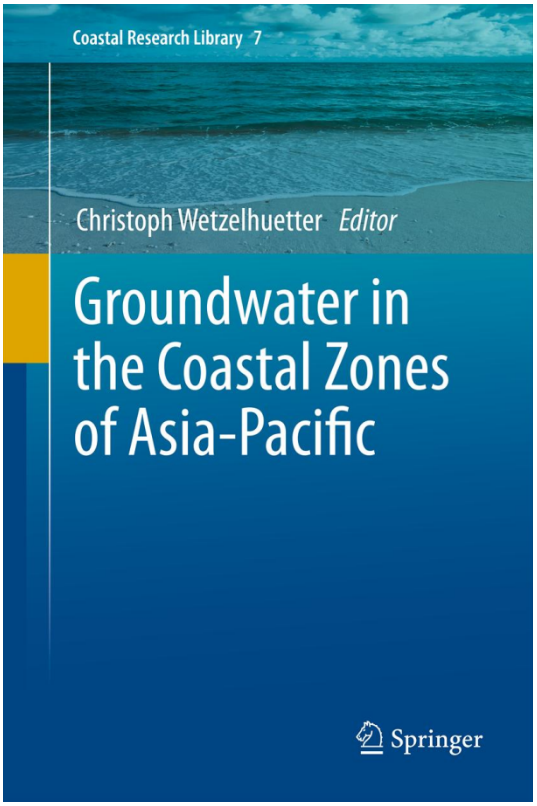

Groundwater in the Coastal Zones of Asia-Pacific

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Coastal groundwater and its support to the development of Gunungsewugeopark, Java, Indonesia.

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Abstract Gunungsewu is a largest Tropical karst terrain of Southeast Asia, about 800 km2 broad, and composed of around 45,000 hills of cones and domes, belongs to the territory of Central Java, Yogyakarta, and east Java provinces. This area is now developed to be a national geopark, therefore such facilities including the availability of fresh water sources must be adequate. But in the matter of fact, Gunungsewu is always subjected to water scarcity especially in every dry season. Aquifer of Gunungsewu is predominantly composed of reef limestones with conduit flow typeand underground drainage system thatdischarge their water to Indian Ocean through coastal springs. The occurrence of coastal springs are generally associated with unique hydrogeologic phenomena and beautiful landscape.Due to very rough topography, steep cliffs, and difficulty to be accessed, to explore the existence of groundwater discharge in coastal area, fractal geometry analysis is applied. From the analysis, there is a correlation between the fractal dimension value of coast shoreline and the existence of spring. Shoreline segments with fractal dimension (D) higher than 1.30 is potential to the existence of coastal spring, whereas on the segments with fractal dimension less than that, spring is absent. Baron is the biggest verified coastal spring of Gunungsewu area, with flow rate 9000 l/sec average. The physical and chemical quality of the water do not exceed the drinking water standard. This represents that the existence of coastal springs in Gunungsewu area is actually potential to support the development of geopark, as additional fresh water sources and as geosites or geo heritages.

Keywords Karst topography. Unique hydrogeology. Coastal groundwater discharge. Geopark

Introduction

Background

Gunungsewu is a largest Tropical karst terrain of Southeast Asia. Broad of the area is about 800 km2, and composed of around 45,000 hills displaying specific conical morphology (Kusumayudha 2005). Right now the area is developed to preparing itself to be a national geopark. As it is known, that a National Geopark is an integratedpreservation of significant examples of geological heritages in a strategy for regional sustainable socio-economic and cultural development, and safeguarding the environment (Unesco, 2010).

In order to set Gunungsewu area up to be a national geopark, such facilities including the availability of fresh water sources must be adequate. But in the matter of fact, Gunungsewu since a long time ago is well known as an area which always subjected to water scarcity especially in every dry season. Water deficiency particularly happens in the middle parts of the Gunungsewu area. Now the problem is where to get water sourceslocally, in order to avoid importing water from other areas, because it will be inefficient and costly.

In the southern parts of Gunungsewu area, there are plenty of groundwater outlets from such subsurface rivers, channels, and conduits to the sea, so called coastal springs. The occurrence of coastal springs are generally associated with unique hydrogeologic phenomena and beautiful amazing landscape. In the present time, groundwater of the coastal springs in the Gunungsewu area is not optimallyused to fulfill the needs of fresh water yet, especially to support the development of geopark, althoughfrom thequantity and quality point of view seems to be adequate.In relation to this, more information on the existence of potential springs need to be explored and identified.

Location

Referring to the phyisiographic map of Van Bemmelen (1949), the study area is situated in the Southern Mountains of East Java, but administratively belongs to territories of Yogyakarta Special province, Central Java, and East Java provinces, involving Gunung Kidul regency, Wonogiri regency, and Pacitan regency (Figure 1). Its geographic position is in the coordinate of 6^o 10’ to 6^o 30’ latitudes and 99^o 35’ to 100^o longitudes. The area is able to be reached easily by four wheels vehicle from Yogyakarta city, Wonogiri and Pacitan towns. It is about 25 km from Yogyakarta to the southeast direction.

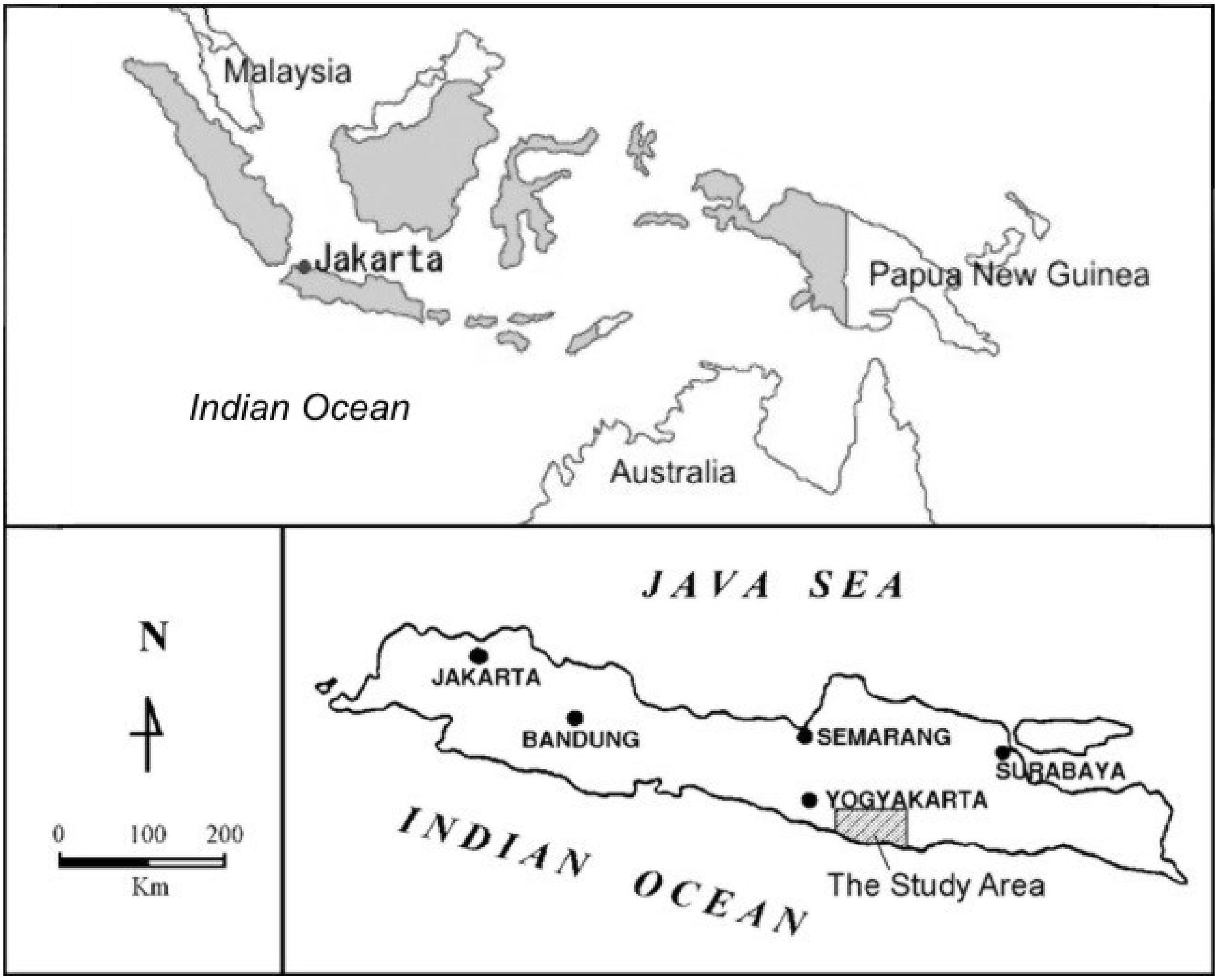

Fig. 1 Location of the study area

Objectives

The objective of this study is to explore and analyze the existence of coastal springs of Gunungsewu area, in order to obtain information on their hydrogeologic characters and potential to contribute the development of Gunungsewu area to be a national geopark.

Method of study

Approach applied in this study is analytical method using primary and secondary data. The primary data was derived from field surveying and mapping, while the secondary data was collected from the existing studies. Flow rate measurement and water samplingwere done to Baron Spring for physical and chemical quality testing.

Kusumayudha (2009) applied fractal analysis to explore and identify the occurrence of coastal springs in Gunungsewu area. During doing fractal analysis, air photos of 1 : 30,000 scale were usedto trace and reprint the shoreline pattern of the study area. Curve of the shoreline was then divided into segments of about 2 km length. The fractal dimension of the curve of each shoreline segment was then determined using box counting method.

Fractal terminology is used for determining non-euclidean objects, which have non-integer dimension (Mandelbrot 1983). It is formed from a simple shape, which grows more complex as the shape is repeated in miniature around the edges of the first shape (Xie 1993). A fractal object usually shows infinite, swirling, and complex, but unique shape. In this study, the curve of shoreline is assumed to be a fractal object.

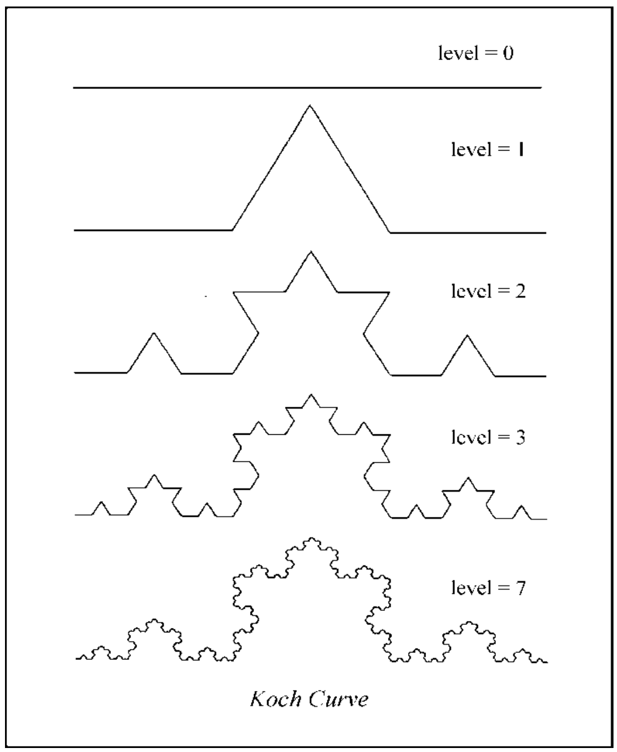

Fig 2 Koch curve, a model of similarity fractal (Mandelbrot, 1983)

There are some characteristics of fractal, i.e. self-similarity, self-affinity, self-inverse, and self-squaring (Peitgen, et.al. 1992). Fractal scaling system is specified by a non-integer number called fractal dimension (Mandelbrot 1983), which can be used to quantify the degree of fractal irregularity (Sukmono 1996). Fractal objects themselves are classified into some types, i.e. self similar fractal (Figure 2), self affine fractal, self inverse fractal, self squaring fractal, and complex fractal. The dimensions of self similar, self affine, self squaring, and self inverse fractals can be determined by similarity method, but the dimension of complex fractal will valid being computed by other methods which are applicable for statistical fractal, e.g. objects that statistically show fractal configuration.

There are several methods to determine a fractal dimension, e.g. similarity method for similarity fractal, cantor dust, balls covering, sandbox, and box counting methods for statistical fractals (Mandelbrot 1983). The method used by Kusumayudha (2009) to determine the fractal dimension is box-counting. The determination of the fractal dimension is by drawing grids with certain length of side (*r*) over the fractal object. Then the fractal dimension (*D*) is determined using equation (Tricot 1996):

$$D = \lim_{r \to 0} \frac{\log Nr(F)}{-\log r} \qquad (1)$$

where *Nr(F)* is the number of boxes that cover the fractal set *(F)*, and *r i*s the length of the box side.

Geology

According to Van Bemmelen (1949), the Southern Mountains of East Javaconsists of three physiographic subzones, i.e., the Baturagung range, the Panggung massive, and the Plopoh range in the north; the Wonosari plateau in the central area; and the Gunungsewu subzone in the south. The area display a unique karst topography with about 45,000 hills of cones and domes, closed basins, caves, shafts, and sink holes of totally about 800 km2 broad (Kusumayudha 2005), that the distribution can be seen from satellite image of Figure 3**.**

Geology of Gunungsewu Area is mainly developed of Tertiary volcanic rocks and karstic limestone. Formations exposed in this areaare predominantly composed of carbonate rocks, including Oyo Formation, Wonosari Formation, and Kepek Formation. This group of carbonate formations is underlain by a unit of volcanic deposits of Semilir, Nglanggran, and Besole formations. In some parts, Sambipitu Formation is found as another bedrock unit of the Gunungsewu limestones (Kusumayudha 2005). Geologic map of Gunungsewu area is shown in Figure 4.

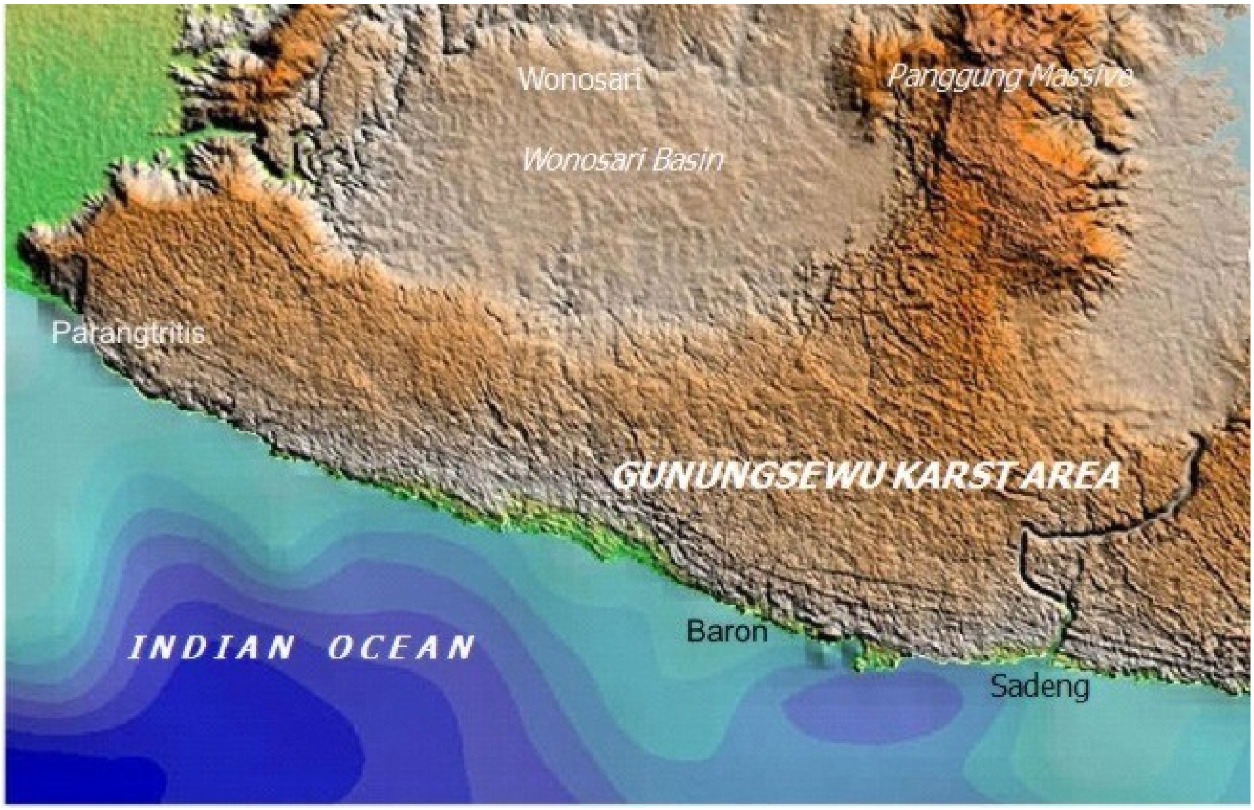

Fig 3. Satellite image of the Gunungsewu Area (Pacitan Regency data, 2011)

Stratigraphy

Rock formations in Gunungsewu Area from the oldest to the youngest can be described as follows:

Semilir Formation. Semilir Formation is sedimentary rocks from deep sea environment that is composed of andesitic tuffs, sandstones, tuffaceous sandstones, lapilli, agglomerates, claystone, siltstone, shale, and andesitic to basaltic breccias. The formation is Oligocene to early Miocene age (Kusumayudha, 2005).

Nglanggran/Besole Formation. Nglanggran Formation conformably overlays Semilir Formation, but in some places the formation shows interfingering relationship to Semilir Formation. Nglanggran Formation predominantly consists of andesitic to basaltic breccias, lava deposits, agglomerates, polymixed breccias, sandstones, and tuffaceous sandstones. Some time limestone blocks can be found as exotic fragments in the volcanic breccias. The formation was deposited during Oligomiocene to middle Miocene (Kusumayudha, 2005).

Sambipitu Formation. Sambipitu Formation conformably overlays Nlanggran Formation and particularly possesses interfingering relationship in its bottom parts. The formation consists of marl, mudstone, interbedded calcareous sandstones, marl, and tuffaceous sandstones. These marine sedimentary rocks are middle Miocene age (Kusumayudha, 2005). All Together with Semilir, Nglanggran and Sambipitu formations construct the basement of the carbonates of Gunungsewu.

Oyo Formation. Oyo Formation comprises bedded limestone, sandy limestone, calcarenites, marl, marly sandstones, and marly – tuffaceous sandstones. The stratigraphic relationship between Oyo and Sambipitu formations is conformity at some places, and interfingering at other places. The age of Oyo formation is middle Miocene to Miopleistocene (Kusumayudha, 2005).

Wonosari Formation. Wonosari Formation is composed of bedded limestone, massive limestone, and reefs. There are two specific characters of the formation, i.e. karstic and chalky (caliche). Typical of karstic limestone is cavernous, while chalky limestone is specified by intergranular porosity. This formation is middle Miocene to Pliocene age (Kusumayudha, 2005).

Kepek Formation. The main composition of Kepek Formation is claystone, sandy marl, calcarenite and bedded limestone. They were deposited in an isolated shallow marine environment during upper Pliocene to Pleistocene (Kusumayudha, 2005).

Terra Rossa and Merapi Deposits. The youngest lithology in the Gunungsewu area is terrarrose. In spite of terrarrose, there also deposits of Merapi volcano and alluvium. The alluvium consists of clay, silt, sands, granules, gravels and cobbles, and flora remnants. On the other hand, the Merapi deposits comprises of fine grained pyroclatics such as sands, volcanic ash and dusts.

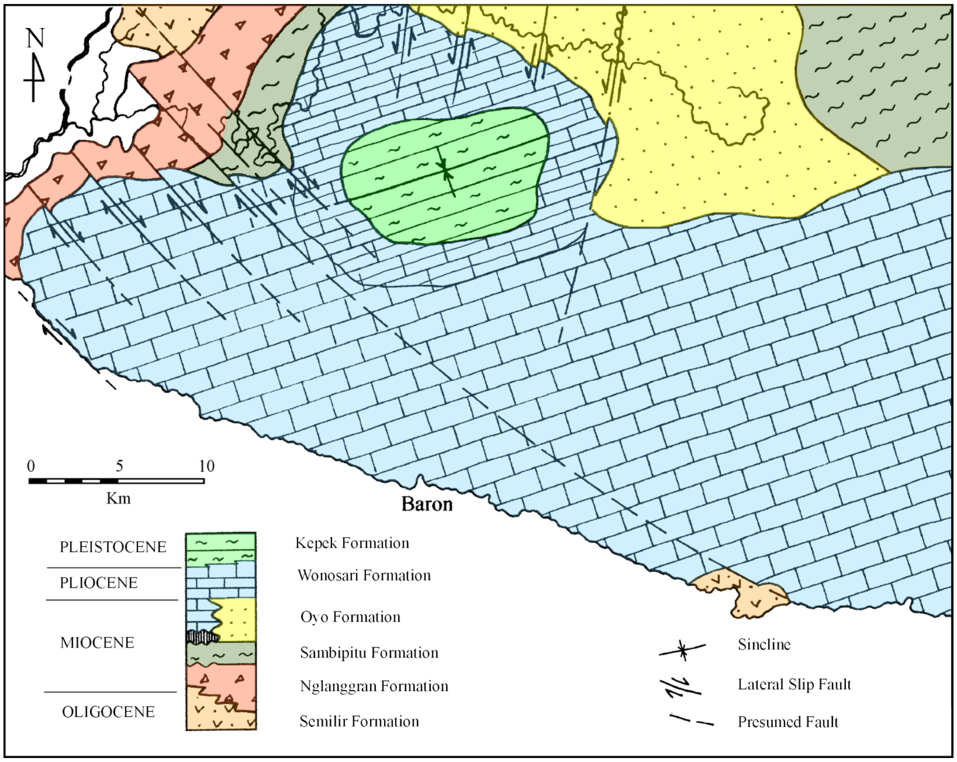

Fig. 4 Geological map of Gunungsewu Area (Kusumayudha, 2005)

Geologic structures and history

Generally, the Southern Mountains was uplifted and little bit folded. There is a syncline in the center part of the Southern Mountains with a northeast (N75^{o}E - N255^{o}E) trending axis. This part is topographically performs a plain and known as Wonosari Plateau. In the southern part, Gunungsewu subzone displays a homoclyne about 5^o to 15^o dipping southward. There is fissure system as joints, cracks and faults that their pattern orientation is northwest-southeast and northeast-southwest (Kusumayudha, 2005).

Geological history of Gunungsewu had started since Oligocene, initiated by volcanism producing the basement rocks that comprise Semilir, and Nglanggran formations. The tectonic environment of this area was magmatic arc of the Indo-Australian plate subduction beneath the Eurasia plate in the Tertiary period (Suyoto 1994). The volcanism was then followed by deposition of carbonate rocks of Sambipitu Formation, Oyo Formation, Wonosari Formation, and Kepek Formation respectively, in middle Miocene, to Pliocene. The process continued with uplifting and folding that brought about the expose of the carbonates. Interaction of carbonate rocks with exogenic processes in tropical condition, forms karst topography.

Surface processes happened in the Quaternary period. The influence of volcanism from northern side of Gunungsewu produced terrarrose deposits, found on the base of karst basins such as doline, uvala, and polje.

Hydrogeology

Gunungsewu area is a representative of a specific karst hydrogeologic system that is very unique. The aquifer in this system is predominantly composed of reef limestones. Physically the limestone tends to show karstification and calichification processes. Both the karstic limestone and kaliche limestone are able to function as good aquifer. The difference of physical characteristics of the karstic limestone and caliche aquifers is in its porosity type. Secondary conduit system occurs in karstic limestone, while intergrain system exists in chalky limestone (caliche). Caliche or chalky limestone is usually locally spread, and therefore in general forms perched aquifer (Kusumayudha, et al. 1999).

Sir MacDonald & Partners (1979) vide Kusumayudha (2005) through tracing method using dye, verified that some underground rivers in Gunungsewu area discharge to the open sea through Baron coastal spring. Result of reconstruction based on gravity anomaly map (Kuysumayudha and Santoso, 1998) and the geologic structure pattern, it can be concluded that there is underground drainage system with a main river and its tributary channels. This subsurface river system discharges to Indian Ocean through coastal springs, as the hydrogeologic model is shown in Figure 5. The subsurface flow pattern and networks in the Gunungsewu is controlled by fracture structures (Kusumayudha, et al. 1999, Kusumayudha, 2005).

Existence of coastal springs and fractal geometry

There are more than 36 springs found along the coastal area and surroundings from Ngrenean beach in the west to Sadeng beach in the east. The springs in general are subjected to rate decreasing in the dry season, except for Ngobaran spring and Baron spring. Ngobaran spring flow rate is about 200 to 500 l/sec, Baron spring flow rate is around 9,000 l/sec, while the other springs flow rate is only 50 l/sec or less (Kusumayudha, 2009).

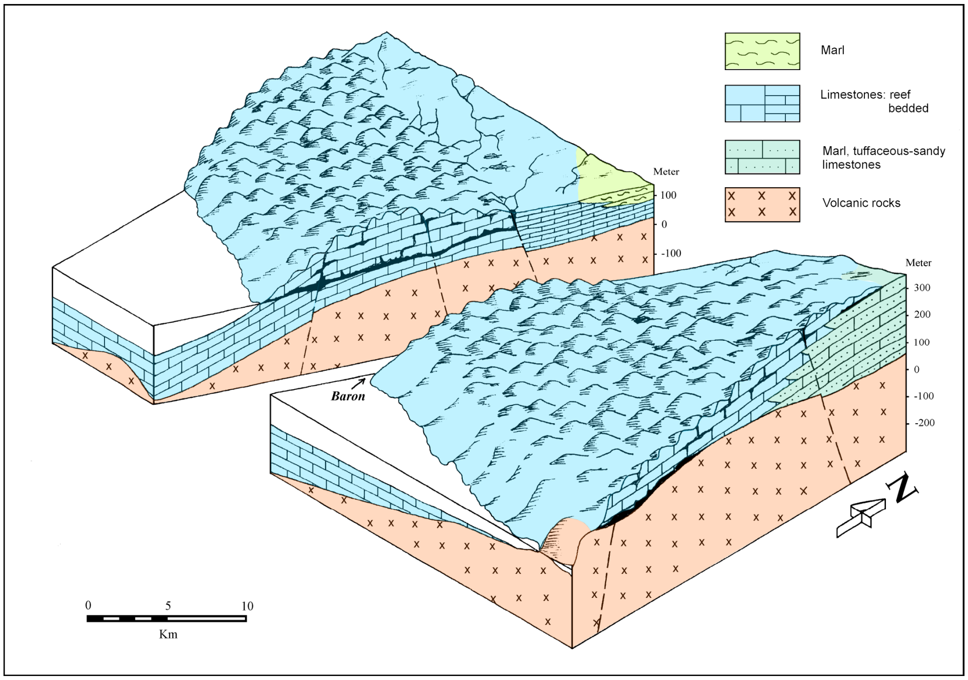

Fig. 5 Block diagram showing the hydrogeologic conceptual model of Gunungsewu area (Kusumayudha, 2005)

Due to very rough topography and steep cliffs, some coastal areas are difficult to be accessed. In order to explore the existence of more springs, some suitable method is needed to be applied. In order to help find other coastal spring, fractal geometry analysis is applied (Kusumayudha, 2009). This method is able to quantify the shape of shoreline in the coastal part of the Gunungsewu karstic area. Result of the analysis showed that fractal dimension of the shoreline of Gunungsewu area ranges from 1.230 $\pm$ 0.01 to 1.665 $\pm$ 0.01 (Kusumayudha, 2009).

There is a correlation between the fractal dimension value of shoreline of a coast and the existence of spring. Shoreline segments with fractal dimension (D) higher than 1.30 is potential to the existence of coastal spring, whereas on the segments with fractal dimension less than that, spring is absent (Kusumayudha, 2009). Figure 5 illustrates the location of springs in Gunungsewu area, Figure 6 shows the situation of Baron spring in dry season, while the fractal dimensions of the shoreline are written in Table 1.

Table 1 Fractal dimension of the shorelines and the existence of coastal springs (Kusumayudha, 2009)

Segment	Location	Fractal Dimension	Spring	Rate (l/sec)	Remarks
1	Teluk Becici	1.230 $\pm$ 0.01	absent		verified
2	Teluk Pule - Gebangkara	1.284 $\pm$ 0.01	absent		verified
3	Teluk Nunggah - Karangtelu	1.445 $\pm$ 0.01	present	?	presumed
4	Pantai Gesing	1.251 $\pm$ 0.01	absent		verified
5	Ngobaran - Ngrenean	1.382 $\pm$ 0.01	present	200	verified
6	Teluk Baron - western coast	1.469 $\pm$ 0.01	present	300	verified
7	Kukup - Spanjang - Drini	1.239 $\pm$ 0.01	absent		verified
8	Watulawang	1.315 $\pm$ 0.01	present	?	presumed
9	Watulawang - Wediamba	1.308 $\pm$ 0.01	present	1 – 50 (episodic)	verified
10	Wediamba – western coast	1.365 $\pm$ 0.01	present	?	presumed
11	Eastern coast of Wediamba	1.355 $\pm$ 0.01	present	?	presumed
12	Ngungap - Sadeng	1.630 $\pm$ 0.01	present	> 5000	verified
13	Eastern coast of Sadeng – Tanjung Dadapan	1.448 $\pm$ 0.01	present	5 – 50 (episodic)	verified
14	Slili	1.324 $\pm$ 0.01	present	50 - 200	verified
15	Sundak	1.317 $\pm$ 0.01	present	50 - 200	verified
16	Baron Beach	1.665 $\pm$ 0.01	present	9000	verified

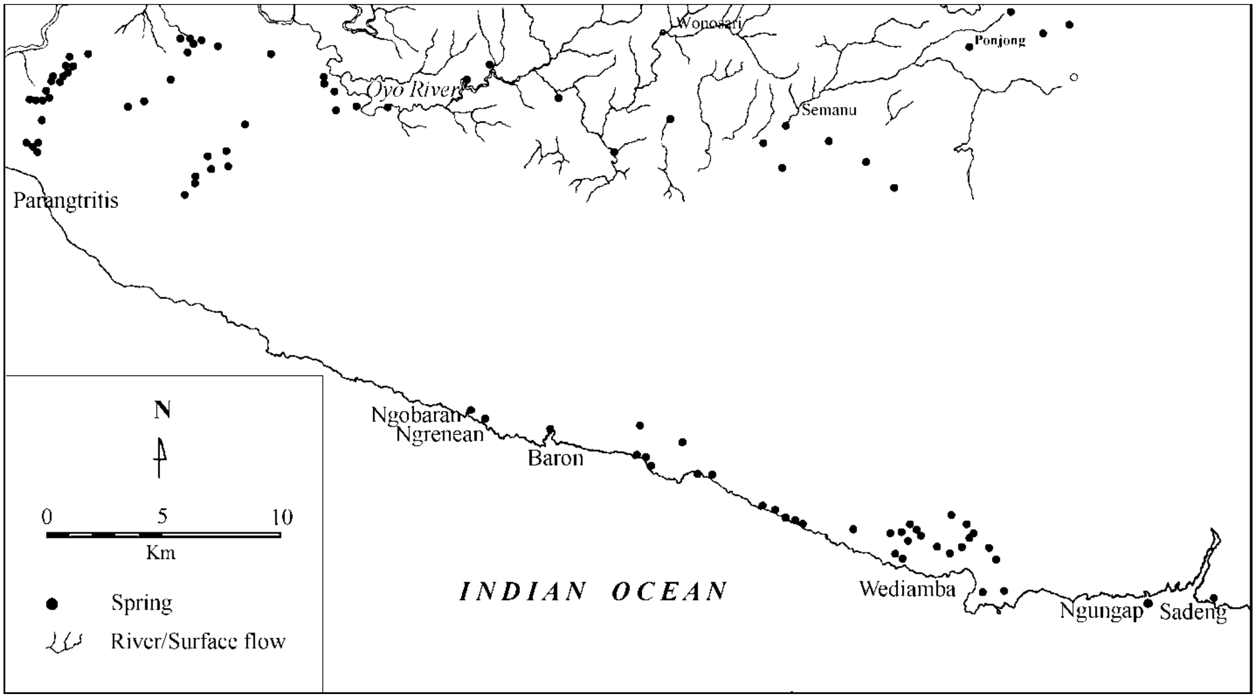

Fig.5 Location of identified springs in Gunungsewu area (revised from Kusumayudha, 2005)

Fig. 6 Groundwater outlet at Baron beach in dry season, with 9,000 l/sec average rate.

Characteristic and conceptual model

Baron is the biggest verified coastal spring of Gunungsewu area. The spring occurs within the karstic limestone of Wonosari Formation, which is underlain by volcanic rocks of Semilir and Nglenggran formations. The water source of Baron spring is such underground conduit flows from northern and middle parts of Gunungsewu area. Data derived from field surveys demonstrate that there are many caves and shafts located in the north part of Gunungsewu area, connected with subsurface flows, such as Bribin cave, Seropan cave, and Suci cave. The subsurface flows in general are supplied from superficial rivers which sink downward to perform underground rivers. The underground rivers then merge to a main flow, floating out to the south, to Indian Ocean, creating a coastal spring. Based on the geological and hydrogeological data, the conceptual model of Baron Spring can be drawn as shown in Figure 7.

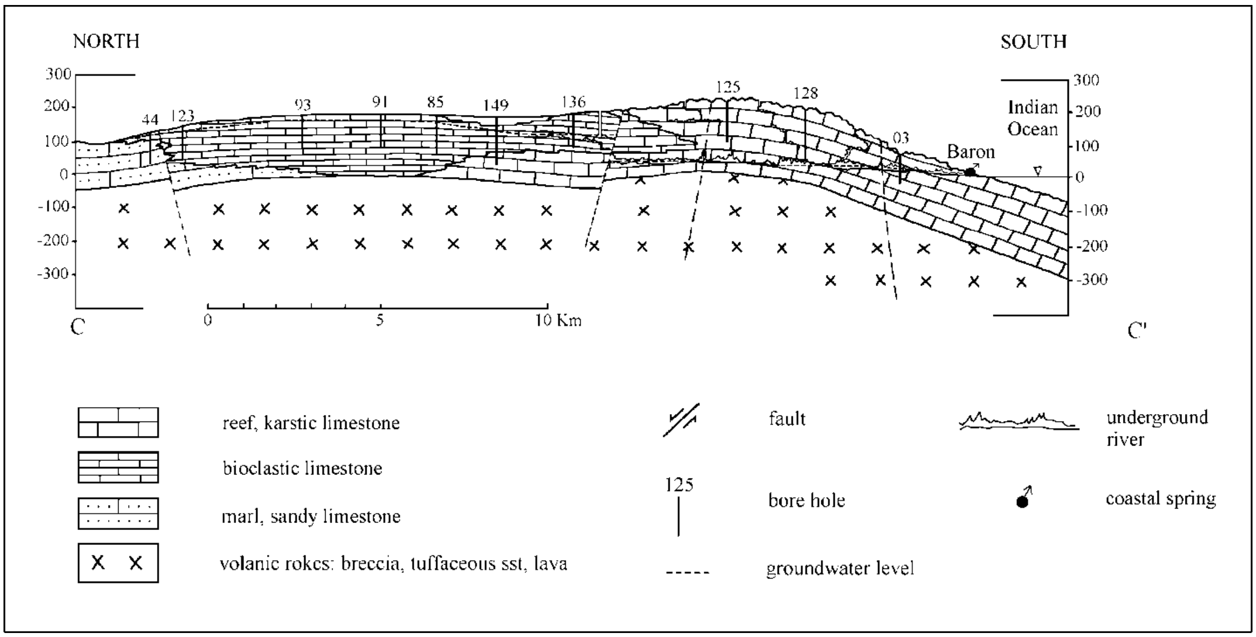

Fig. 7 Hydrogeologic model of Baron spring (updated and revised from Kusumayudha, 2005)

Measurements records from 1998 to 2009 show that the average flow of Baron Spring is 9000 l/sec. Maximum rate in the peak of rainy season reaches 20,000 l/sec, while the minimum flow in dry season is about 5,000 l/sec. Up to now the water is not consumed yet, but only for recreation, because people think that the water is not fit to fresh water quality standard, due to its location that is very close to the open sea. In order to know the quality of water, sample was taken from the spring. The sample is physically colorless, odorless, and tasteless. The TDS = 218 mg/l, electric conductivity = 362 micro Siemens, pH = 8. Comparing to the groundwater quality of Gunungsewu area, hydrochemistry of sample from Baron is shown in the Table 2.

Table 2 Groundwater chemistry of the study area

Chemical Compound	Consentration (mg/l)	
	Gunungsewu Area (Kusumayudha, 2005)	Baron Coastal Spring
Ca (mg/l)	35,00 - 51,56	34.67
Mg (mg/l)	8,00 - 20,00	18.31
Na (mg/l)	3,50 - 12,00	6.51
K (mg/l)	0.00	0.00
Fe (mg/l)	0,00 - 0,15	0.00
Cl (mg/l)	4,00 - 7,00	5.95
HCO3 (mg/l)	109,00 - 191,00	177.86
CO3 (mg/l)	0.00 - 6,00	0.00
SO4 (mg/l)	0.00 - 7,00	0.05
NO3 (mg/l)	1.56 - 3,00	2.65
PO4 (mg/l)	0.02 - 0,04	0.02
SiO2 (mg/l)	10,00 -15,62	14.26

Groundwater type of Baron spring is calcium-bicarbonate, and the concentration of every chemical compounds is not exceeding the standard for drinking water.

Support to development of geopark.

Gunungsewu fresh water is actually yielded from underground rivers. The underground rivers outlet to Indian Ocean forming coastal springs. Coastal springs of Gunungsewu area are controlled by specific karstic hydrogeology, and show unique interaction with sea water. Water of some big springs are not much influenced and contaminated by sea water, but some small springs seem to be disturbed when the sea water tides. This kind of spring usually decreases its flow rate in dry season. There is different condition with the Baron and Ngobaran that the water is remain fresh although in the long dry season, and the concentrations of chemical compounds are not exceeding drinking water standard.

From the geomorphologic point of view, coastal springs of the study area in general associate with beautiful landform, therefore they are attractive as tourism objects. In relation with the development of Gunungsewu as a geopark, the existence of coastal springs contribute to provide unique hydrogeologic condition and amazing scenery of beautiful landscape with interesting view to the open sea (Fig. 8). Therefore they will take the role as geosites or geoheritages that deserve to be conserved. From the usage point of view, these coastal springs are potential to support the need of fresh water not only for the local people, but also potential to support the development of geopark. As example, Baron spring with its flow rate that is 9,000 l/sec in average.

Fig.8 Beautiful scenery of Ngobaran coast. There is a spring with 200 – 500 l/sec rate.

Conclusions

1. There are some coastal springs in Gunungsewu area, that controlled by a unique karst hydrogeologic system with conduit flow type. The springs are supplied by surface rivers which sink downward to become underground flows, discharging to Indian Ocean. Lithology composing the karst is limestone of Wonosari Formation, underlain by volcanic formation consisting of tuffaceous sandstone, breccias, and lava of Semilir and Nglanggran formations. The biggest identified coastal spring of Gunungsewu area is Baron spring with about 9,000 l/sec of average flow rate
2. In order to explore the occurrence of spring in the remote areas, fractal geometry analysis can be applied (Kusumayudha, 2009). Result of fractal analysis shows that there is a correlation between the existence of spring and shoreline which displaying a curve with fractal dimension > 1.3
3. Water quality of the coastal springs, represented by water from Baron outlet demonstrates that physical and chemical characteristics of the water do not exceed the drinking water standard.
4. The existence of coastal springs in Gunungsewu area is potential to contribute two important roles related to the development of this area to be a national geopark, they are as additional fresh water sources and as geosites or geoheritages, because the springs are generally associated with such unique hydrogeologic phenomena and beautiful coastal landscape.

References

Kusumayudha SB (2009) Detecting springs in the coastal area of the Gunungsewu karst terrain, Yogyakarta Special Province, Indonesia, using fractal geometry analysis. Majalah Iptek, ITS:

Kusumayudha SB (2005) Karst hydrogeology and fractal geometry of Gunungsewu area. Adicita Publisher, 171 pp.

Kusumayudha SB (2004) Introduction to karst hydrogeology. Karst Study Center UPN "Veteran" Yogyakarta, 137 pp

Kusumayudha SB, Santoso A (1998) Underground river of Gunungsewu based on gravity anomaly and the geologic structure patterns. Proc PIT HAGI XXIII: 66-72.

Kusumayudha SB, Zen MT, Notosiswoyo S, Gautama RS (1999). The hydrogeologic system of Gunungsewu. Proc. IAGI The 28^{th} Annual Convention, Vol IV: 73-84

Mandelbrot B (1983) The fractal geometry of nature. WH Freeman & Co, New York, 468 pp

Matthes G (1982) The properties of groundwater. John Wiley & Sons, Canada, 406 pp

Pacitan Regency (2011) Pacitan as global geopark network. Seminar on socialization of Pacitan as Global Geopark Network. Pacitan, 20 July 2012

Peitgen, HO, Jurgen H, & Saupe D (1992) Fractals for the Classroom: Part One Introduction to Fractals and Chaos. Springer Verlag, 450 pp

Sir MacDonald & Partners (1979) Gunung Kidul Groundwater Project Final Report. Geohydrology. Vol 3A. Department of Public Work Republic of Indonesia

Sukmono, S (1996) Fractal Analysis on the seismicity of Sumatera active fault, Proc. Annual Meeting, HAGI XX, 78 - 83

Suyoto (1994) Stratigraphic sequence of the Gunungsewu carbonates.Proc. PIT IAGI XXIII,Vol 1: 19-32

Tricot C (1996) Curves and fractal dimension. Springer Verlag, 323pp

Unesco (2010) Guidelines and Criteria for National Geoparks seeking UNESCO's assistance to join the Global Geoparks Network (GGN). Unesco, 12 pp

Van Bemmelen, RW (1949) The Geology of Indonesia. Vol IA, Martinus Nijhoff, The Hague, 792 pp

White WB (1988) Geomorphology and Hydrology of Karst Terrains. Oxford University Press, New York, 464 pp

Xie H (1993) Fractals in Rock Mechanics. A.A. Balkema, Rotterdam, 453 pp