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Anuran communities in the dry karst ecosystem of Central Java, Indonesia

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Abstract. *Febriyono M, Nayasilana IN, Masyithoh G. 2023. Anuran communities in the dry karst ecosystem of Central Java, Indonesia. Biodiversitas 24: 6484-6492.* Dry physical conditions characterize karst ecosystems. This affects the distribution of the Anura-amphibian that depend on water sources. The presence of anurans in an ecosystem can be used as an environmental bioindicator. In this study, we used a visual encounter survey to document and provide information on the presence of anurans in Pucung village, Wonogiri District, Central Java, Indonesia, to provide information for the sustainable management of this karst ecosystem. The study was conducted from January to March 2023. Observations were made at two sites--Gundi Hamlet and Dunggudel Hamlet--and covered each of the different land covers found in the region. Then, anuran species diversity was analyzed using an index calculated using Barbour diversity analysis and the Shannon-Wiener diversity index (H'), species richness index, species dominance index, and species evenness index. Environmental parameters were investigated using canonical correspondence analysis. We found eight species belonging to five families. The Rice Field Frog (*Fejervarya cancrivora*) was the most abundant species, with 95 individuals. The least common species was Asian Toad (*Duttaphrynus melanostictus)* with two individuals. The H' values ranged from 1.21 to 1.58. The highest diversity value was found in the community forest habitat. A comparison of the values for the environmental factors, including climate (air temperature and humidity) and water pH in the three habitat types studied, showed low significance, meaning that the three habitat types were suitable for the presence of anurans. Based on the observations and environmental factors, we determined that the karst ecosystem in Pucung village could support a diversity of anuran species.

Keywords: Amphibians, climate, diversity, groundwater, Pucung village

INTRODUCTION

Amphibians are an important component of ecosystems, although their presence receives little attention (Wake and Koo 2018). Amphibians are divided into three classes-the Gymnophiona, Caudata, and Anura (Jayson 2020). The Anura is a group of tailless amphibians, including frogs and toads that are species-rich and regionally widely distributed (Liedtke et al. 2022). They are also diverse in morphology, physiology, and ecology. Amphibian habitats are mostly terrestrial, but some are closely tied to water or wet microhabitats for reproduction. Most amphibians require moisture to survive, but some species have adapted to exist in extreme habitats (Vitt and Caldwell 2014). The Anura are widely distributed in various habitats, including forests, rivers, rice fields, highlands, and human settlements (Shahrudin 2021). The type of habitat strongly influences the presence of anurans in a habitat. Forest trees are not only inhabited by tree frogs, but also by terrestrial frogs that hide between tree branches or in holes in deadwood. Rice fields are also a habitat for anurans, including rice field frogs and grass frogs, which tend to dominate those frog communities (Kusrini 2020). According to Weiss et al. (2021), most anurans forage and move around on land, although their reproductive success is highly dependent on the presence of water; for example, arboreal anurans fertilize and store their eggs in vegetation near water, while fossorial anurans store their eggs in water-filled holes in wood, soil, and rock.

Anurans play an important role in ecosystems' food chains, being both the prey and predator of pests and insects that harm humans (Battaglin et al. 2016). Amphibians, especially anurans, can also be used as environmental bioindicators. According to Pérez-Iglesias et al. (2021), anurans can be used as indicators to monitor environmental health due to their morphological and physiological uniqueness. They are highly sensitive to environmental changes due to their evolutionary story, which includes having highly permeable skin (Ruthsatz et al. 2018). Anurans need to live in the presence of water to keep their skin moist (Widiana et al. 2023), and because the development of anuran tadpoles often requires the puddles or ponds that appear during the rainy season in forests, gardens, and wetlands (Arifin et al. 2018). According to Hilmi et al. (2020), water sources are one of the primary factors that influence the presence of anurans in any location.

Karst ecosystems host groundwater sources, biodiversity, and various cultural resources that provide important ecosystem functions (Goldscheider et al. 2020). In Indonesia, these ecosystems can be quite extensive; for example, the karstic area on the island of Java covers up to 5,000 km^2 and is spread across the northern and southern mountains (Rahmadi et al. 2018). Wonogiri District in Central Java is included in this area, forming part of the Gunung Sewu karst, which extends from Gunung Kidul District in the west to Pacitan District in the east (Soedwiwahjono and

Pamardhi-Utomo 2020). The Gunung Sewu karst area is one of Indonesia's most unique karst areas, as evidenced by its designation as a World Natural Heritage Site by the Asia Pacific Forum on Karst Ecosystems and World Heritage. One part of this system that needs to be managed is its groundwater (Ridwan et al. 2020). According to Li et al. (2021), karst ecosystems have low environmental carrying capacity because the karst is constantly changing due to karstification. Karst ecosystems can exhibit dry and arid conditions (Retnowati et al. 2014), even though, below the surface, there are potential water sources, including springs (Yuan et al. 2017). According to Sigit et al. (2015), karst has the potential to be a disaster-prone environment characterized by periodic drought (5-9 months) that results in water shortages for plants, animals, and humans. These environmental conditions may affect the presence of anurans because they are water-dependent. In this study, we aimed to determine the presence of anurans in the Wonogiri karst ecosystem to provide information for its sustainable management.

MATERIALS AND METHODS

Study area

This study was conducted from January to March 2023 in Pucung Village in the Eromoko District of the Wonogiri District. The Pucung village area lies within the karst landscape. Land use in this area is dominated by dryland agriculture, characterized by plantings of cassava, corn, and rice (Sigit et al. 2015). Observations were conducted at two locations, Gundi Hamlet and Dunggudel Hamlet (Figure 1). Each location contained three habitat types, community forest, agricultural land, and river.

Research procedure

The data was collected using the visual encounter survey method, involving transects and identification. This is an effective way to quickly record the amphibian species encountered while surveying various habitat types (Dodd 2009). The data collected during observation included the species names, number of species, number of individuals per species, snout-vent length (svl), spatial coordinates, vertical position of each anuran relative to the ground, and horizontal location of each anuran from the riverbank and observation path in each habitat type (Rumanta et al. 2019). Samples of several anuran species were also collected. These were preserved by anesthetizing them using a syringe needle and 70% alcohol, which was injected into the back of the head until it entered the brain. Following anesthesia, the anuran is properly positioned so as not to be easily damaged. After properly positioning the specimen is usually preserved in 70% alcohol. This was done so that the specimens were not exposed to decay from bacteria that could enter and live inside the specimens (Jamdar 2021). Measurements were taken of environmental parameters, including air temperature, air humidity, pH of water, canopy density, and altitude, using equipment such as a thermohygrometer, pH meter, and GPS. According to Caldas et al. (2019), environmental factors in a region that affect anura, such as rainfall, humidity, and temperature, are mainly related to the duration of water bodies. Therefore, when depreciated, these characteristics contribute to the loss of puddles, as the presence of water is an important factor for anuran.

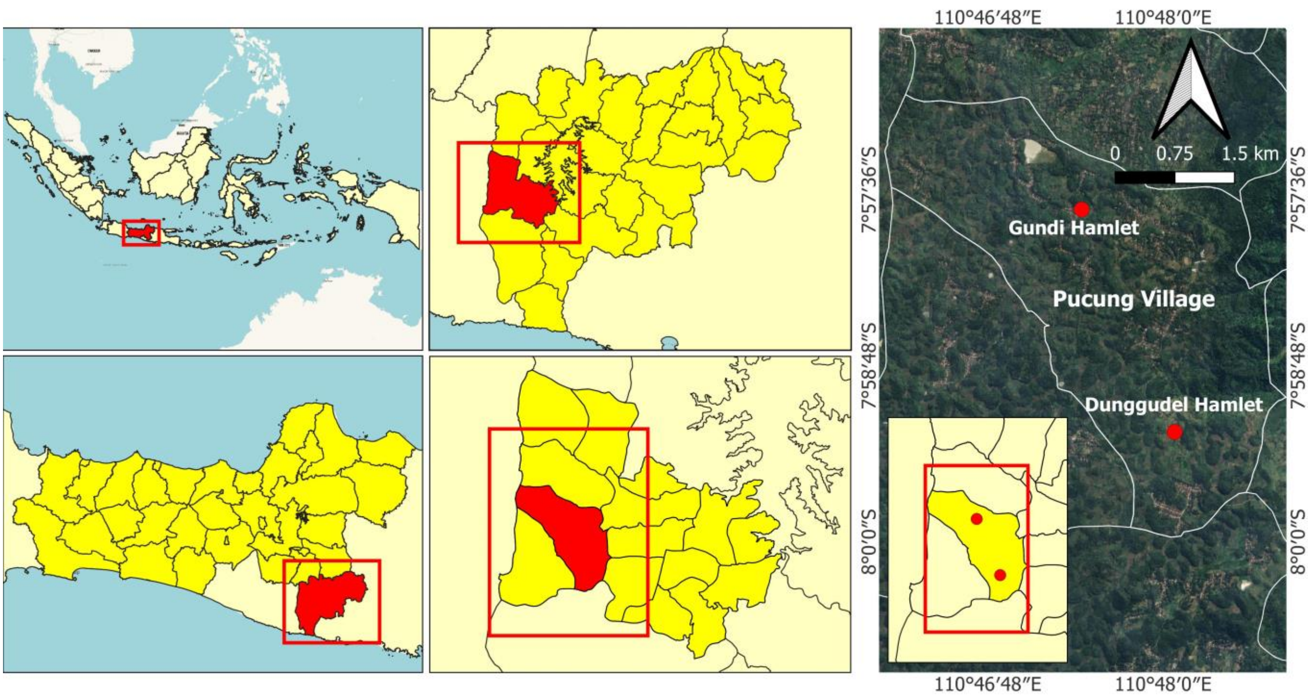

Figure 1. Map showing the studied locations in Pucung village, Eromoko, Wonogiri, Central Java, Indonesia

Observations were made along three transects in each hamlet with three observers, each covering a length of 500 m and a left and right sweep of 10 m. The sampling was conducted between 20:00 and 23:00, with three repetitions over three days for each transect. The anuran data were collected by exploring the entire observation area and directly capturing the anurans by hand to calculate the size of the svl and body weight of the anuran. After data collection, anurans were released back to their habitat. Those that were difficult to catch were photographed using a camera from a certain distance. This was done so as not to damage the nest or habitat of the anurans. The identification process was done with previous reference (Kusrini 2013; Alhadi et al. 2021).

Data analysis

Using the observed data, we calculated the species diversity (Barbour Diversity Index and Shannon-Wiener Index), species richness (Margalef Index), species dominance (Simpson Index), and species evenness (Pielou Evenness Index) with the help of Past4Project software (Zakaria et al. 2022), were used to compare the species compositions within the different habitat types. The environmental data were analyzed using Canonical Correspondence Analysis (CCA) to determine which factors influenced the presence of each anuran species. In addition, environmental factors such as air temperature, air humidity, pH of water, canopy density, and altitude were included as explanatory variables in CCA.

RESULTS AND DISCUSSION

Anurans were successfully found in all the study locations. They consisted of several species belonging to five families-the Bufonidae (one species), the Dicroglossidae (three species), the Microhylidae (two species), the Ranidae (one species), and the Rhacophoridae (one species), as indicated in Table 1. Based on data in Table 1 showed that the average number of individuals during the three repetitions at the three collection sites in Pucung Village were 232 individuals, of which 122 were found on agricultural land, 81 in the river habitat, and 29 in the community forest.

Fejervarya cancrivora (Figure 2) was the most common species in all three habitat types, but it mostly preferred agricultural land (Table 1). Rice fields provide the ideal vegetation for amphibians to hide in, as well as diverse insects for food (Narayana et al. 2014). According to Wiradana et al. (2021), *F. cancrivora* is abundant in rice fields because of the standing water, where it can reproduce quite well, although it is not uncommon to find it in other habitats, such as primary forests or on the banks of quiet-flowing rivers (Iskandar 1998; Kusrini 2013).

The least common species (two individuals) encountered was *Duttaphrynus melanostictus* (Figure 2). This species was only found in the community forest and river habitats, each hosting one individual, likely because *D. melanostictus* prefers open spaces, including in villages and cities. Our records are consistent with the statement by Licata et al. (2020) that Asian toads are mainly terrestrial and generalist and have strong invasive potential due to their tolerance of disturbed environments. This species is known to tolerate human habitats and to spread widely in various regions (Moore et al. 2015), and often be found far from water, sometimes gathering in stagnant water or sluggish waters during the breeding season (Widiana et al. 2021; Licata et al. 2023).

Anuran species diversity, richness, dominance, and evenness

The species diversity calculated based on Barbour et al. (1999) showed that the community forest habitat had a similar diversity to the agricultural land habitat, with six species common to both and one species only found in each habitat (Table 2). The community forest habitat had a similar diversity to the river habitat, with six species common to both and one species only found in the community forest habitat, with no species only found in the river habitat. The agricultural land habitat had five species in common with the river habitat: two species found on agricultural land and not in the river habitat, and one species only found in the river habitat and not on the agricultural land (Table 2). Several factors, such as differences in land cover, the presence of water and food sources, and the presence of predators, influenced these results. In general, species choose and occupy a niche that fulfills their life needs, even though that may mean sharing the same habitat with other species (Carscadden et al. 2020).

The Shanon-Wiener Diversity Index value for Pucung village was 1.42, which is obtained from the combined total of the three habitat types. This supports the value Yudha et al. (2019) determined, who calculated the diversity in the karst areas of the Paliyan Wildlife Sanctuary, Gunung Kidul, to be 1.43. According to Baihaqi et al. (2022), environmental pressures and change influence diversity in the population structure and the number of species.

The highest diversity value was obtained from the community forest habitat (1.58), as shown in Figure 3, and the lowest was from the agricultural land habitat (1.21). According to Oda et al. (2017), more anuran species are found where there is a high level of vegetation heterogeneity, while Kusrini et al. (2020) found that the lowest anuran diversity occurs in agricultural land habitats where there is a high level of human disturbance, such as land conversion. Changes in land use and a reduction in the amount of land covered by vegetation affect the microclimate, such as temperature and humidity, which can lead to differences in species compositions between ecosystems (Muslim 2017). According to Brüning et al. (2018), habitats with diverse vegetation are more likely to conserve and maintain amphibian diversity, although not all species respond equally to a particular land-use system. Rather, each land-use type supports a specific set of species that make up the overall biodiversity of a region. Rohman et al. (2020) found that ecosystem conditions and other organisms typically influence community structure and the distribution of amphibian species.

Table 1. List of anuran species found and their habitats

Family	Species	Habitat type			Total
		CF	AL	R	
Bufonidae	Asian toad (*Duttaphrynus melanostictus*)	1	-	1	2
Dicroglossidae	Rice field frog (*Fejervarya cancrivora*)	11	54	30	95
	Grass frog (*Fejervarya limnocharis*)	8	49	27	84
	Sumatran puddle frog (*Occidozyga sumatrana*)	-	11	-	11
Microhylidae	Flower pot toad (*Kaloula baleata*)	3	2	2	7
	Javan chorus frog (*Microhyla achatina*)	1	2	-	3
Ranidae	White-lipped frog (*Chalcorana calconata*)	1	1	5	7
Rhacophoridae	Striped tree frog (*Polypedates leucomystax*)	4	3	16	23
	Total	29	122	81	232

Note: CF: community forest; AL: agricultural land; R: river

Table 2. Species diversity for each plot based on Barbour's analysis

Plot	Species per habitat	Agricultural land		River	
		Found	Not found	Found	Not found
Community forest	Found	6	1	6	1
	Not found	1	0	0	0
Agricultural land	Found	-	-	5	2
	Not found	-	-	1	0

Figure 2. Asian toad (*Duttaphrynus melanostictus*) (*left*) and rice field frog (*Fejervarya cancrivora*) (*right*). Source: Author's images

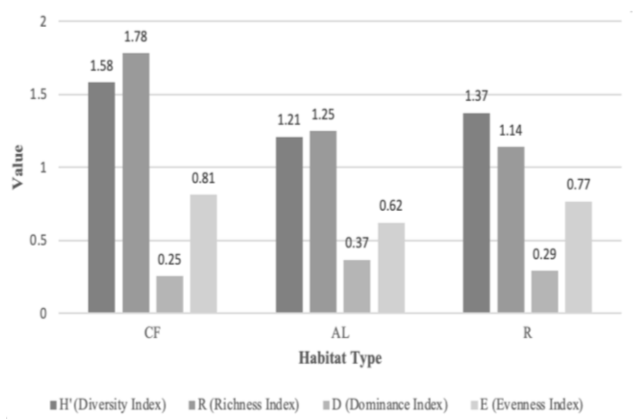

Figure 3. Comparison between the diversity, richness, dominance, and evenness of the anuran species in each habitat type in Pucung village

The Margalef Index value for Pucung village was 1.29. The community forest habitat had the highest species richness value among the habitat types, at 1.78 (Figure 3). This is consistent with Thomé et al. (2021), who found that species richness was higher in habitats with more diverse vegetation. According to Boissinot et al. (2019), species richness is positively influenced by vegetation cover and water sources, which provide benefits in terms of reproduction and protection from predators. Structured vegetation can also provide moist microhabitats that minimize physiological conflicts between water loss and thermoregulation (Forget-Klein and Green 2021).

The species richness values likely differed for each habitat type because of differences in human activity in the habitats, such as agriculture and motorized vehicle lanes, which affect which anurans can survive. Rahman et al. (2022) found that several anuran species had low adaptability to high human activity. Intensive human activities especially affect amphibian groups by geographically restricting them (Bolochio et al. 2020).

The species dominance values from the Simpson's index, presented in Figure 3, showed that the highest dominance was from the agricultural land habitat (0.37), then the river habitat (0.29), and then the community forest habitat (0.25). The higher the dominance index value, the greater the tendency for a species to dominate in a habitat. The lower the dominance index value, the more evenly distributed the abundance of each species is and the higher the evenness and diversity index of the area (Sulistyani et al. 2014).

The species evenness index calculated for each habitat type showed that the community forest habitat had the highest value and the agricultural land habitat had the lowest, as shown in Figure 3. The higher value for the community forest was because it had a relatively equal number of individuals per species. In contrast, one species dominated the agricultural land (*F. cancrivora* at 54 individuals). According to Drayer and Richter (2016), a dominant species in a habitat will result in a low species evenness index. Several factors can cause a low species evenness index, including competition for using existing resources in a habitat (Kurniawan et al. 2018).

Environmental physical and chemical parameters

The physical and chemical environmental factors measured were air temperature, humidity, water pH, habitat distance from the river, canopy density, and altitude. The measurements were made simultaneously with collecting the anuran species data per observation plot. The study area was located at an altitude of 500-600 masl, with an average air temperature of 22-24°C, as shown in Table 3. Pucung village is in a karst area dominated by limestone, so the obtained water pH measurements were alkaline, ranging from 7.8 to 8.3. According to the study of Sunar et al. (2022), a pH range of 6.5-8.5 more conducive to the survival or growth of tadpoles at their research site, whereas according to Feldman et al. (2023) water with low pH negatively affect on anurans (in this study using species Wood Frogs (*Lithobates sylvaticus*), Mink Frogs (*Lithobates septentrionalis*), and Spring Peepers (*Pseudacris crucifer*).

The air temperatures were similar for the three habitat types, all at the optimal values for amphibians; Vasanthi et al. (2020) remarked that amphibians require ectothermic conditions with a stable ambient temperature from 20°C to 30°C. Air temperature significantly impacts amphibian development and growth and often regulates behavioral and reproductive cycles (Widiana et al. 2021). The air humidity at the study site was very high, ranging from 96% to 98% because the study was conducted during the rainy season; hence, the air had a high water vapor content (Fadholi 2013). According to Rumanta et al. (2019), rainfall, humidity, and temperature affect the reproductive cycle of anurans, and any change in the abiotic factors of an environment can disrupt their life cycle.

Figure 4 shows the CCA analysis results as a scatter plot. *Duttaphrynus melanostictus* and *Kaloula baleata* preferred the community forest habitat, while *Chalcorana chalconota* and *Polypedates leucomystax* preferred the river habitat. These four species were supported by the relatively high elevation, canopy density, air humidity, lower air temperature, and water pH. The community forest and river habitats had relatively higher humidity due to the closed tree canopy, affecting temperature, humidity, and sunlight intensity (Rostikawati et al. 2022). The presence of a river can also affect the presence of anurans in a habitat because amphibians must have access to aquatic habitats, which help amphibians avoid water loss from their bodies due to the high ambient temperatures during the day and keep their bodies moist (Iskandar 1998; Burrow and Maerz 2022).

The agricultural land habitat was preferred by *F. cancrivora*, *Fejervarya limnocharis*, and *Occidozyga sumatrana*. These three species were supported by the relatively high air temperature and water pH. The higher air temperatures for the agricultural land were caused by the lack of vegetation cover, according to Pangkey et al. (2022), with sunlight able to penetrate directly to the soil surface. The high pH of the water was due to the use of pesticides by the farmers, albeit not very significant. The inappropriate use of pesticides can cause a decrease in water quality (Lawniczak et al. 2016; Babini et al. 2018). Ali et al. (2018) determined that an excessive use of pesticides affects the presence of amphibians because the chemicals directly affect the insect population, which is the main food source for amphibians. However, in the study of Wei et al. (2021), pesticides' effect on the growth of species *F. limnocharis* tadpoles was less than the survival of tadpoles in nature. The growth index under pesticide treatment was always lower than the control treatment. *Microhyla achatina* has the ability to adapt to changing environmental conditions, allowing it to survive in disturbed areas (Fathoni et al. 2022); this was identified in Figure 4, where it plots in the space of environmental factors in the medium category.

Physical and chemical environmental factors directly affect the presence of anurans in a habitat because they require moist conditions to maintain their body temperature. The abiotic factors measured at the study locations are not the only ones that influence the abundance of a species. Species abundance is also affected by food sources, natural predator relationships, interspecific competition, and forest degradation (Sredl and Collins 1992; Hocking and Babbitt 2014). According to Zhu et al. (2020), the presence of amphibian species is largely determined by the biotic and abiotic conditions of their microhabitats, which determine the species composition in each habitat.

Ecological distribution

The ecological distributions of each anuran species were described by the locations of the anurans found at the encounter sites, as shown in Table 4, with the vertical position relating to distance from the ground and the horizontal position from the river or observation trail. According to Johana et al. (2016), understanding the distribution of anurans and their preferred habitat types is important because, if there are changes in those habitats and anuran behavior due to human intervention, which species are the most vulnerable can be predicted. Based on

Table 4, we found that the number of anurans was highest near the water. These results are consistent with those of Supsup et al. (2022), who determined that anuran species richness near water is much higher than in locations without water.

Duttaphrynus melanostictus was found at the edge of the forest, above ground level, and some distance from water. This is consistent with other studies. It has mostly been found on land, although breeding occurs in aquatic locations, ponds and other water bodies, also around slow-flowing rivers (McClelland et al. 2015). According to Mo (2017), ecologically, *D. melanostictus* can be found in most lowland habitats below 1,800 masl, including disturbed forests, agricultural land, and urban areas.

Fejervarya cancrivora, *F. limnocharis*, and *O. sumatrana* are anurans in the Dicroglossidae commonly found in rice fields. *Fejervarya limnocharis* and *F. cancrivora* have similar habitat preferences--watery and muddy rice fields near human settlements. According to Susanti and Sumarmin (2020), these two species are found more frequently in rice fields and plantations than in residential areas because rice fields and plantations have relatively lower temperatures. *Fejervarya cancrivora* can also adapt to brackish water (Kusrini 2013). *Occidozyga sumatrana* is usually found near water sources, including ponds (Hilmi et al. 2020).

Table 3. Physical and chemical environmental conditions per habitat type

Habitat type	Alt. (m)	Air temp. (°C)	Air humidity (%)	pH of water
Community forest	600	23.4	98	7.8
Agricultural land	500	22.3	96.2	8.3
River	536	24.1	97.6	8.1

Table 4. General location of each species when encountered

Species	Horizontal position	Vertical position
Fejervarya cancrivora	Near puddles and 1-3 m from riverbanks	On soil, grass, rocks, litter, and underwater
Fejervarya limnocharis	Near puddles and 1-4 m from riverbanks	On soil, grass, rocks, litter, and underwater
Occidozyga sumatrana	Puddles	Underwater
Kaloula baleata	Around puddles and tree trunks	On the ground and tree trunks (±1 m above ground level)
Microhyla achatina	Around puddles with grass edges	On the grass
Duttaphrynus melanostictus	Near settlements and at forest edges	On dry soil and rocks
Chalcorana calconota	Near puddles and riverbanks	On top of tree leaves and branches, stones
Polypedates leucomystax	By the river	On top of tree leaves and branches

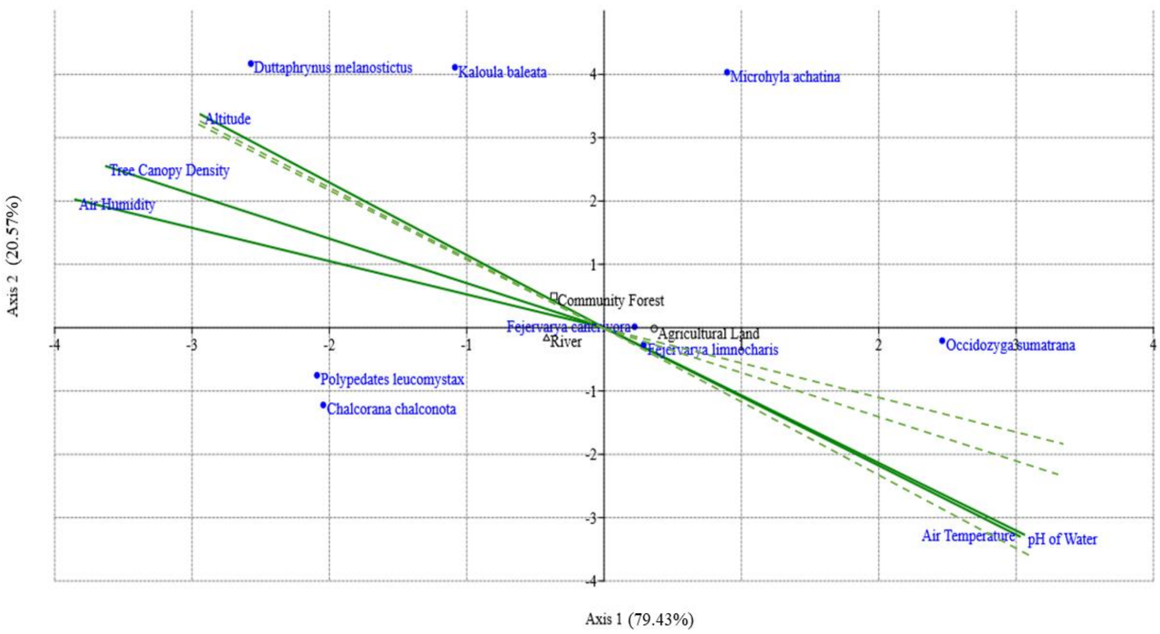

Figure 4. Graph showing the results of the CCA analysis

Kaloula baleata and *M. achatina* belong to the Microhylidae, a family characterized by small body size. *Kaloula baleata* prefers holes in trees and rock crevices, while *M. achatina* was found around shrubs and litter in this study, although it was quite difficult to find due to its very small size. This supports the statement by Kusrini (2013) that *M. achatina* is usually found around ponds or lakes with grass and standing water. *Chalcorana chalconota* is a semi-aquatic anuran, so it was found in vegetation near water sources at the study site. According to Kusrini (2020), this anuran is usually found on rocky substrates and in vegetation along small streams in forests, highlands, and ponds. Adult anurans are usually widespread in forests and can even be found in plantation areas.

Polypedates leucomystax was also found around shrubs and grasses near water sources. This is consistent with the findings of Gunzburger and Travis (2004), who determined it to be dominant in vegetated habitats and near water sources-*P. leucomystax* is an arboreal anuran highly dependent on water. In addition, their eggs are usually deposited in foam nests attached to vegetation near water (Kusrini 2020). According to Cooper et al. (2017), foam nests are a strategy by some anuran species to provide a suitable environment for their eggs and embryos when standing water is rare and/or temporary.

In conclusion, the anurans in the karstic study area comprised eight species belonging to five families. The anuran diversity values for each habitat were 1.58 (community forest), 1.37 (river), and 1.21 (agricultural land). The physical and chemical parameters of the environment (air temperature, humidity, water pH) were optimal for the presence of anurans in each habitat. Several factors influenced the results of canonical correspondence analysis for each spesies, primarily altitude, tree canopy density, air temperature, humidity, and water pH. Each anuran species and community has different characteristics that require specific environments and habitats. The anurans and environmental factors of the karstic study area in Pucung village indicate that the area has the potential to support a diversity of anuran species in their preferred habitats.

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