Multi-disasters took place in the Mampituba River basin, southern Brazil, as a consequence of the passing of two cyclones, in July 2020. The first one was a bomb cyclone that caused several storm winds, damaging the rooftops and overthrow countless trees. The second was an extratropical cyclone that brought extreme precipitation, and triggered storm winds, debris flow, debris flood, woody debris flow, and floods. In the study area, there are two National Parks (Aparados da Serra and Serra Geral). The multi-disasters destroyed a river gauge station used as a part of an early warning system by the National Parks and destroyed partially a marked trail. The most affected municipalities were Praia Grande and Mampituba, where the damages were more related to the storm winds, floods, and debris flood. Furthermore, during the passing of the cyclones, many people were affected, and some of them should be moved to public shelter. Such multi-disasters occurred during the pandemic of COVID-19 in Brazil, which might increase the synergy of the simultaneous occurrence of such extreme events.

Key words: Sediment disaster, bomb cyclone, extreme hydrological events, National Park, Early-warning system, ecotourism

1. INTRODUCTION

As a result of the passing of two cyclones in July 2020, multi-disasters were registered in the Mampituba River basin, southern Brazil. The first event was a bomb cyclone that took place on July 1 and caused a storm wind that damaged rooftops and fell countless trees. One week later, an extratropical cyclone took place on July 7 and 8, and caused extreme rainfall. Because of the extreme rainfall, debris flow, debris flood, woody debris flow, and floods were registered in the basin.

Two municipalities (Praia Grande and Mampituba) were directly affected by the storm winds due to the passing of the bomb cyclone at the first week. Then, the municipalities were also affected by the floods due to the passing of the extratropical cyclone in the following week. Furthermore, the multi-disasters struck the early warning system of the Aparrados da Serra National Park and destroyed partially a marked trail used for ecotourism.

Such multi-disasters took place during the COVID-19 pandemic in Brazil [Simões e Silva et al., 2020], which might intensify the disasters effects, and created a more complex management of disasters in this region.

At the federal level, the Brazilian National Early Warning and Monitoring Center of Natural Disasters (CEMADEN) did not warn about such extreme events because they do not cover these municipalities in the basin. At the state level, the Protection and Civil Defense warned insufficiently a vast area about the occurrences of the bomb and the extratropical cyclones. Because of the COVID-19 pandemic, the capacity of response of the Protection and Civil Defense of Santa Catarina state has been reduced. At the municipal level, the Praia Grande city hall warned about both cyclone events. The warnings had been updated as soon as they were getting additional information.

Because of these occurrences, a team composed of
two groups (Natural Disasters Research Group (GPDEN) of Federal University of Rio Grande do Sul (UFRGS) and Laboratory of Water and Energy (HidroEN) of Federal University of Santa Catarina (UFSC)) worked and conducted field surveys to understand these multi-disasters.

2. STUDY AREA

The Mampituba River basin (1,886 km²) is located at the border between Santa Catarina and Rio Grande do Sul states, southern Brazil (Fig. 1). The region is characterized by the presence of escarpments of the Serra Geral Formation, especially basaltic spills. Headwaters are located on a plateau followed by the escarpments. The hillslopes are extremely steep, presenting a large altimetric amplitude with strong embedded valleys and canyons that open into the flood plain forming deposits of alluvial fans.

These geomorphic characteristics make the basin prone to landslides, debris flows, debris floods and floods. In the regional history, catastrophic events were recorded in 1903, 1911, 1947, 1995, 2007, and 2020. Ronsani [1999] reported that the worst disaster event occurred in 1974 when several municipalities were severely affected, and dozens of people died.

According to the Köppen-Geiger classification, the climate in the portion of the basin located on the plateau is classified as Cfb (temperate oceanic climate), and that in the alluvial fan is classified as Cfa (temperate subtropical climate). There are efforts to promote environmental conservation and ecotourism in the region. Two conservation areas are located in the region: Aparados da Serra National Park – PNAS (10,250 ha) and Serra Geral National Park – PNSG (17,300 ha), which have an ecotourism infrastructure with marked trails and accessible with accredited guides. Also, a local group (Cânions do Sul Geopark) was created to boost the local economy through sustainable ecotourism and geological conservation.

Hence, many domestic and foreign tourists have visited the parks, and ecotourism is the most important economic activity in the region. Such an economic activity increases the importance and the need to carry out the hazard assessment in the study area to guarantee the safety of ecotourism.

3. METEOROLOGICAL DESCRIPTION

3.1 General regime and antecedent drought

The basin presents the four seasons defined with precipitation well distributed along the year. The mean precipitation in the basin during 2016 – 2019 is 1657 mm/year. Figure 2 shows the monthly precipitation regime in the Mampituba River basin, and also the 2020 precipitation. The mean monthly precipitation values were obtained by the arithmetic mean of precipitation during the period 2016 to 2020. Although such arithmetic procedure could increase uncertainty especially in the headwaters areas, the basin’s monitoring system for rainfall data has not been well established yet.

The mean precipitation in the basin is 114 mm in July, meanwhile, the total rainfall in July 2020 was 355 mm. The total amount should be larger because the first extreme event that have triggered the disaster reported here took place partially on June 30. Thus, the total amount of rainfall for July 2020 was more than three times the expected amount.

We performed a calculation of the Antecedent Precipitation Index (API) as an estimation of the basin wetness during the previous days as follows:

\[
API = \sum_{i=1}^{n} \frac{P_i}{t}
\]

where \(P_i\) is the precipitation at \(i\)-antecedent daytime.

The various API values are shown in Table 1, and the daily precipitation in the basin during the period from June 25 to July 16 is shown in Fig. 3.

We consider that the events took place on 1 July, and 7 July, respectively. However, the rainfall for the
second event exceeded the daytime. Thus, we considered the API as the total amount of rainfall during the entire occurrence of such an event.

The API values for both events indicate that the basin area was wetter at the second event than at the first event. By considering both events, the increase of API values from 20 to 30 days does not differ very much. Furthermore, for the first event, the API values from 7 to 30 days do not vary very much. It may indicate that antecedent precipitation from 7 to 20 days may strongly influence the basin wetness.

The total amount of 268 mm is one of the maximum historical precipitation observed in Praia Grande municipality during an event. On the other rain gauges, although the amount of precipitation is high, their registers were not historical ones. It indicates that the rainfall distribution for both events were more concentrated around Praia Grande municipality.

Previously, a prolonged drought was recorded in the basin. From February to June the precipitation was below the average. In some regions of Rio Grande do Sul and Santa Catarina states the drought had been registered since November-2019, including the headwaters of the Mampituba basin. This antecedent drought was the major since 2012, and it is not credited to La Niña [INPE, 2020] which usually causes drought in southern Brazil. It should be noted that the antecedent drought had caused damages to agriculture and even to municipal water supply in the basin.

### 3.2 Bomb cyclone #1

On July 1 a rare cyclone, reported as bomb cyclone (Fig. 4a,b) took place in southern Brazil, reaching three states (Rio Grande do Sul, Santa Catarina, and Paraná). This phenomenon was characterized by a rapidly developing storm in which the atmospheric pressure decreases at least 24 hPa (from 1020 hPa to 996 hPa) in up to 24 hours, which is a quite rare situation [INMET, 2020]. Fig. 4a and Fig. 4b show a cloud formation of the bomb cyclone only in three hours, which is extremely fast and rare. Furthermore, the large coverage area and the location where the bomb cyclone deepened made this phenomenon much rarer. Normally, the bomb cyclones took place over the Atlantic Ocean not on the continent. Such conditions made this bomb cyclone an extreme and destructive event, which caused critical situations in the study basin.

It generated several precipitations (Table 1) and storm winds. The maximum wind speed registered at the GPDEN meteorological gauge was 122 km/h at 4:30 p.m. Local community reported that strongest winds took place between 11:00 p.m. (July 1) to 3:00 a.m. (July 2) in Praia Grande and Mampituba municipalities.

Due to the bomb cyclone #1, several damages were reported in the basin, such as knocked down of countless trees and damages to the roofs.

### 3.3 Extratropical cyclone #2

One week after the bomb cyclone #1, on July 7, an extratropical cyclone (Fig. 4c) took place in the basin. It was supposed to be weaker than the previous

| Rain Gauge | API1 | API2 | API15 | API20 |
|------------|------|------|-------|-------|
| GPDEN      | 52.2 | 63.4 | 64.1  | 65.6  |
| P. Grande  | 90.6 | 104.6| 105.1 | 109.5 |
| Sombrio    | 50.8 | 59.5 | 59.9  | 63.1  |

Table 1 Antecedent Precipitation Index (API) in the Mampituba basin for two events

Fig.3 Daily precipitation in the basin area: 25 June – 16 July 2020

Fig.4 Cyclones: a) and b) rapid formation of the bomb cyclone (Source: GOES-East/ABI, NASA); c) extratropical cyclone (Source: GOES 16, CPTEC/INPE)
cyclone in terms of storm winds (winds between 60 to 80 km/h). However, the GPDEN meteorological gauge recorded the maximum wind speed of 122 km/h, same as the bomb cyclone #1, at 6:50 p.m. Such condition did not persist for many hours like the previous bomb cyclone.

The extratropical cyclone brought extreme precipitation in the basin. Analogously to the bomb cyclone, the extratropical cyclone is characterized by a reduction on atmospheric pressure. Such a reduction is not too fast as the bomb cyclone. Due to this extreme precipitation, debris flow, debris flood, woody debris flow, and flood were recorded in the basin.

Considering that the extratropical cyclones can directly influence the weather conditions and can cause several impacts to society, it is essential to improve the knowledge about these events, in order to enable managers to better mitigate their damages [Jantsch and Aquino, 2020].

4. FIELD SURVEY

Field survey was conducted for 5 days in July and August 2020. It consisted of two main activities: interviews with the affected communities, and on-site observations. Two groups composed by researchers from two universities (UFRGS and UFSC) visited the damaged area in the basin to evaluate its extension. The on-site observations allowed identifying distinct disasters in different portions of the damaged area.

We mapped the extension of the flood, and identified places where debris flow, debris flood, and woody debris flow took place in the basin.

On July 31 and August 1, we conducted semi-structured interviews and applied questionnaires to 38 families in Praia Grande and Mampituba municipalities whose estimated populations are totally 7,312 and 2,990, respectively. Among the interviewees, the major part was composed by women, and 40+ years old (91.5%).

According to the community communication, the first bomb-cyclone caused more damage in the infrastructure in comparison with the second one. The inhabitants commented that the first bomb-cyclone had caused strong winds, and consequently, damage to the roof differentiating only the proportion of the damages. On the other hand, they reported a flood during the occurrence of the second extratropical-cyclone. Furthermore, the damages caused by the floods were more serious in Praia Grande than in Mampituba. There was no report of flooding in cities located downstream.

The inhabitants also reported that the electricity supply was interrupted for two days due to the passing of the first bomb-cyclone, and for a few hours during the flood. The population also reported a fear that new extreme events will occur causing larger material and emotional damages.

During the field survey, we identified 15 points of flooding and other 17 points of damages in the alluvial portion of the basin.

5. DISASTER SITUATIONS

Several damages were registered in the Mampituba River basin, especially in the upper portion of the basin, due to the occurrence of multi-disasters in July 2020. The highlighted disasters were antecedent draught, storm winds, debris flow, debris flood, woody debris flow, and floods. Here, we present the disaster situations chronologically, and from upstream to downstream. The summary of registered damages from different phenomena can be seen in Fig. 5.

5.1 Storm Winds

Though the storm winds reached the whole part of the basin, damages were not registered on the plateau site. However, storm winds (up to 110 km/h) caused several damages to rooftops on the alluvial fan regions. Furthermore, they fell countless trees (native forest trees, and banana agriculture). In Mampituba municipality, 80% of the banana agriculture and 10% of passion fruit agriculture were totally destroyed. Some of the native trees were delivered into river-channels that compound the river basin during the first bomb cyclone. Lately, they were transported by the floods, triggering a woody debris flow and floating wood in the basin (Fig. 6).

5.2 Debris flow

The passing of the second cyclone caused extreme precipitation that triggered debris flow in the Boi River (Fig. 7). Although historical debris flow occurrences in the basin were associated to landslides, no landslide was recorded at this time. It can be, therefore, thought that this debris flow took place with remobilization of bed material, based on the evidences observed in field, i.e., the features of sediment deposition in the upper and lower reaches of the Boi River: large (Fig. 7a) and angulated (Fig. 7b) sediments deposited on top of the sedimentation layer, and the presence of fine sediments as interstitial sheet. Fig. 7a shows transported large boulders with ~1.70m of diameter deposited on top of the sedimentation layer. The mean gradient in this region is 0.015 n/m.

5.3 Debris flood

The extreme precipitation due to the second cyclone also caused a debris flood in the Boi River. We walked along marked trails and evaluated the damages in the Aparados da Serra National Park. The Boi River trail
(Fig. 8) consists in an 8-km length crossing the river several times, and sometimes walking inside the river course.

The large amount of transported sediment drastically changed the river course and partially destroyed the marked trail (Boi River trail). The second extreme event also destroyed a river gauge station (Fig. 9) located at the beginning of this trail. This cross section and the station had been used by the national park since 2014 as the basis for an early warning system to keep tourists safe during the trail. In 2018 the cross section was equipped with a level sensor, recording the water level every 10 minutes. After this event, a geomorphic change was clearly observed in the river (Fig. 10). The gradient along the river of Fig. 10 is 0.010 m/m.

The alterations in the geomorphic conditions have created an expressive gravel bar that makes it impossible to measure discharge at the same cross section as before. In case of normal floods, the river gauge station would not be destroyed. In this way, it is extremely important for the National Park to establish another methodology to manage the safety of the trail with new data as early as possible, by a new simple equation.
In the Malacara River, another river gauge station was destroyed by the occurrence of debris flood. The Malacara River is an important affluent of the Mampituba River and has contributed for the flooding registered in the basin. Although the river gauge station was severely damaged, the sensor was recovered. Installation of future gauge station should be at the same place, and it will be conducted by HidroEN/UFSC.

5.4 Woody debris flow

Countless trees were disposed on rivers and then transported by the water (Fig. 11). Woody debris flows were registered in different portions of the basin, however, it was more pronounced in the Boi River.

According to local people, the first bomb cyclone fell down a lot of trees. Then the potential floating woods were disposed along and near river channels. Therefore, the second cyclone generated woody debris more easily. It implies that the second cyclone could not generate a lot of woody debris without the first one (storm disaster). Thus, the occurrence of multiple events might be essential for such woody debris conditions.

5.5 Floods

The passing of the bomb cyclone on July 1 did not cause floods in the basin rivers. However, the passing of the extratropical cyclone on July 7 seriously damaged the municipalities of Praia Grande and Mampituba in the upper portion of the basin in relation to floods. The water level for two fluviometric...
stations during the flood on July 7 is shown in Fig. 5.

In Praia Grande, two affluents of the Mampituba River caused floods in the downtown area, and some neighborhoods became isolated (Pintada, Rio do Boi, Alto da Esperança, Mãe dos Homens, Aparecida, São Roque, and Vila Rosa communities). The most affected neighborhood was the 1° de Maio district (Fig. 12b), located about 2 km downstream from the downtown of Praia Grande. In downtown area, a fluviometric station (Fig. 12a), and a public balneary (Fig. 12c) were partially destroyed by the floods and the sediment transport. According to the Municipal Protection and Civil Defense, 80 houses were flooded, and 70 people were evacuated.

6. DISASTER MANAGEMENT AND RESPONSE

6.1 Federal level

Despite natural disasters, especially hydrological disasters, occurred on the basin scale, the Brazilian disaster management is performed on a municipal scale with support from State and Federal Governments [Brasil, 2012].

Currently, the Brazilian National Early Warning and Monitoring Center of Natural Disasters – CEMADEN is responsible for monitoring and early warning only in 17.2% of the total Brazilian municipalities [CEMADEN, 2020]. In the study basin, just three municipalities were covered by the CEMADEN. However, the most damaged municipality, Praia Grande, has not been included into the CEMADEN’s supporting areas yet.

Both the parks PNAS and PNSG usually inform operational conditions and warnings in its social media (Twitter: @PNAS_PNSG; and Facebook: (facebook.com/parquenacional_aparadosdasera)) : weather, trail’s operation, and restrictions due to COVID-19 pandemic. In these social media about meteorological hazards, the bomb-cyclone was informed on June 28 and 29. On the following days low temperature and frost were reported without disaster notifications nor closed trails. Also, the National Parks kept the access to visitors with restrictions conditions of visitor’s number.

On July 8, social media informed the closure of the operations in the Cotovelo trail (plateau area) due to the overflow of the Perdizes river. By the following days, some photographs and videos showed rain and flood resulting in interdicted roads and closed trails (Cotovelo and Boi River trails). On July 19, visitors were warned about geomorphic changes in the Boi River trail due to sediment transport.

6.2 State Governments level

The Protection and Civil Defense of Santa Catarina state performs hydrometeorological monitoring for its state. They are responsible for warning the Municipal Protection and Civil Defense, underpinning humanitarian logistics, and promoting conditions for the reconstruction of the involved municipalities. However, the conditions of response by the Protection and Civil Defense of Santa Catarina had been negatively affected by the pandemic of COVID-19, and a reduction in the response capacity was observed [Santa Catarina, 2020].
The State Protection and Civil Defense of Santa Catarina released warnings before the passing of the two cyclones. On June 30, they warned winds from moderate to strong, between 50 to 70 km/h for a large area in the southern state. On July 6, they warned the formation of a new cyclone with less intensity.

6.3 Municipal level (City halls, Protection and Civil Defense, and Public Health)

Praia Grande city hall warned the occurrence of meteorological disaster (strong winds) on July 1, and hydrological disaster (flash flood) on July 8 in the Integrated System on Disasters Information - S2ID. Although the bomb cyclone developed on July 1, on June 30 the city had already been suffering from strong winds that damaged houses.

The city hall recorded that 68% of the population (7,312 inhabitants) was affected by these disasters. The wind disaster on July 1 made 118 homeless people, of whom 13 people required the public shelter. Meanwhile, the flash flood resulted of the extreme rainfalls on July 7 left 70 homeless people, among which 10 families required the public shelter.

The population affected by the hydrological disaster was rescued by the city hall staff, including the Civil Defense and the Firefighters. Persons who were evacuated during the flood event communicated that the shelter was clean and that they received masks and alcohol gel. However, it was not observed the good protection against the closed space, crowded place, and close scenes. Some people refused to go to the public shelter because of the anxiety and fear of the pandemic situation and looked for relative's houses. Multi-disasters are not common in Brazil, and the pandemic is the first experience for the Protection and Civil Defense at all the levels (federal, state, and municipal). It is, therefore, very important to register the occurrences for the prevention.

7. SUMMARY

As a result of the passing of two cyclones on July 1 and July 7, multi-disasters were registered in the Mampituba River basin, southern Brazil. The reported disasters were storm winds, debris flow, debris flood, woody debris flow, and floods.

Thus, we reported here the results of the surveys performed by the GPDEN/UFRGS and HidroEN/UFSC in partnership with the Aparados da Serra National Park Office and Praia Grande city hall. The occurrence of multi-disasters during the pandemic of COVID-19 may have negative effects of such disasters, because the situation of the pandemic in southern Brazil was still not under control.

The official and surveyed data present some divergences, especially concerning the number of affected people, and the number of people who required the public shelter. This difficulty is inherent to the complexity of disaster management, especially during the occurrence of multi-disasters.

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