Allogenic River in the Hydrogeological System of Gremeng Cave, Gunungsewu Karst Area, Java Island, Indonesia

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Abstract. Allogenic rivers play a pivotal role in the development of the karst area. Their open system creates aggressive conditions that cause more intensive rock dissolution and, therefore, possibly form a primary underground river system in a hydrogeological regime. This study aimed to inventory allogenic rivers in the hydrogeological system of Gremeng Cave. This study also investigates Gremeng Cave typology based on underlying geological conditions by analyzing Indonesian topographic and geologic maps and high-resolution remote sensing imagery. In this study, a detailed geological survey was conducted to determine factors triggering the formation of allogenic rivers at the research site based on geological and geomorphological characteristics. The results showed at least five allogenic river subsystems uniting into one primary system. Allogenic from underlying beds exposed updip was the type of the allogenic rivers emerging exactly at the contact between tertiary volcanic rocks and limestones at the Gunungsewu karst area.

1. Introduction
Karst area is known as a landscape that often experiences drought. On the other hand, it is also frequently used as water reservoirs by nearly a quarter of the world population [1]. These conditions are mostly caused by the growth of solution conduits that shape a subterranean river system [2], triggering contrast situations, i.e., dry on the Earth surface but with abundant water on the subsurface [3].

Groundwater recharge at karst area generally originates in two types of recharge, namely allogenic and autogenic recharge [4, 5, 6]. Allogenic means that the groundwater recharge at a karst area coming from a non-karst area. It is from a surface river outside a karst area that flows into subterranean river systems through ponor. Meanwhile, autogenic is the groundwater recharge coming from within the karst area itself. Rain falling on karst regions flows into underground river systems by infiltration and percolation and through karst joints and solution conduits.

Understanding the characteristics of an allogenic river is significantly essential in that this river plays a crucial role in supplying karst groundwater [7, 8, 9, 10, 11, 12, 13]. It also has an open system that allows carbon dioxide from the air to dissolve in it during its flow on the surface. Therefore, an allogenic recharge is more aggressive than its autogenic counterpart in dissolving limestones [14, 15, 16]. This
condition enables allogenic recharge to significantly contribute to the development of primary subterranean river system at the karst area [17]. Another urgency of allogenic river system management is related to the high pollution vulnerability of allogenic recharge [18] since the water flows in an open system and an underground river without any filtering process either by soil or rock pores. This study was designed to inventory allogenic rivers in the hydrogeological system of Gremeng Cave. One of the crucial springs in Gunungkidul Regency [19, 20, 21] (figure 1). Besides, it also aimed to analyze their typology based on underlying geological conditions. The results of this study are expected to provide inputs to the management of the karst area at the research site in general and of the hydrogeological system of Gremeng Cave in particular.

2. Methods
The inventory of allogenic rivers was performed on a detailed scale by examining the Indonesian topographic maps (1:25,000) and high-resolution GeoEye satellite imagery. The interpretation results were further validated by comprehensive field survey. The typology of allogenic rivers was analyzed based on geological and geomorphological conditions to determine their genesis. It was also classified according to Ford and Williams's classification (2007) [1] into (1) allogenic from overlying beds, (2) allogenic from underlying beds exposed updip, and (3) across a faulted contact with impervious rocks.

3. Results and Discussion
The results of the interpretation and field survey showed that the hydrogeological system of Gremeng Cave contained five allogenic rivers, namely Garuda, Grembel, Seropan, Kalimati, and Sumurup River, which shape one first river flowing into Gremeng Cave. On Indonesian topographic maps and GeoEye satellite imagery, each of them appears as an interrupted river that is not connected to other streams. The allogenic rivers, ponor, and resurgence in the hydrogeological system of Gremeng Cave are presented in figure 2.

Figure 1. Map of study area
The flow characteristics of the identified allogenic rivers varied. Sumurup flows throughout the year, whereas the other four rivers only flow during rainy seasons (figure 3). Nevertheless, their discharge during the rainy season was somewhat significant due to their extensive catchment area. Moreover, the upstream characteristics that are composed of old volcanic materials, primarily andesitic-basaltic rocks, lead to poor water-storing capability; consequently, rainfalls transform into surface runoff only during the rainy season.

The occurrence of allogenic rivers at the research site is inseparable from the genesis of the area. The limestone formation is situated on the tertiary volcanic formation, which is dominated by andesitic-basaltic rocks formed during the late Miocene [23, 24, 25]. Volcanoes producing these materials include Panggung Masif Ancient Volcano, Wuryantoro Ancient Volcano, and Wonodadi Ancient Volcano [26]. Part of these ancient volcanoes remains visible in the northern part of the Gunungsewu karst area, forming the Panggung Masif Physiography [27].

The contact between limestone and volcanic formations, for instance, is visible in figure 4. Figure 4 was taken at Garuda, i.e., a ponor in the northern part of the hydrogeological system of Gremeng Cave. At this site, limestone appears to overlie the volcanic materials, i.e., sandstone. The development of the cave passage at this site was identified as having the same dip as the rock slope in the contact zone.

Based on the land use in the watersheds of the identified allogenic rivers, pollution potentially occurs due to waste generated by domestic and agricultural activities [28]. Owing to the dominance of farming activities in the study area, they will most likely be the primary cause of pollution in the future.
general, the agricultural land was multiple-species plantation (figure 5) and rain-fed rice fields. The excessive use of fertilizers and pesticides in agricultural activities can contaminate the water flowing into the underground river in the hydrogeological system of Gremeng Cave.

Figure 3. Kalimati Allogenic River during the dry season (left) and the rainy season (right)

Figure 4. The limestone-sandstone contact near the ponor, that is, the outlet of Garuda River.
4. Conclusion
This study has inventoried five allogenic river subsystems, which unite into one primary allogenic river system in the hydrogeological regime of Gremeng Cave. They are Garuda, Grembel, Seropan, Kalimati, and Sumurup Rivers. Allogenic from underlying beds exposed updip is the type of the allogenic river emerging at the exact point of contact between the tertiary volcanic rocks (Wuryantoro Ancient Volcano, Panggung Masif Volcano, and Wonodadi Volcano) and limestone at the Gunungsewu karst area.

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