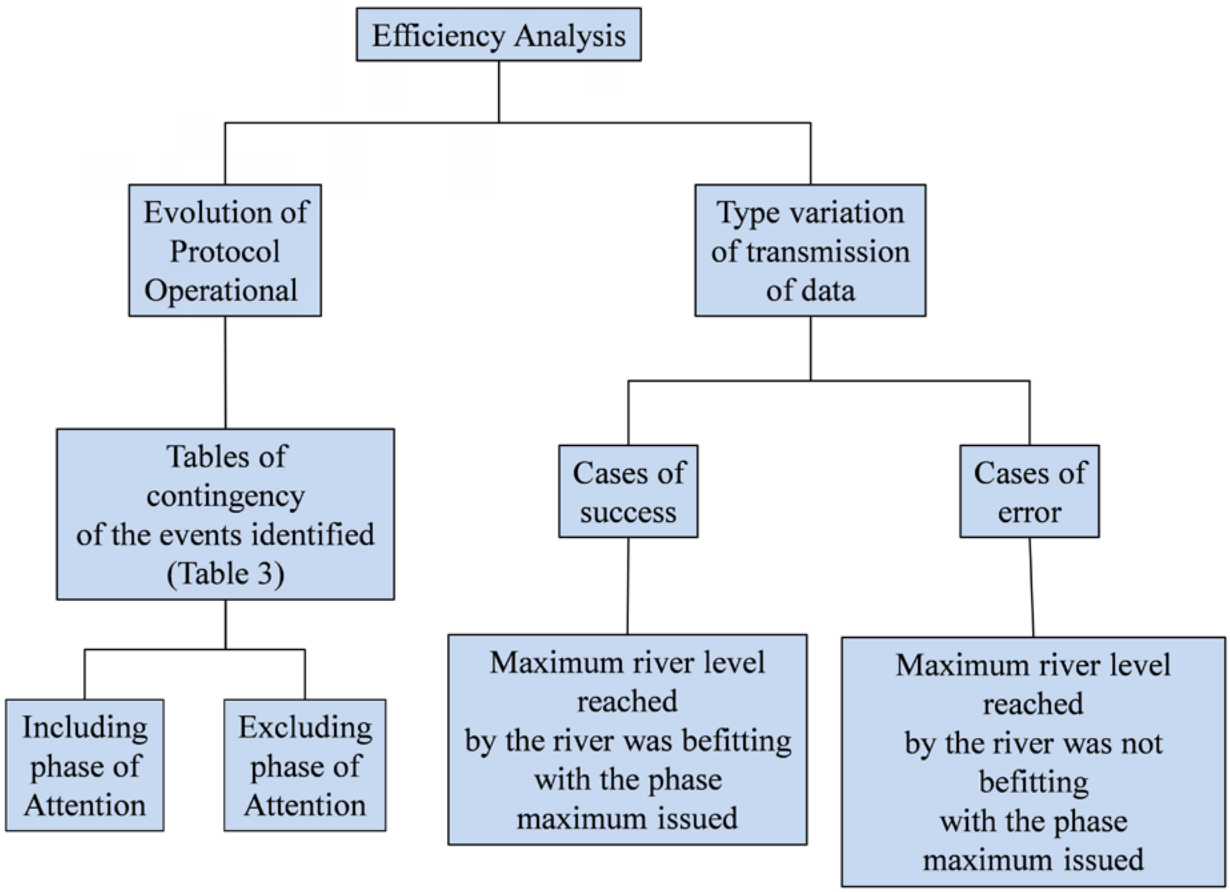

Figure 3 Flowchart of the steps performed to calculate the efficiency.

Table 4 Contingency table schema.

	ALERT	NO ALERT
ALERT	a	b
NO ALERT	c	d

- Variable **a** corresponds to the values in which the alerts of the Attention stage evolved to the other alerts of the Operational Protocol;
- Variable **b** corresponds to the values in which the Attention stages did not evolve to the other alerts or to cases in which there were errors in issuing the alerts;
- Variable **c** corresponds to the values in which alerts of the Attention stage were not given, but alerts of the Alert, Maximum Alert and Overflow stage were issued;
- Variable **d** was disregarded in the analysis because it did not present criteria that fit into a situation of No Alert X No Alert.

For the calculation of efficiency through the variation of alerts in relation to the variation of the type of data transmission (GSM/GPRS and GOES/NOAA), the variables have the following representation:

- **a** corresponds to the ATE in which the maximum stage emitted was consistent with the maximum level reached by the river;
- **b** corresponds to ATE in which the maximum stage emitted is higher than the reached river level (overestimated) or for ATE in which there was an error in the emission of alerts, associated with spurious level data recorded by the station;

- **c** corresponds to ATE in which the maximum stage obtained is lower than the maximum reached river level (underestimated);
- **d** was disregarded in the analysis because it did not present criteria that fit into a No Alert × No Alert situation.

From the elaboration of the contingency tables, the results obtained from variables **a**, **b**, **c** and **d** were applied in the formulas of Correct Proportion, Critical Success Index, False Alarm and Bias (Wilks 2011), determined by Equations 1, 2, 3 and 4, respectively.

Correct Proportion	(a+d) / (a+b+c+d)	**(1)**
Critical Success Index	a / (a+b+c)	**(2)**
False Alarm	b / (a+b)	**(3)**
Bias	(a+b) / (a+c)	**(4)**

2.2.3. Weather Systems

In order to understand the precipitation regime in the region, a survey was carried out of all the meteorological systems that acted on the dates of the ATE in which the Alert, Maximum Alert and Overflow types of alerts were issued to verify the association between the incidence of ATE and the occurrence of meteorological systems, such as Cold Fronts, South Atlantic Convergence Zone, troughs, among others.

2.2.4. Rainfall Anomaly Index (RAI)

The Rain Anomaly Index (RAI) was used to assess the frequency of positive anomalies in months in which there were records of ATE that involved the issuance of Alert, Maximum Alert and Overflow alerts. This index is determined by Equations 5 and 6:

$$RAI = 3\left[\frac{(N-\underline{N})}{(\underline{M}-\underline{N})}\right] \quad \text{for positive anomalies} \qquad \textbf{(5)}$$

$$RAI = -3\left[\frac{(N-\underline{N})}{(\underline{X}-\underline{N})}\right] \quad \text{for negative anomalies} \qquad \textbf{(6)}$$

where N corresponds to the total monthly precipitation, N corresponds to the average monthly precipitation of the historical series, M represents the average of the ten highest monthly precipitations of the historical series and X represents the average of the ten smallest monthly precipitations of the historical series.

This test was carried out for the Resende station, belonging to INMET, as it is the station that has the longest period of precipitation data for the region. The evaluation of rainy periods follows the classification described in Table 5.

3 Results

3.1 Alert History

The total number of alerts issued between 2014 and 2020 is shown in Figure 4. It can be seen that there is a significant amount of Attention alerts in relation to the other stages issued. This discrepancy can be explained by the subjective content of the Attention stage concerning the other stages since the issuance of an Attention alert is subject to the meteorologist's interpretation. However, it is a stage that does not demand mobilization of the Civil Defenses, as it only intends to communicate to the authorities and the population the possible risk of elevations in the levels of the rivers that can cause floods.

Accounting of the alerts issued for the Bananal, Barra Mansa, and Preto rivers, can be seen in Figure 5. The Ribeirão Manoel Pereira River and the Saco River were not mentioned because they did not present a number of alerts issued of the Alert, Maximum Alert, and Overflow types of stages.

Barra Mansa River has the highest incidence of alerts between May 2014 and March 2020, in which a total of 37 stages of Alert, 22 stages of Maximum Alert, and 15 stages of Overflow were issued. For the Bananal and Preto rivers, only 8 and 2 Alert stages were issued, respectively. Thus, the Barra Mansa River was the only river that presented flooding ATE in the Hydrographic Region of the Médio Paraíba.

It is important to note that in the survey carried out, there is no quantity of alerts of the Alert, Maximum Alert, and Overflow type in a period before 2016. This fact can be explained by the change in the value of the overflow river level threshold of the Barra Mansa River, which changed on 01/21/2016. Between 2014 and 2016, flooding alert trigger events are assumed to have occurred in the region, but they were not recorded by the fluviometric station, as the initially established overflow river level threshold was not representative of this river. During 2017 there were also no alert due to technical operational problems.

Transforming the number of alerts presented in Figure 4 into the number of alert trigger events, we have the following result presented in Figure 6. To carry out this process, an alert trigger event was considered from the first alert issued and may be of the type Attention, Alert,

Table 5 Rainfall Anomaly Index (RAI) classification. Source: Adapted from Noronha, Da Hora and Silva (2016).

Rainfall Anomaly Index (RAI)	Classification
Bigger then 4	Extremely Rainy (ER)
Between 2 e 4	Very Rainy (VR)
Between 0 e 2	Rainy (R)
0	Neither Rainy Nor Dry
Between 0 e -2	Dry (D)
Between -2 e -4	Very Dry (VD)
Less than -4	Extremely Dry (ED)

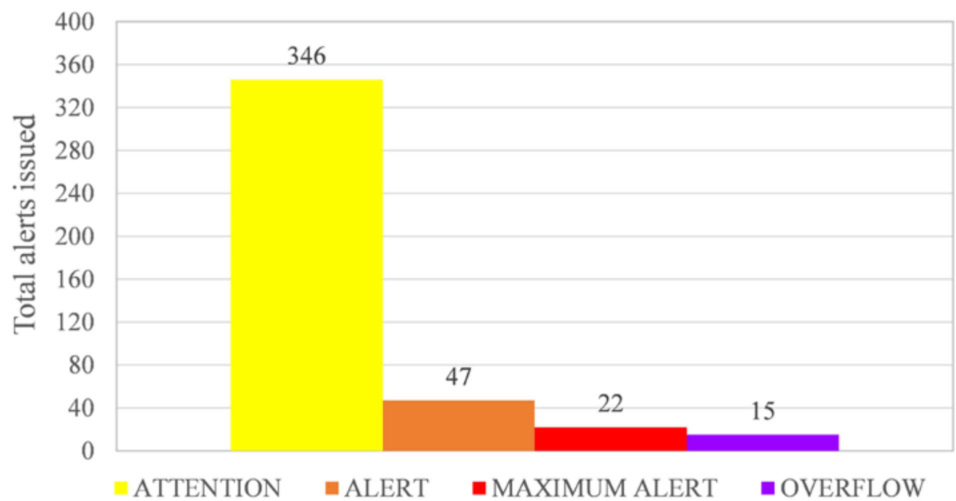

Figure 4 Total alerts issued between 2014 and 2020 for the Médio Paraíba do Sul Hydrographic Region.

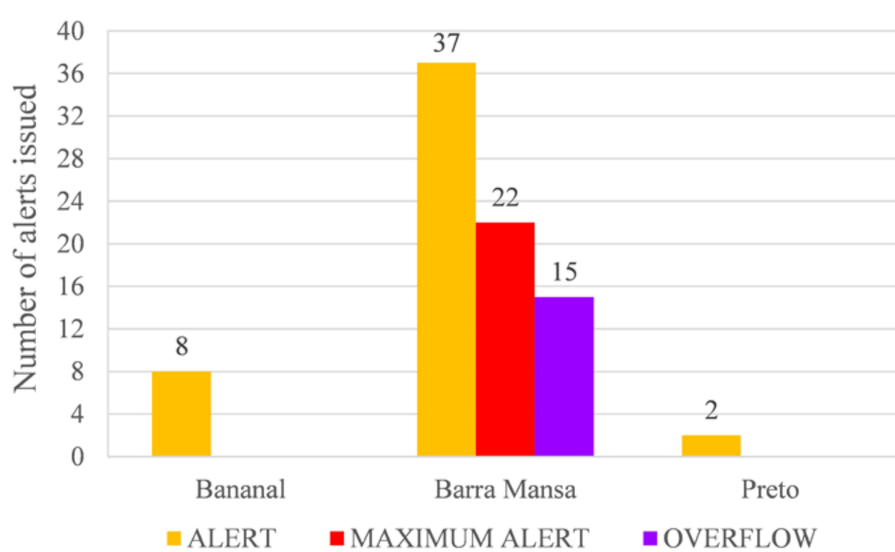

Figure 5 List of alerts issued for monitored rivers in the Médio Paraíba do Sul Hydrographic Region.

Maximum Alert, or Overflow. Each of these ATE was also considered to have ended when the Surveillance stage was issued. In this way, all ATEs were recorded, including all Operational Protocol alerts that were issued (Issuance stage to the Surveillance stage). Thus, in Figure 6, it is possible to observe a total of 299 ATE identified, where 261 of them were only started with the Attention stage and ended with the Surveillance stage, which corresponds to 87.3% of the total identified alert trigger events. Therefore, in these 261 alert trigger events, no changes were observed in the Operational Protocol. However, in the other 38 alert trigger events (12.7% of the total ATE), evolutions were observed in the Operational Protocol; that is, the stages of Alert, Maximum Alert, and Overflow were issued, and in 32 of them, the Attention stage was initially issued and in the remaining 6, they were not alerts of the Attention type are initially issued.

3.2 Efficiency

To analyze how efficient the FWS is concerning the evolution of the stages of the Operational Protocol, contingency tables were created considering the number of identified ATE, and the results were applied in the Critical Success Index, False Alarm, and Correct Proportion. As shown in Table 6, 32 ATE were identified with alerts of the Attention type that evolved to other stages of the Operational Protocol, one of which was added to the category of overestimated because it was an ATE that was considered a failure, as it was associated with spurious data registered by the station. In addition, 6 ATE were considered underestimated, as the Attention stage was not issued, but the Alert, Maximum Alert, and Overflow stages were issued. Finally, 261 ATE were considered overestimated, as Attention type alerts were issued that did not progress to other stages. Based on Table 6, the following results were obtained, as shown in Table 7.

According to Table 7, 10% of the Correct Proportion and 10% of the Critical Success Index were got, indicating the level of accuracy and correct proportion within the sample, representing very inadequate results. As for the False Alarm Index, 89% was obtained, indicating a high level of cases detected as an error within the sample, which reinforces the unsatisfactory results mentioned above. In addition, a 15.5 of Bias was obtained, indicating that the number of predicted cases was more significant than that observed. With these results, it is understood that the FWS is not efficient concerning the evolution of the stages of the Operational Protocol for the Hydrographic Region of Médio Paraíba do Sul, when the Attention stage is considered.

However, to investigate the efficiency of the evolution of the Operational Protocol stages only for the ATE in which the Alert, Maximum Alert, and Overflow stages were issued, a new contingency table was built. Thus, in Table 8, the same ATE mentioned in the preparation of Table 6 was considered, except for the 261 ATE in which Attention type alerts were issued and which did not evolve into other alerts of the Operational Protocol of the FWS. Based on Table 8, the following results were obtained, as shown in Table 9.

According to Table 9, 82% of the Correct Proportion and 82% of the Critical Success Index were obtained, indicating satisfactory results in terms of accuracy and correct proportion within the sample. As for the False Alarm Index, 3% was obtained, which indicates a low level of cases detected as an error within the sample, reinforcing the satisfactory results mentioned above. In addition, 7.0 of Bias was obtained, a result that is more satisfactory compared to the results obtained in Table 7.

Regarding the evaluation of the results obtained in Table 9, it is concluded that the indices indicated results that are considered satisfactory with the results obtained when compared to those in Table 7, which allows us to understand that the Attention stage is what makes the FWS

Figure 6 Flowchart of the survey of considered alert trigger events.

Table 6 Contingency table considering all ATE from May 2014 to March 2020.

	ALERT	NO ALERT
ALERT	31	262
NO ALERT	6	0

Table 7 Results of the indicatives obtained to assess the efficiency of the FWS regarding the evolution of the stages of the Operational Protocol.

Indicatives for the evaluation of the efficiency of the Flood Alert System	
Correct proportion	10%
Critical Success Index	10%
False alarm	89%
Bias	15.5

Table 8 Contingency table considering only the ATE that involved the Alert, Maximum Alert, and Overflow stages.

	ALERT	NO ALERT
ALERT	31	1
NO ALERT	6	0

Table 9 Results of the indicatives obtained to assess the efficiency of the FWS regarding the evolution of the stages of the Operational Protocol, disregarding the Attention stage.

Indicatives for the evaluation of the efficiency of the Flood Alert System	
Correct proportion	82%
Critical Success Index	82%
False alarm	3%
Bias	7.0

less efficient for the Hydrographic Region of the Médio Paraíba do Sul. It is then suggested that the Attention stage starts to have a criterion based on the elevation of river levels for its emission, and this river level threshold value should be adjusted with the Civil Defense. If this investigation is carried out in other hydrographic regions of the state, and it is found that the Attention stage negatively influences the efficiency of issuing alerts by the FWS then it is recommended that it should be removed from the Operational Protocol.

To analyze whether the types of data transmission (GSM/GPRS and GOES/NOAA) influence the efficiency of the FWS by applying alerts during ATE in which there were significant increases in the levels of monitored rivers, a contingency table was drawn up, as shown in Table 10. It presents the results of the analyses carried out in the river level thresholds, where 30 ATE considered to be correct were identified, as the maximum level of the river was consistent with the maximum stage emitted. However, 8 error ATE were identified, 6 of them were considered as underestimated, since the maximum stage obtained is lower than the maximum reached river level and 2 of them were considered as overestimated, since the maximum stage emitted is higher than the reached river level, one of which was considered an error because it was associated with spurious river level data. Based on Table 10, the following results were obtained, as shown in Table 11.

According to Table 11, 79% of the Correct Proportion and 79% of the Critical Success Index were obtained, indicating satisfactory results in terms of accuracy and correct proportion within the sample. As for the False Alarm Index, 6% was obtained, which indicates a low level of cases detected as an error within the sample, reinforcing the satisfactory results mentioned above. In addition, 7.1 of Bias was obtained, a satisfactory result.

Thus, indices showed results that are considered satisfactory, which allows us to understand that the variation in the type of data transmission (GSM/GPRS and GOES/NOAA) does not significantly reduce the efficiency of the FWS through the application of alerts during ATE in which significant elevations occurred in the monitored rivers of RH-III.

Table 10 Contingency table considering only the alert trigger events that evolved within the Operational Protocol.

	ALERT	NO ALERT
ALERT	30	2
NO ALERT	6	0

Table 11 Results of the indicatives obtained to assess the efficiency of the FWS regarding the type of data transmission (GSM/GPRS and GOES/NOAA) carried out by the stations through the application of alerts.

Indicatives for the evaluation of the efficiency of the Flood Alert System	
Correct proportion	79%
Critical Success Index	79%
False alarm	6%
Bias	7.1

3.3 Meteorological Systems

Figure 7 shows the grouping of the total monthly alerts associated with the main meteorological systems observed. The period between December and March has the highest number of alerts issued of the Alert, Maximum Alert, and Overflow stages, which is consistent with the rainy season in the Southeast region.

From the general analysis of monthly distribution, it can be seen that the highest incidence is concentrated almost entirely in summer. They are recurrently associated with the configuration of Cold Fronts and SACZ, as can be seen in Figure 8, with these systems being associated with large volumes of rainfall, a result that corroborates Brasiliense et al. (2018), Lima, Satyamurty and Fernández (2010), and Zilli, Carvalho and Lintner (2019) who cites the association of heavy rains caused in the Southeast region during the summer with the Cold Fronts incursion and a configuration of the SACZ.

In Figure 9, the relationship between the types of alerts issued and the active meteorological systems is also presented. It is observed that the greatest emission of alerts was related to the passage of Cold Fronts, systems that are linked to demanded 37% of the total emitted alerts when compared to other types of meteorological systems. In addition, it is noted that the Alert stage was the most issued amidst the passage of the Cold Fronts, corresponding to 40% of the total alerts involving this type of meteorological system. As for fulfillment with the Operational Protocol, it was observed that the ATE related to the passage of Cold Fronts showed a better performance for the evolution of stages if also compared to other meteorological systems.

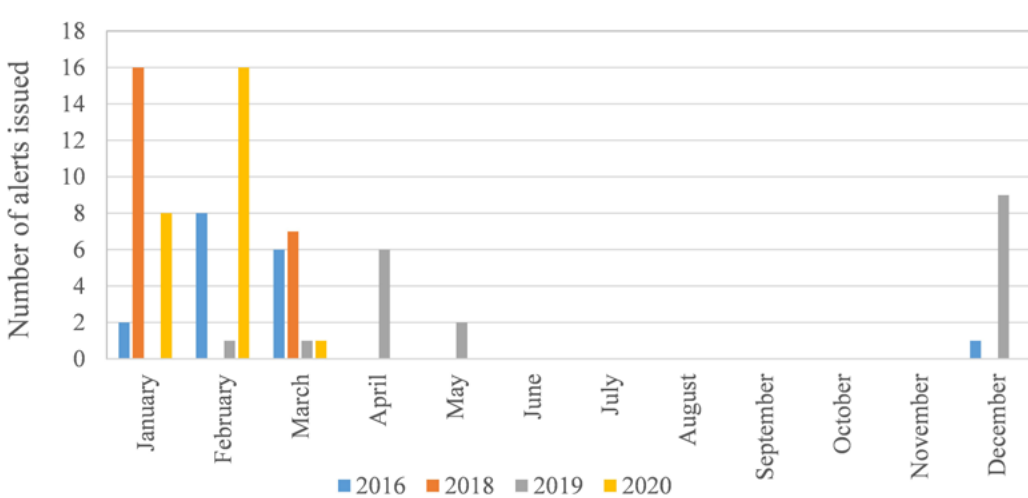

Figure 7 Quantitative number of alerts issued per month for the Médio Paraíba do Sul Hydrographic Region.

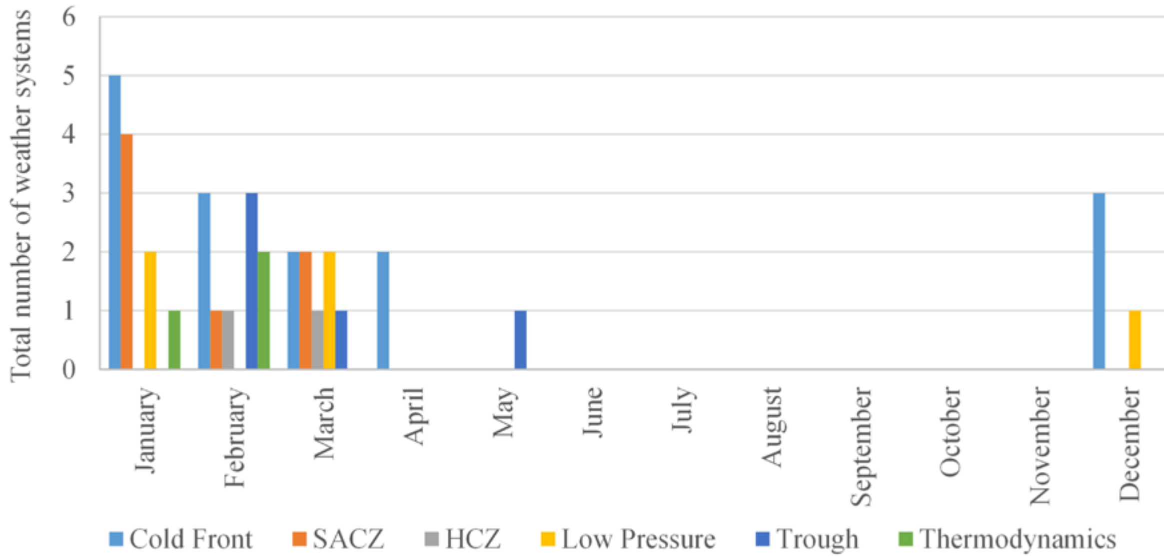

Figure 8 Monthly total of meteorological systems that acted in the state of Rio de Janeiro in the period of alerts issued.

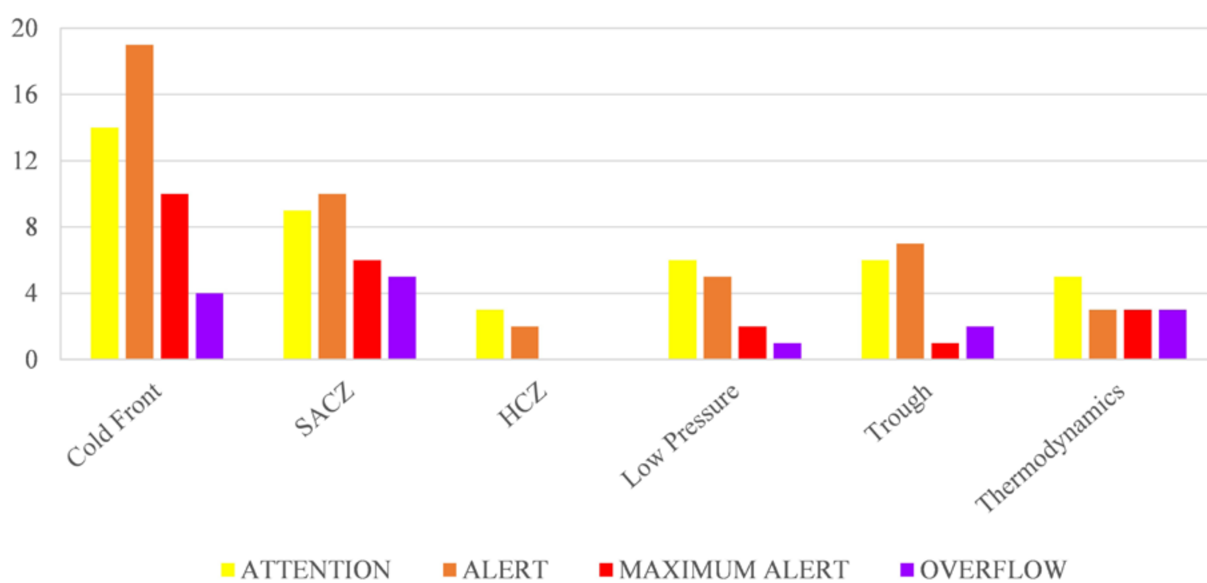

Figure 9 Quantitative alerts issued by type and by meteorological systems for the Hydrographic Region of Médio Paraíba do Sul.

However, in a more careful evaluation, it was found that during the Barra Mansa River overflow ATE, the most active meteorological systems were the South Atlantic Convergence Zones (SACZ) with 36%, followed by Cold Fronts with 29%, 14% for troughs in the upper atmospheric layers and for the thermodynamic effect of daytime heating, and finally, low-pressure systems with 7%. Therefore, it is understood that the meteorological systems that favor the occurrence of continuous and more well-distributed rain have a greater influence on floods in the Barra Mansa River instead on more localized rains.

Obtaining these results contributes to a better characterization of the flood scenario in RH-III, which allows the operational team to better understand the dynamics of interaction between the meteorological systems and the rivers in the region of interest, helping to identify scenarios prone to the occurrence of floods.

3.4 Rainfall Anomaly Index (RAI)

The Rain Anomaly Index (RAI) was also applied to assess the behavior of precipitation in the months in which Alert, Maximum Alert, and Overflow stages were recorded for rivers monitored by the FWS in the Médio Paraíba do Sul Hydrographic Region.

As observed in Figure 10, most months evaluated are classified as rainy, very rainy, or extremely rainy, as the observed value is above the climatological average of precipitation for the region, except for February 2016, January 2018, March, and December 2019 and January 2020. For these months, the anomaly was negative, but it is not of strong intensity, which allows us to understand that, even if the precipitation for these months was below the expected average, it did not alert trigger event it from generating changes in the levels of monitored rivers for RH-III and, consequently, that alerts were issued.

Da Rocha, Silva and Ribeiro (2019) explain that most of Southeastern Brazil is characterized by a tropical climate, which defines rainy summers and dry winters. Therefore, it is a region with high interannual variation in precipitation, with a greater tendency for the occurrence of extreme events between October and March (southern spring and summer). However, anomalous configurations between April and September (southern autumn and winter) can also favor the occurrence of extreme events, which corroborates the results presented in Figure 10, where alerts were issued upon elevation of the level of rivers monitored in RH-III during April and May 2019, months that were considered, through the application of the RAI, as extremely rainy.

According to De Oliveira et al. (2020) and Sanches, Verdum and Fisch (2014), the RAI has become a widely used tool in meteorology and climatology studies, as it allows the qualitative assessment of extreme precipitation anomalies through simple procedures. Applying this index to INEA stations would create a more accurate result, as it could not be carried out for this research because the stations did not present data sufficient.

4 Conclusions

Considering the importance of a better understanding of the dynamics that involve flooding events, this work had as its primary objective to evaluate the efficiency of the FWS from INEA, in the Rio de Janeiro state, particularly for the Médio Paraíba do Sul (RH-III) region.

Regarding the history of alerts om RH-III, results show that the FWS is efficient in fulfilling the Operational Protocol. However, this is only done by disregarding the *Attention stage* since it significantly increases the false alarm rate. It also emphasizes the importance of seeking solutions that tackes the time delay between transmission/ reception of the flooding information and the availability of data on the INEA server, since the itis also a substantial false alarm source.

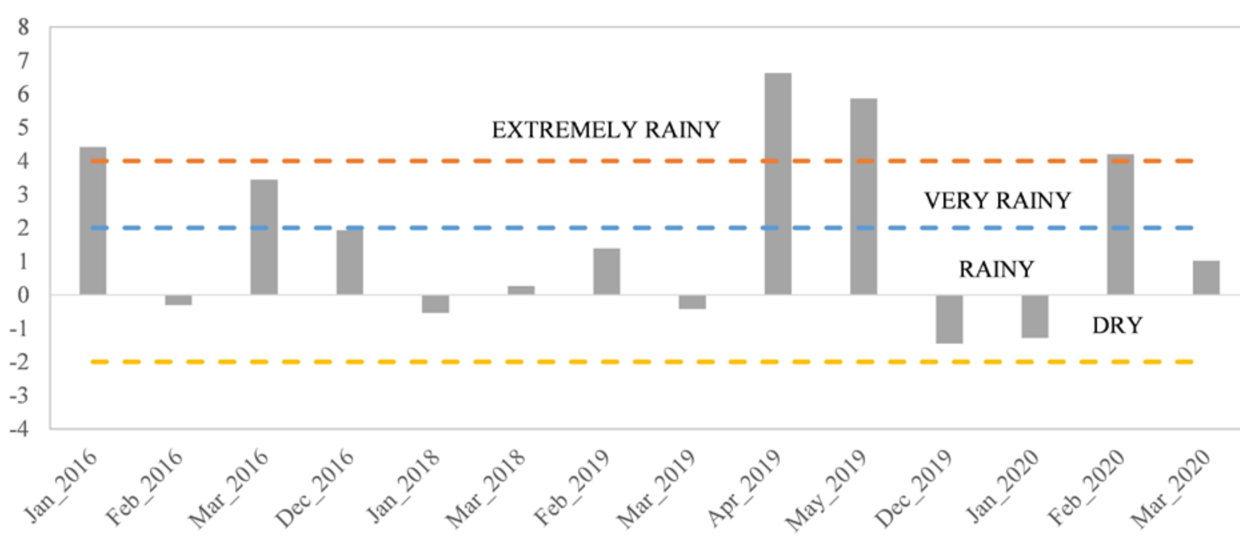

Figure 10 Rain Anomaly Index (RAI) for the Resende station – INMET.

Among the rivers monitored by the FWS at RH-III, only one has registered cases of flooding. It is considered, then, that the absence flooding records on the other monitored river may be associated with the lack of fine-tuning in the overflow river level threshold or even the need to relocate the monitoring stations, as they may be installed in locations that are not suitable for monitoring the RH-III flood scenario. influences.

Concerning meteorological aspects on flooding events in the RH-III, results show that floods were recurrent in episodes of SACZ. However, the Cold Fronts are the ones that most demanded issuing alerts. Also, the results obtained from the application of the RAI indicate that it is not the anomalous precipitation behavior that induces the emission of alerts in RH-III, since, in the dry periods, alerts were also emitted from FWS. From an alert system administration standpoint, meteorological information based on episodes of SACZ and the conclusion taken from RAI index analysis can both be used in training the operational team so that professionals can have a broader perspective on the characterization of pre-flooding conditions in RH-III.

As a final statement, this work highlights that flood alert trigger event policies have a crucial role for the Rio de Janeiro State society and should be carried out and increased by INEA, throughout structural and non-structural initiatives. The FWS is a solid example of a non-structural initiative which will benefit from both, an increase in funding and a continuous update in its methods, guided by science/technological investigations.

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