IOP Conference Series: Earth and Environmental Science

PAPER • OPEN ACCESS

Fuzzy logic application for cave entrance identification

To cite this article: Ridwan Arif Pambudi *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **311** 012074

Fuzzy logic application for cave entrance identification

Ridwan Arif Pambudi*, Astrid Damayanti and Kuswantoro Marko

Department of Geography, University of Indonesia, Jl. Margonda Raya, Pondok Cina, Beji, Depok 16424, Indonesia

E-mail: ridwan.arif@ui.ac.id

Abstract. Fuzzy logic allows ambiguity and obscurity. Fuzzy logic explains that truth is not an absolute way. Rather, it presents data in ranges. This becomes the advantage of fuzzy logic in categorizing spatial data in a natural way. Cave entrance identification in karst landscape has an important value because caves are the alternative water resources and conservation region for biota biodiversities, archaeological heritage, and other research for the different discipline of science. This research was conducted in Gunung Sewu Karst Landscape with varied physiography, Ponjong and Semanu District, Gunungkidul Regency. The purpose of this research is to examine the accuracy of fuzzy logic in identifying cave entrance. This research is an integration between geographic information system and remote sensing. Alos Palsar imagery is processed to produce drainage density, slope, and elevation region, while Sentinel 1 imagery processing produces lineament density. Other spatial data used in this research include monthly rainfall data and geology formation. All variables in raster format are reclassified using fuzzy membership and then overlaid with fuzzy overlay. The result is that cave entrance is found in the region with high fuzzy logic value range. Fuzzy logic has high accuracy in identifying cave entrance in Ponjong and Semanu District, Gunungkidul Regency.

1. Introduction

A classical logic is built on the basic concept of the set, in which an individual is viewed as a member or not a set member [1]. A classical logic in modeling, reasoning, and computing is generally sharp, deterministic, and precise [2]. The sharpness of the classical logic proposition results in a dichotomy of truth value being two things; "true" and "false"[1]. The factual model is a modeling type that has a basic hypothesis on an object that needs to be verified [2]. However, the factual model or modeling language has the problem of a real situation that is often not sharp, not deterministic, and cannot be explained precisely, showing uncertainty in the real situation [2]. Based on this, fuzzy logic with the concept of a continuum set has the advantage in accommodating the existence of ambiguity in a real situation and the obscurity of the boundary class of the data set, since fuzzy logic explains the truth in the form of a range of values [3]. This becomes the advantage of fuzzy logic in categorizing spatial data in a natural way, including identifying the existence of cave entrances.

* To whom any correspondence should be addressed.

Cave entrance identification is based on factors influencing karstification. As for the cave entrance formation in Gunung Sewu Karst Landscape, i.e., rock type, geological structure, rainfall, elevation, slope, and drainage density. This research is an integration between geographic information system and remote sensing. The accuracy level of fuzzy logic results in cave entrance identification will be known from this research. The fuzzy logic application for cave entrance identification is a preliminary research for potential underground water identification in Gunung Sewu Karst Landscape. This research can be a solution for surface water crisis in Gunung Sewu Karst Landscape.

2. Materials and Methods

2.1 Study area

This study was conducted in Ponjong and Semanu District, Gunungkidul Regency, Special Region of Yogyakarta (Fig 1). Ponjong and Semanu Districts with varied physiography are an ideal representative of Gunung Sewu Karst Landscape which has an area of about 1.730 km^2. Lithology in Ponjong and Semanu District consists of four rock types i.e., Alluvium (Qa), Oyo Formation (Tmo), Semilir Formation (Tms), and Wonosari-Punung Formation (Tmwl).

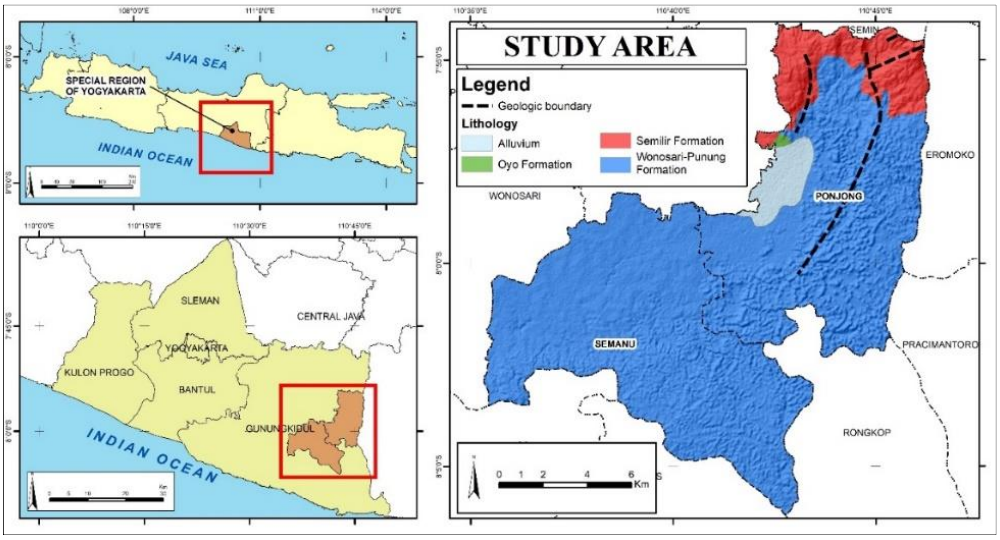

Figure 1. The location of the study area

2.2 Materials

Sentinel 1 was acquired on January 26th, 2018 with path/frame of 127/1151 and 10 meters spatial resolution from European Space Agency [4]. Alos Palsar was acquired on October 26th, 2008 with path/frame of 431/7020 and 12,5 meters spatial resolution from Japan Aerospace Exploration Agency [5]. Geological data is acquired from Surakarta and Giritontro Geology Map with a scale of 1:100.000, from Center of Geology Research and Development, Geology Agency, Energy and Mineral Resource Ministry. Climatological data is in the form of monthly rainfall 2011-2015 periods in Ponjong and Tepus Climatological Station is acquired from Meteorological Climatological and Geophysical Agency of Yogyakarta, Mlati.

2.3 Methods

In general, the flow of work in this research is the result of fuzzy logic overlay generated from various variables tested its accuracy based on cave entrance coordinates of field survey (Fig 2). Alos Palsar is processed into elevation, slope, and drainage network density variables. Drainage network is further processed with 'line density' in ArcMap software to generate a variable of drainage network density. Identification of geological structures on karst landscape is performed by using a lineament [4]. A lineament is acquired by extraction of Sentinel 1 using lineament extraction algorithm in PCA

Geomatica software based on six parameters (Table 1) [6]. Lineament is then further processed with 'line density' in ArcMap software to generate a lineament density variable. Geological data in the form of the rock types from Surakarta and Giritontro Geology Map with the scale of 1:100.000 are georeferenced and re-digitized, then converted from polygon to raster. Climatological data in the form of rainfall is interpolated using interpolation distance weighted (IDW) method.

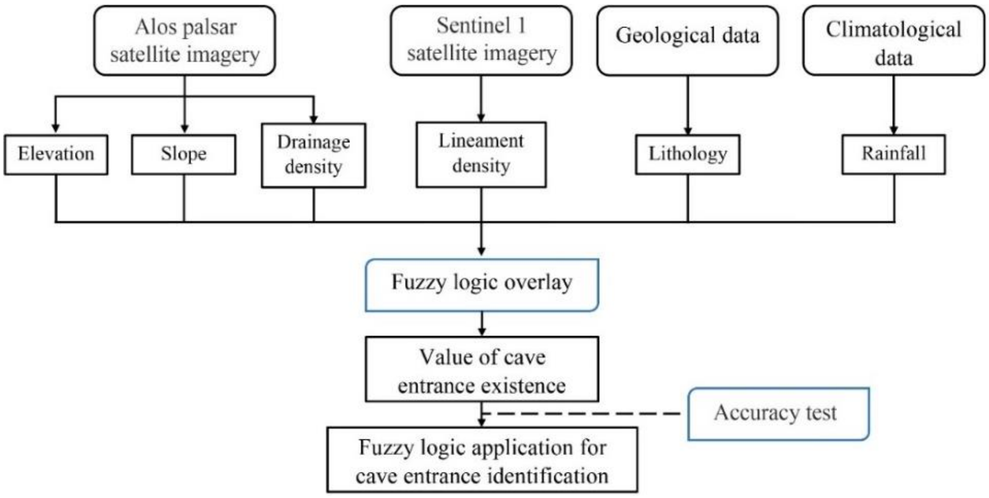

Figure 2. Study workflow chart

Table 1. The Parameters value applied for automatic lineaments extraction.

Parameters	Applied values
RADI	5
GTHR	55
LTHR	10
FTHR	2
ATHR	20
DTHR	20

The fuzzy logic used in this study is a gamma fuzzy logic type (Formula 1). Before processed using fuzzy logic, each of variables is reclassified using fuzzy membership with various types (Table 2).

$$\text{Fuzzy gamma value} = \text{pow(1-((1-arg1)*(1-arg2)*...),Gamma)*pow(arg1*arg2*...,1-Gamma)} \quad (1)$$

Table 2. Fuzzy membership types of the variables

Variables	Fuzzy membership type	Hedge
Elevation	Large	None
Slope	Small	None
Drainage density	Large	None
Lineament density	Large	Somewhat
Lithology	Large	Very
Rainfall	Large	Somewhat

Variable of elevation use 'large' fuzzy membership is based on the higher a karst landscape, the higher the karstification rate is (Fig 3a) [6]. Variable of slope uses 'small' fuzzy membership, which is related to bigger infiltration process that occurs on low until the moderate slope if compared in high slope. High infiltration will trigger high karstification (Fig 3b) [6]. The selection of 'large' fuzzy membership on the drainage network density variable is based on the possibility of cave entrance that formed as a sinking or spring stream which are strongly influenced by water flow (Fig 3c) [7,8]. The selection of 'large' fuzzy membership on the variable of lineament density is based on the lineament is a way to identify geological structure on karst landscape. The denser the lineament, hence the more fragile and bigger the rock gaps that are exploited by water in the karstification process. As a result, high karstification will occur (Fig 3d) [9,10]. The selection of 'large' fuzzy membership on the variable of lithology is based on the suitability rate of rock types which affect the rate of karstification. In this case, rocks with high carbonate composition will have a high effect of karstification (Fig 3e) [9,11]. Rainfall variable uses 'large' fuzzy membership, which is related with karst recharge supply. The bigger rainfall will increase–the karstification rate (Fig 3f) [9]. The result of fuzzy logic is further tested for its accuracy based on the cave entrance coordinates from the field survey. The method of the accuracy test is based on the cave entrances which is high fuzzy logic value area (accurate) divided by the total of cave entrances (Formula 2).

$$\text{Level of accuracy: } \frac{\text{Total of cave entrances on high fuzzy logic value}}{\text{Total of all cave entrances}} \times 100\% \qquad (2)$$

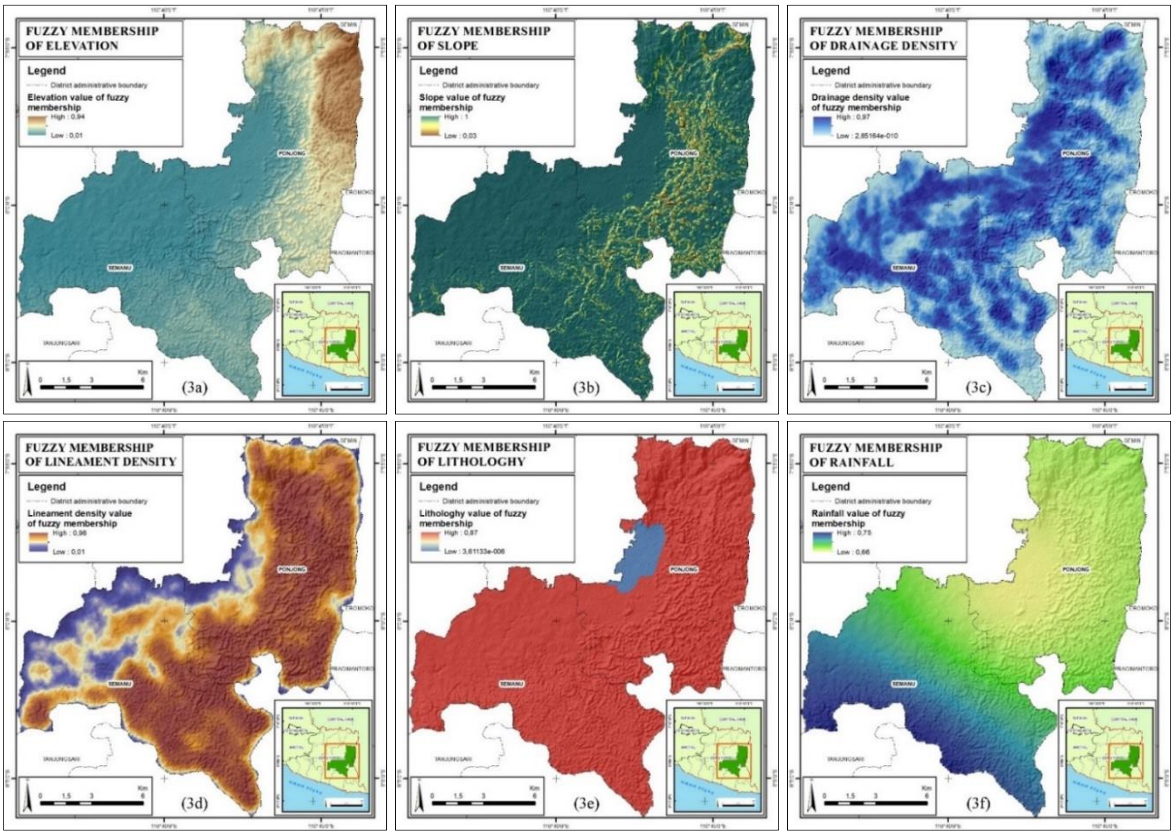

Figure 3. Map of fuzzy membership types on study variables

3. Results and Discussions

Field survey conducted on Gunung Sewu Karst Landscape, Ponjong and Semanu District, Gunungkidul Regency was successful in identifying the existence of 33 cave entrances. The identified cave entrances are dominant on high range of fuzzy logic value. The ten cave entrances are identified in Ponjong District and twenty-three cave entrances are identified in Semanu District (Fig 4).

Cave entrances that were found on study area are dominantly the result of collapse (formed vertical cave entrance like Luweng Jubleng Cave (33)) (Fig 5a) and the aggressive sink and resurgence stream (formed horizontal cave entrance like Gremeng Cave (6)) (Fig 5b). Twenty-nine identified cave entrances are located within the high fuzzy logic value range (above the middle fuzzy logic value), whereas, the remaining four cave entrances are located within the low fuzzy logic value range. These

IOP Conf. Series: Earth and Environmental Science **311** (2019) 012074 doi:10.1088/1755-1315/311/1/012074

remaining four cave entrances are Caves of Jomblang (26), Ngingrong I (31), Ngingrong II (32), and Luweng Jubleng (33). The calculation of fuzzy logic accuracy for cave entrance identification is as follows:

$$\text{Level of accuracy} = \frac{29}{33}\, X\, 100\%$$
$$= 87{,}9\%.$$

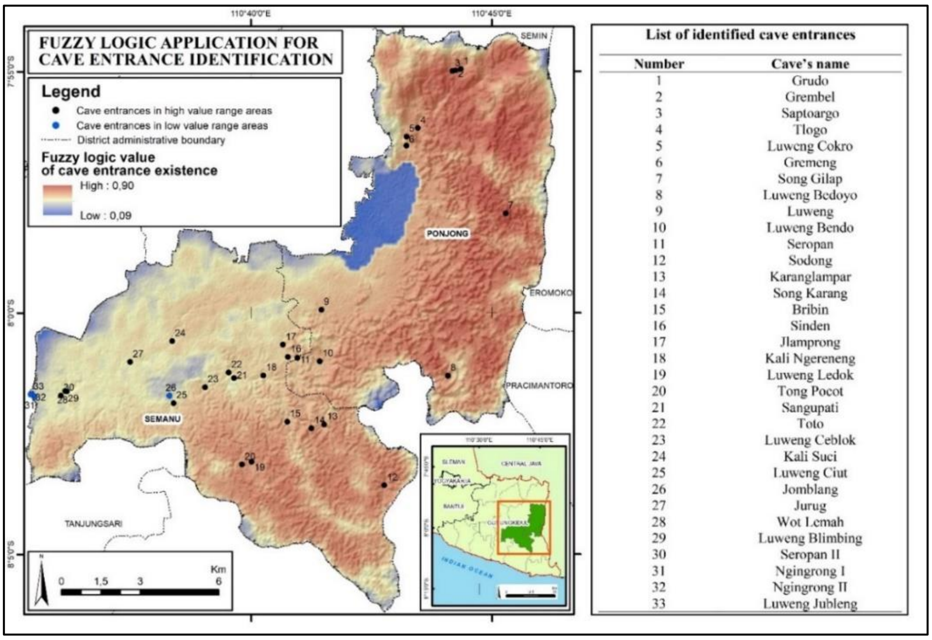

Figure 4. Fuzzy logic application for cave entrance identification map

Figure 5. The identified cave entrances: Luweng Jubleng (5a) and Gremeng (5b)

Surface water crisis phenomenon occasionally occurs in Gunung Sewu Karst Landscape, Gunungkidul Regency. It happens due to high secondary porosity and permeability that was caused by dissolution process (karstification) on carbonate rocks. Thus, the surface water can easily infiltrate the carbonate rock layers towards the saturation zone. [9,11].

Based on the accuracy test, it is known that fuzzy logic application for cave entrance identification has high accuracy i.e., 87,9%. Twenty-nine cave entrances in high fuzzy logic region have region characteristics with high karstification factor. It indicates that the 29 cave entrances in the high fuzzy logic region have potential underground water in their tunnel.

Based on the field survey, 12 out of 29 horizontal cave entrances are a type of sink and resurgence cave entrance. Horizontal cave entrances with sink type are Grudo, Sodong, Sangupati, Sinden, Tong

Pocot, Seropan 2, Jurug, Kali Suci, Jlamprong, and Tlogo Cave Entrance, while horizontal cave entrances with resurgence type are Gremeng and Kali Ngereneng Cave Entrance. Basically, horizontal cave entrance with sink and resurgence type have an overflowing underground water. Though, sink cave entrance water flow have low quality water for society consumption. It is because the water flow from sink cave entrance is a type of point karst recharge that does not have a natural filter [9]. The potential underground water of three cave entrances on the high fuzzy logic region that have been identified and utilized for underground water are respectively caves of Seropan I, Bribin, and Song Gilap. Therefore, the fuzzy logic application can be recommended as a method of early cave entrance identification based on remote sensing and geographic information system for a preliminary potential underground water identification in karst landscape.

4. Conclusion

In this study area, 33 identified cave entrances are dominant in the region with a high range of fuzzy logic value. Fuzzy logic with 87,9% level of accuracy, has high accuracy in identifying the existence of cave entrances in Gunung Sewu Karst Landscape, Ponjong and Semanu Districts, Gunungkidul Regency. Based on the fuzzy logic result, the 29 cave entrances within the high fuzzy logic region have potential underground water in their tunnel. Therefore, the fuzzy logic application can be recommended as a method of early cave entrance identification based on remote sensing and geographic information system for a preliminary potential underground water identification in karst landscape.

Acknowledgment

This research funded by Hibah PITTA with contract number of 2236/UN2.R3.1/HKP.05.00/2018.

References

[1] Chen G and Pham T T 2001 *Introduction to Fuzzy Sets, Fuzzy Logic, and Fuzzy Control Systems* (Washington: CRC Press)
[2] Zimmerman H J 2001 *Fuzzy Set Theory - and its Applications* ed H J Zimmerman (New York: Kluwer Academic Publishers)
[3] Zadeh L A 1965 Fuzzy sets *Inf. Control* **8** 338–53
[4] Attema E, Davidson M, Floury N, Levrini G, Rosich-Tell B, Rommen B and Snoeij P 2007 Sentinel-1 ESA's new European SAR mission *ESA Bull.* **131** 11–7
[5] Rosenqvist A, Shimada M and Watanabe M 2004 ALOS PALSAR: Technical outline and mission concepts *Int. Symp. Retr. Bio- Geophys. Parameters from SAR Data L. Appl.* **1** 1–7
[6] Moradi S, Kalantari N and Charchi A 2016 Karstification Potential Mapping in Northeast of Khuzestan Province, Iran, using Fuzzy Logic and Analytical Hierarchy Process (AHP) techniques *Geopersia* **6** 265–82
[7] Culver D C and White W B 2005 *Encyclopedia of Caves* (California: Elsevier Inc.)
[8] Mylroie J E and Carew J L 2003 Karst development on carbonate islands *Speleogenes. Evol. Karst Aquifers* 55–76
[9] Ford D and Williams P 2013 *Karst Hydrogeology and Geomorphology* (Chichester: John Wiley & Sons Ltd)
[10] Kusumayudha S B 2009 Detecting Springs in the Coastal Area of the Gunungsewu Karst Terrain, Yogyakarta Special Province, Indonesia, Analysis using Fractal Geometry *IPTEK, J. Technol. Sci.* **20** 169–76
[11] Kusumayudha S B 2004 *Mengenal Hidrogeologi Karst* (Yogyakarta: Pusat Studi Karst LPPM UPN Veteran Yogyakarta)