

Groundwater Flooding due to Tropical Cyclone Cempaka in Ngreneng Karst Window, Gunungsewu Karst Area, Indonesia

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Abstract. Tropical Cyclone Cempaka occurred on November 27, 2017 in the Indian Ocean, just south of Central Java. This incident induced high rainfall leading to flash floods in the southern part of Central Java, including Gunungsewu Karst Area. The highest rainfall recorded on November 28, 2017, in this area was 239 mm/day (Automatic Rainfall Recorder/ARR Station in Pindul Cave) and 341 mm/day (ARR Station in Tepus). The extreme rainfall also caused groundwater flood in Ngreneng Karst Window. This study aimed to analyze the mechanism of this flood. The results of the analysis showed that it was caused by water filling up the conduit passage in the entire Bribin-Baron underground river system. The flow of the conduit pushed the diffuse flow into the surface fast, and the water that came out of Ngreneng Karst Window was thereby clear. The inundation lasted for ten days and submerged up to 26.4 ha of the study area.

Keywords: Tropical Cyclone Cempaka; Groundwater Flooding; Ngreneng Karst Window; Gunungsewu Karst Area.

1 Background

The occurrence of Tropical Cyclone Cempaka in the Indian Ocean, south of Java Island, from late November to early December has left a destructive impact and, at the same time, a valuable lesson for the development of karst hydrology and disaster management. Rarely flooded areas, or rather, drought-affected regions were hit by unprecedented floods that were hydrologically and geomorphologically unique. Lacking preparedness of such events, the people living in these locations had to suffer an enormous impact. They had no prior experience neither expect floods to occur in the areas they had occupied for a long time.

On November 27, 2017, at 07.00 pm, the Indonesian Meteorology, Climatology, and Geophysics Agency identified a tropical low moving from 100 km southeast of Cilacap City, Central Java Province. It intensified to Tropical Cyclone Cempaka and traveled at approximately 65 km/h, causing disasters like landslides, floods, uprooted trees, and hurricanes. Cempaka damaged houses, health and education facilities, offices,

and houses of worship. It affected 122 houses in the Special Region of Yogyakarta: 86 houses were lightly damaged, 21 moderately damaged, and 15 heavily damaged. It also caused the deaths of 19 people in the Special Region and Central Java Province (2 people in Wonogiri Regency and 1 person in Wonosobo Regency) and East Java Province (11 people in Pacitan Regency). The impact of Cempaka in the Special Region of Yogyakarta is presented in detail in Table 1.

Cempaka has opened the public's eyes to the potential of flood disasters even in drought-prone regions [1], such as Gunungsewu Karst Area [2-4]. Therefore, thorough documentation and review regarding the mechanism of these flood occurrences become necessary. This study aimed to analyze the mechanism of groundwater flood at Ngreneng Karst Window, part of the vast area of Gunungsewu (Fig. 1). The flood disaster in this location caused a commotion and raised questions among the community because it formed a temporary lake on a doline.

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Table 1. The Impact of Tropical Cyclone Cempaka in the Special Region of Yogyakarta

Regency/City	Uprooted Trees	Floods	Landslides	Casualties
Yogyakarta	1 location	14 locations	10 locations	3
Kulonprogo	6 locations	61 locations	28 locations	1
Gunungkidul	44 locations	51 locations	26 locations	1
Bantul	57 locations	46 locations	76 locations	0
Sleman	27 locations	20 locations	26 locations	0
Total	135 locations	151 locations	146 locations	5

Source: Operation Control Center, Regional Disaster Management Agency of the Special Region of Yogyakarta (Pusdalops BPBD DIY); Regional Disaster Management Agency (BPDB) of Gunungkidul Regency; Field Survey

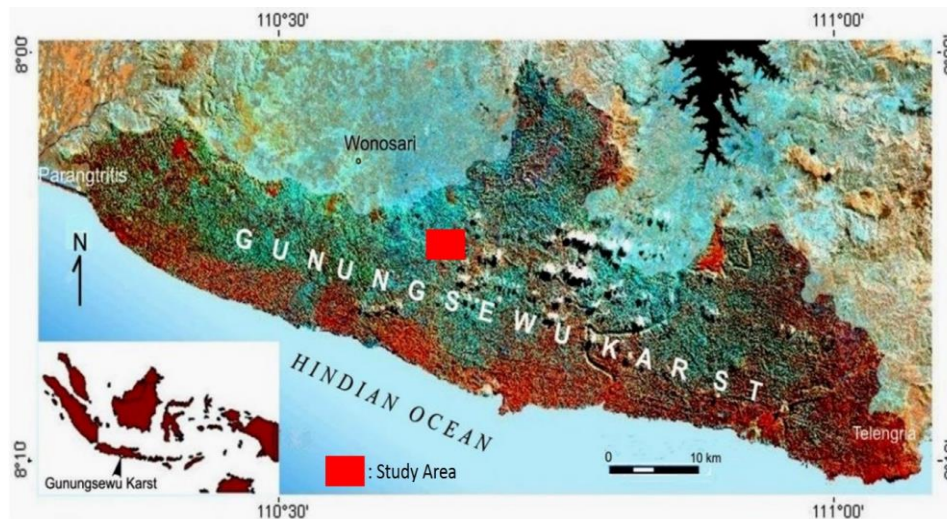


Fig. 1. Map of the Location of Ngreneng Karst Window in Gunungsewu Karst Area

2 Methodology

The discussion in this study covers the characteristics of rainfall, the area and duration of inundation, catchment area, event chronology, and the analysis of groundwater flood mechanism at Ngreneng Karst Window. The rainfall data were obtained from the research station (Automatic Rainfall Recorder/ARR) organized by a karst study group located in Pindul Cave, Karangmojo District, Gunungkidul Regency and Station Tepus (ARR) belonging to the Meteorology, Climatology, and Geophysics Agency (BMKG). The area of inundation was defined by analyzing the aerial photograph of the study area taken with an uncrewed aircraft, while the duration was obtained from observation in the field. As for the condition of the catchment area, it was analyzed from the results of previous studies at the same location and field survey. The analysis results were then synthesized to understand the mechanism of groundwater flooding in the study area.

3 Result and Discussion

The rainfall analysis presented that on November 28, 2017, the study area received high precipitation. The ARR stations in Pindul Cave and Tepus recorded 239 mm/day and 341 mm/day rainfall, respectively. The records at the Climatology Station in Yogyakarta

(BMKG) also showed that the rainfall in the entire Gunungsewu Karst Area on this day was more than 100 mm/day and the highest rainfall was 341 mm/day. At these rates, this event can be categorized as very heavy (>100 mm/day; based on BMKG’s rainfall classification) or extreme (>50 mm/day; BNPB’s classification). Moreover, in Tepus, the mean precipitation is only 200 mm/month and reaches its peaks, i.e., up to 400 mm/month, in January and December (Sudarmadji et.al, 2012). Also, it is not higher than 251 mm/month in November. In other words, the rainfall on November 28, 2017, is equal to one-month precipitation.

Analyzing the aerial photograph taken with an unmanned aerial vehicle (UAV) (Figure 2) and the results of the field survey (Figure 3), the research found that the maximum inundation area due to groundwater flooding at Ngreneng Karst Window was 26.4 ha (Figure 2). The inundation followed the topography of the closed basin or doline. The most extensive flooding occurred on November 29, 2017, which receded ten days later on December 7, 2017.

Judging from the hydrogeological system, Ngreneng Karst Window is part of Bribin-Baron, the largest and widest underground river system in Gunungsewu Karst Area. The subsidence of bedrock beneath the limestone, which is currently visible on the surface, makes the underground river flow in this system become centralized and emerge as a spring on Baron Beach [5,6] Ngreneng Karst Window is a leak in Bribin

Underground River (Figure 4) [7]. The water flow in this cave is highly related to Bribin's river flow. The latest research conducted by Sidauruk et al. (2018) [8] claims that the underground river flow in Ngrengeng Karst Window also receives supply from Seropan Underground River.

As seen from the geomorphological features, Ngrengeng Cave is a "karst window". The karst window (Figure 5) is a natural form in karst region developed from the collapse of underground rivers, exposing part of the underground river to the surface at the base of karst valley (doline). Some experts call it *estavelle*, which is a term derived from Dinarik Karst in Europe [9]. However, some of the features do not meet the conditions of an *estavelle*. *Estavelle* is characterized by an intermittent spring—which periodically ceases to flow—due to changes in the water table (the dominance of diffuse/intergranular flow) and, at a certain time, it functions as a sinkhole [10]. These properties do not accurately represent Ngrengeng even though this cave also acts as water drainage (sinkhole). Ngrengeng has continuous flow all the year and is dominated by underground river flow (conduit).



Fig. 2. The Oblique Aerial Photograph in the Study Area (Photo by HENDY FATCHUROHMAN)



Fig. 3. The Groundwater Flood Footprint in Ngrengeng Karst Window (Photo by AHMAD CAHYADI)

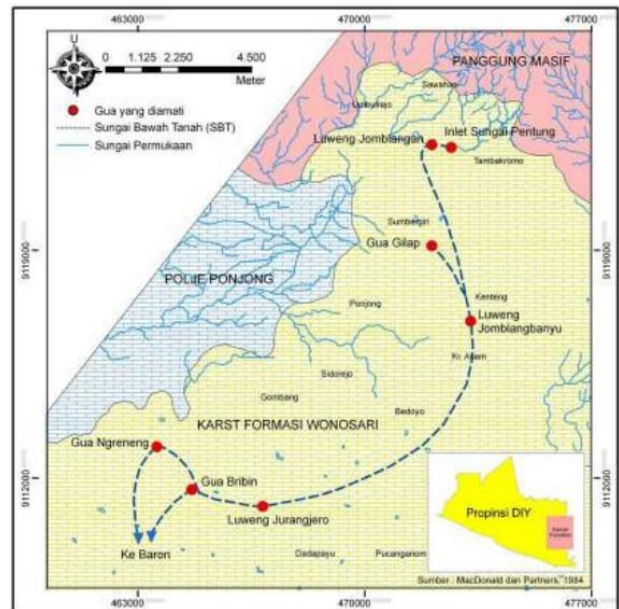


Fig. 4. Ngrengeng Cave as the Leak in Bribin Underground River [11]

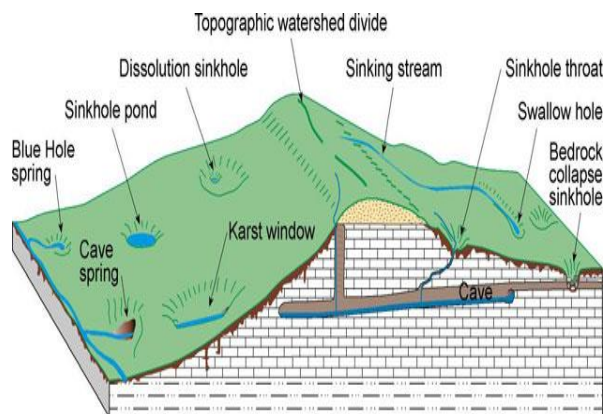


Fig. 5. The Scheme of the Landscape Overview in Karst Area

The main cause of overflow in Ngrengeng Cave was the large volume of water transported by the underground river. The flow exceeded the small drainage capacity of the underground river in Ngrengeng Karst Window (Fig. 6). A large amount of Cempaka-induced rainfall significantly increased the volume of water that had to be transported or drained by Bribin Underground River. The manager of Bribin Dam affirmed this condition. Normally, the water level at the dam was 36 m, but on November 28, 2017, it rose to 64 m. Therefore, the water pump machine at Bribin Underground River II or Sindon had to be turned off. The water input was greater than the distribution capacity of the underground river passage, causing water to rise through the karst window and then recede after a certain period. A simple scheme of this mechanism is presented in Fig. 7.

The groundwater flooding in Ngrengeng Karst Window was unique because the overflow was clear or not murky. This condition is different from the flooding in Kalisuci Cave and Sumurup Cave (Figure 8). There are at least two reasons that can explain this uniqueness. First, it is attributable to the main recharge that flows

into Ngreneng Cave and, second, the diffuse flow dominates the drainage mechanism.

In karst hydrology, the recharge of groundwater or underground river is broadly divided into two, namely allogenic and autogenic. Allogenic recharge originates from non-karst regions and enters through surface rivers that flow into underground rivers as sinking streams [12], such as Kalisuci Sinking Stream and Sumurup Cave. Kalisuci Sinking Stream, for example, is an outlet of Jirak River that flows from Ponjong District and some regions in Semanu District [12-14]. Water that flows on the surface is murky because it mixes with eroded soils [15]. Different conditions occur if the water recharge is autogenic, i.e., rainwater seeping through cracks in karst areas and gravitationally descending into an underground river [16-18]. The filtering process by the soil, cracks, and rock cavities purifies the water that enters the underground river [7]. Although Ngreneng Karst Window has both autogenic and allogenic systems [12], the discharge capacity of its diffuse flow is considerably large [10]. Consequently, clear diffuse discharge is dominant, which was the same case as the large autogenic recharge at November 30, 2017. The allogenic flow pushed the diffuse flow that had already filled the underground river passage during the flood. In other words, the water rising to the surface and inundating the base of karst basin was diffuse flow. It was also evidenced by the color change that began to occur after four days. The allogenic flow entered later and made the water inundating Ngreneng Karst Window murky.



Fig. 6. The Small Drainage Tunnel of Ngreneng Cave (Photo was taken in the dry season of 2011, by Ahmad Cahyadi)

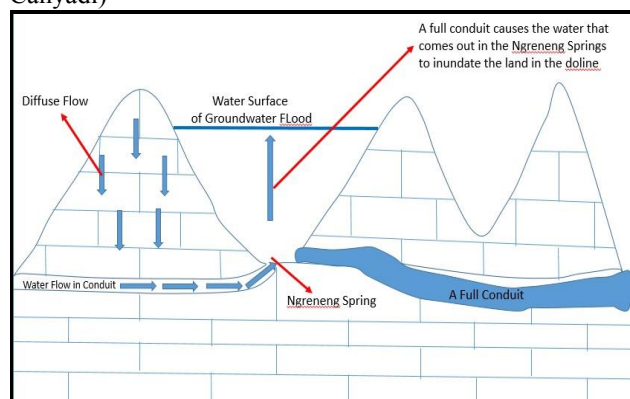


Fig. 7. The Mechanism of Flooding in Ngreneng Cave

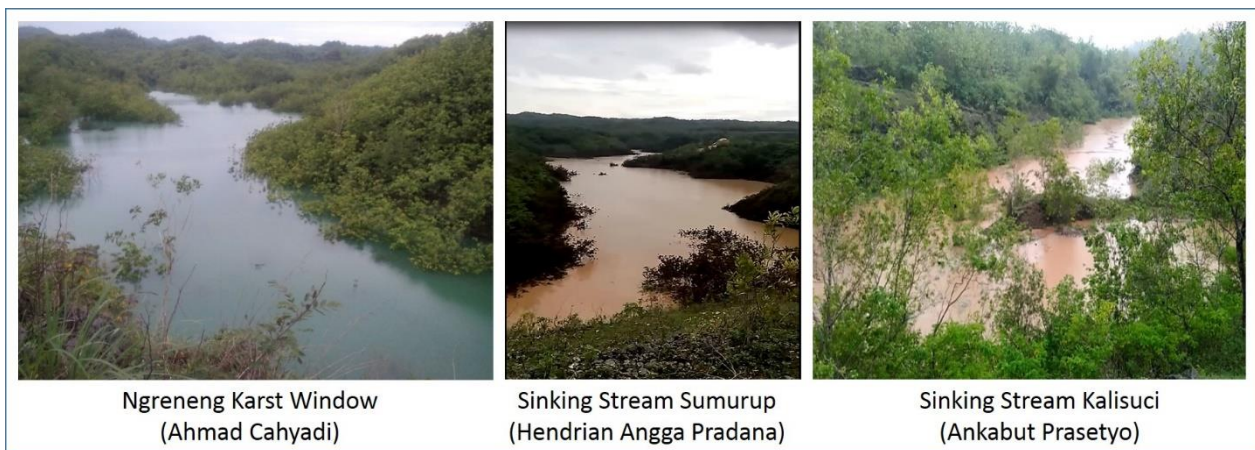


Fig. 8. The Differences between the Indundations around Ngreneng Cave, Sumurup Cave, and Kalisuci Cave

4 Conclusion

The results showed that during the groundwater flood in Ngreneng Karst Window, the rainfall continuously occurred for three days. The inundation began on November 28, 2017. On this day, the ARR stations in Pindul Cave and Tepus recorded 239 mm/day and 341 mm/day precipitation, respectively. The catchment area of Ngreneng Karst Window is the Upper Bribin Watershed that is supplied by allogeneic flow from outside Gunungsewu Karst Area. The inundation lasted

for ten days over a maximum area of 26.4 ha. The groundwater flood in Ngreneng Karst Window occurred because the water flowing through the conduit tunnels exceeded the distribution capacity. As a result, the water rose through the karst window and created a lake on the doline. The diffuse flow that filled the tunnels first rose into the surface. Therefore, the lake water was initially clear. However, after three days, the water from the conduit channels started to emerge and made the lake water murky.

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