Unusual rainfall intensity and total amount causing more than 200 deaths in Petrópolis City, Rio de Janeiro State, Brazil, in February 2022.

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On the afternoon of February 15th, 2022, heavy rainfall triggered shallow landslides, debris flows and flash floods in Petrópolis City (22° 30' 17" S and 43° 10' 56" W) which is located in mountain region of Rio de Janeiro State, Brazil. The incident resulted in 234 deaths, 3 missing persons, 994 homeless people and an economic loss of about US$ 133 million (considering only the direct damage to companies). The population, area and mean elevation of this city are 306,678 in 2020, 795.798 km^2, and 838 m, respectively. According to METSUL (2022), the Civil Defense of Petrópolis City Hall reported that there were 325 incidents in 24 hours, including 269 landslides. Figure 1 shows one of shallow landslides occurrences in the city.

Figure 1 – Shallow landslide in Petrópolis City in February 2022 (Source: METSUL, 2022).

The intensity of the rain that fell in a very small region of the city was 230 mm in just three hours and the maximum intensity was recorded of 199.2 mm/h at the Alto da Serra rain gauge in the city. These values are extremely rare in the region. The total amount of rainfall in 24 hours was 259 mm which is the highest record in Petrópolis since the beginning of measurements in 1932. In fact, this amount occurred in 6 hours. This extremely-heavy rainfall was caused by the combination of heat and humidity, which favored the development of nuclei in atmospheric instability areas in Petrópolis. In this city, the previous rainfall record in 24 hours was 168.2 mm that occurred in 1952, and the average monthly rainfall in February is 240 mm.

In order to collect information for supporting decision making, the Geological Survey of Brazil (*Serviço Geológico do Brasil* – CPRM) sent a specialized technical team during the period February 17th to March 2nd. By carrying out the field survey and also using other available data such as airplane and DRONE photos and old hazard maps of mass movements and floods, the team analyzed and identified hazard areas in the city. Finally, the team presented a synthesis report with 11 technical reports as supplement materials (Modesto et al., 2022). Each of these 11 technical reports corresponds to a severely-affected neighborhood or street. Some photos presented in these reports are shown in Figure 2.

Figure 2 – Several localities of hydrological disasters in Petrópolis, Rio de Janeiro, Brazil (Sources: Modesto et al., 2022)

The social element associated to residents' vulnerability and exposure further intensified this tragedy. At the moment of a certain survey performed in 2012, Petrópolis City had 500 hazard areas. The evolution of the number of hazard areas and exposed people has been greatly intensified due to the large population growth as well as the lack of territorial control in the city. Therefore, in 2022, the numbers of hazard areas and highly-vulnerable population could be much higher. Such population growth results from the fact that Petrópolis belongs to the Metropolitan region of Rio de Janeiro and has many tourist spots.

Most of all places where disasters occurred are located at the foot of the steep hillslopes (Figure 1) and characterized with precarious land-occupations. There is no good infrastructure in these places, where, without projects approved by the city hall, residents have been carrying out self-constructions. This actual situation makes the areas even more fragile. Such a land-occupation's style can be considered typical both in Brazil and in Petropolis and is becoming common more and more. In other words, these areas have turned into shantytowns (or slums), i.e., 'favelaizations' (Müller, 2017). Thus, hazard areas have been occupied by a poor population with no other choice.

Furthermore, as a part of the metropolitan region, Petrópolis has been exercising typical (or conventional) urbanization without adequate land-planning. In this city, there is a strong tendency to reduce river channel width for construction of roads and buildings, which certainly reduce river's transport capacity. Vegetation areas have been also decreasing. Urbanized areas without planning should seek for ecosystem services and/or ruralization proposed by Kobiyama et al. (2021).

According to Xavier (2022), the administrative movement for regularization of residences demonstrated the seriousness' lack in the housing policies of the city hall. In 2017, the Municipal Risk Reduction Plan had already indicated that more than 28,000 houses were in high or very high hazard areas which represented one third of the total area of the city at that time.

Thus, inappropriate (and sometimes illegal) land-occupation of vulnerable population and inefficient land-management of public institutions have been increasing social vulnerability and population exposure, consequently increasing risk of residents. In this sense, Daré (2022) presented common opinions of several experts of Geosciences Institute of State University of Campinas (*Universidade Estadual de Campinas* – UNICAMP). Their opinions are that excessive rainfall should not be considered the sole cause of the tragedy in Petrópolis and that the tragedy in Petrópolis was not a natural disaster. Social factor should be always considered a key in disaster risk management.

The society itself which may be the principal social factor consists of local habitants and public institution such as city hall as well as scientists and so on. Hence, it is worth discussing actions of scientists especially meteorologists. The Brazilian Center for Monitoring and Early Warnings of Natural Disasters (*Centro Nacional de Monitoramento e Alertas de Desastres Naturais* – CEMADEN) warned about rain in Petrópolis by sending a "very intense weather event" alert to Petrópolis City two days before the tragedy, but without informing the probable rainfall intensity. Responding to an interview, the director of CEMADEN said that people need to fully understand that the CEMADEN informed the weather scenario and that it was impossible to predict how much it would rain. He emphasized that the natural disaster alert had been issued two days in advance by CEMADEN. According to him, Brazil has improved weather monitoring system very well; however, there has been no progress in prevention work (forecasting system).

One meteorologist of the CEMADEN explained that there had been practically no displacement of the clouds. In this case, the rain appeared on top of Petrópolis and remained there practically until it dissipated. In case of this phenomenon, the monitoring equipment and system were very inefficient. Besides, in the world there is no meteorological model capable to predict this type of natural phenomenon even now. In summary, he commented that there were no models, methodologies and tools that could predict this very large amount of rain in a very small space in a very short time, and concluded that it was not a failure of Brazilian meteorology.

Even though his comment "it was not a failure of Brazilian meteorology" can be true, I surely think that Brazilian science and technology related to hydrometeorology could have reduced the magnitude of this tragedy. In my opinion, weather monitoring system is not satisfactory in Brazil even now, especially in mountain regions. Based on the fact that water-related and sediment-related disasters have been intensified in mountain regions in Brazil (Kobiyama et al., 2019), it is exactly the moment to improve more the weather monitoring system in this country. In case that immense difficulty in predicting rainfall in mountain regions results from the poor investment for monitoring system, rainfall-induced disasters in Brazil might become social disasters indeed.

As Daré (2022) criticized the public policies in the city by mentioning frequent occurrences of tragedy, Petrópolis is well-known as a city frequently suffering from hydrological disasters. In the mountain region of Rio de Janeiro State, on January 11th, 2011, intense rainfall (281.6 mm in eight hours in Nova Friburgo) caused a historic tragedy, where 947 deaths, nearly 300 disappearances, more than 50 thousand homeless, affecting nearly 1 million people were reported (Dourado et al., 2012). Petrópolis was one of three most damaged cities in this tragedy. Table 1 shows the history of hydrological disasters with the number of victims recorded by the Civil Defense of Petrópolis during the period 1966 to February 2022.

Table 1 – Number of human deaths of hydrological disasters in Petrópolis during the period from 1966 to 2022 February.

Year	**Death**	**Year**	**Death**	**Year**	**Death**
1966	80	2003	17	2013	34
1977	11	2007	3	2016	2
1979	87	2008	9	2017	1
1988	171	2009	6	2018	4
1997	6	2010	1	2021	1
2001	51	2011	73	2022	234

Pinto and Iory (2022) demonstrated that Petrópolis City Hall invested US$ 26,000 in Civil Defense in 2020. This amount is just 0.009% of the municipal revenue of US$ 298 million in 2020. In 2021, the City Hall cut spending on Civil Defense, investing only US$ 18,000, which is only 0.007% of the revenue of US$ 250 million in 2021. Though this investment reduction may be serious concern for Petrópolis City residents, various actions in disaster risk reduction (DRR) can be performed with low cost. In risk and disaster management, there is the principle where education is the key to DRR. In the case of a city with economic problems such as Petrópolis, it is necessary to return to this principle and enhance education for DRR.

According to Silva et al. (2021) which reported the “Civil Defense Program in School” executed by Santa Catarina State government, Brazil, it is not easy to carry out a insertion of civil defense activities to primary and secondary schools. However, since education is the principle and does not demand high-cost investment, Petrópolis city residents together with their city hall must implement several educational activities for DRR.

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