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Original Article

The volcanic aspect on determining Site of nuclear power plant in Indonesia: Gap analysis between standard and regulations

Widjanarko [a], Budi Santoso [a], Rismiyanto [a], Kurnia Anzhar [b], Joko Waluyo [a], Gustini H. Sayid [a], Khusnul Khotimah [a,**], Nicholas Bertony Saputra [a,*], Agus Teguh Pranoto [a], Hadi Suntoko [b], Siti Alimah [b], Sriyana [c], Roni Cahya Ciputra [d], Alfitri Meliana [e]

[a] Research Center for Safety, Metrology, and Nuclear Quality Technology, Indonesia
[b] Research Center for Nuclear Reactor Technology, Indonesia
[c] Directorate of Environment, Maritime, Natural Resources, and Nuclear Policy, Indonesia
[d] Research Center for Nuclear Material and Radioactive Waste Technology, Indonesia
[e] Directorate of Laboratory Management, Research Facilities, and Science and Technology Park, National Research and Innovation Agency, Indonesia

A R T I C L E I N F O

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A B S T R A C T

The development of nuclear power plants is in three phases. The first phase is a consideration before the decision on the NPP construction program is approved, the second phase is the preparatory work for making contracts and preparing for the construction of NPP after the NPP construction policy is approved, and the third phase is contracting, licensing and building the first NPP. As a volcanically active country, Indonesia contains over 130 active volcanoes that are part of the Pacific Ring of Fire. The volcanic aspect is one of the safety factors considered while deciding the location of an NPP. Research on the potential of natural external risks to the determination of nuclear power plants in Indonesia, including the volcanic aspect, has been conducted based on the safety reference or safety guide of the IAEA and the Nuclear Energy Regulatory Body (BAPETEN) Regulation. Due to technological advancements, safety needs have evolved so the existing Indonesia National Standard (SNI) must be updated to comply with BAPETEN regulations. The substance in SNI 18-2034-1990 relating to volcanic features seems less relevant in actual conditions, given that more complete and exact criteria for determining a site guarantee the safety and health of residents and surrounding the environment site. The study intends to conduct a gap analysis of volcanic issues in SNI and volcanic regulations. The method used is identification requirements for volcanic aspects in SNI 18-2034-1990 about Determining Site of Nuclear Reactor Guidance with BAPETEN Chairman Regulation (BCR) number 4 of 2018 about Nuclear Installation Site Evaluation Safety Provisions and BCR number 5 of 2015 about Evaluation of Nuclear Installation Sites for Volcanic Aspects, and analysis uses a qualitative method of inductive techniques. The outcome of this research applies to suggesting a revision of SNI number 18-2034-1990, especially the volcanic aspect.

1. Introduction

BRIN's strategic plan to support State Mid-Term Planning and Development Strategy and Policy Directions for 2022–2024 is the development of nuclear facilities [1,2]. Development of nuclear power plants is a complex work with high technology, has high risks, and uses specially designed equipment. NPP project management has a high level of performance, prudence, economy, integration, accuracy, precision, and safety. According to a recommendation from the IAEA, the construction of NPP has three phases. The first phase is a consideration before the decision on the NPP construction program is approved, the second phase is the preparatory work for making contracts and preparing for the construction of NPP after the NPP construction policy is approved, and the third phase is contracting, licensing and building the first NPP.

As part of the pre-project site study of NPP, prospective sites for nuclear power plants have been identified (Fig. 1), including locations in the Muria peninsula, Banten, Bangka Island, Batam, Serpong, East

* Corresponding author.
** Corresponding author.
E-mail addresses: khus003@brin.go.id (K. Khotimah), nich001@brin.go.id (N.B. Saputra).

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Fig. 1. Prospective NPP sites in Indonesia (drawn from Ref. [3] database).

Kalimantan, West Kalimantan, and West Nusa Tenggara [3,4].

So far, Indonesia has three nuclear power plant sites that have been preferred and evaluated site, namely the Muria, West Bangka, and South Bangka sites. The Muria Peninsula feasibility study was completed in 1996 meanwhile A feasibility study was conducted on Bangka Island from 2011 to 2013 [3,4].

Indonesia has obtained a site permit for an Experimental Power Reactor from BAPETEN in 2017. This site is located in the Serpong Nuclear Area [3].

Development of the NPP requires site safety requirements following applicable regulations. NPP is a sustainable development requiring high-cost investments and high environmental sensitivity, so the selection of NPP sites can be the focus of community controversy [5]. The site selection procedure for a nuclear facility consists of an initial stage of study (pre-survey), a site survey, and a site evaluation [6]. Site evaluation is a procedure that comprises the examination of potential sites, the assessment of the selected location, the confirmation and completion of the survey during the pre-operational stage of the installation, and the end of the operational stage installation [7]. The site evaluation is to produce a safe, proper, and suitable site according to safety and non-safety aspects and applicable standards. Site evaluation demands focus on site characteristics, obtainable data and information, functional records, regulatory procedures, assessment methodologies, and safety requirements [8]. Indonesia, being a volcanically active country, has roughly 130 active volcanoes that are part of the Pacific's Ring of Fire. Out of these, 117 are Holocene [9]. One of the studies of the potential of natural external hazards to the determination of nuclear power plants in Indonesia is the volcanic aspect [6]. Seismic and volcanic hazard potential are key factors to consider when locating an NPP and must be assessed together because they are inextricably linked [10]. SSG-21 IAEA, 2012 provides recommendations and general guidelines for hazard evaluation of volcanic phenomena. In the seismic aspect hazard assessment, a comprehensive assessment has committed the volcanic hazard assessment model has not been reviewed, evaluated, and tested regulatory conformity in evaluating hazards at the proposed NPP site [11].

Regulations and standards used for NPP siting in Indonesia regarding volcanic aspects are Nuclear Energy Regulatory Body (BAPETEN). BAPETEN Chairman Regulation (BCR) number 4 for the year 2018 about Nuclear Installation Site Evaluation Safety Provisions, BCR number 5 for the year 2015 about the Evaluation of Nuclear Installation Sites for Volcanic Aspects, and Indonesia National Standard (SNI) number 18-2034-1990. BCR already aligns with SSG-21 IAEA, 2012, which offers recommendations and general guidelines for evaluating volcanic hazards. In terms of seismic hazard assessment, a thorough evaluation is needed to ensure the volcanic hazard assessment model complies with regulatory standards for assessing hazards at the proposed nuclear power plant site. BCR number 5 of 2015 and BCR number 4 of 2018 are regulations that ensure the requirements for the volcanic aspect are met by Owners who will build a nuclear power plant, particularly in site evaluation. BCR number 5 of 2015 details the requirements for the volcanic aspect, while BCR number 4 of 2018 prioritizes safety aspects in determining the nuclear power plant site. BCR number 4 of 2018 regulates the site selection requirements from various aspects, including the volcanic aspect, referring to the IAEA SSG-21, thus directly linking to BCR.

Several studies have evaluated volcanic hazards at potential nuclear power plant sites in Indonesia, following guidelines, regulations, and standards. The volcanic hazard assessment at the Muria site focused on volcanic phenomena within a 150 km radius and was carried out in 1999 and 2003. The results indicated safety from potential impacts such as pyroclastic flows, lahars, and base surge avalanches, considering the last volcanic activity at Mount Muria occurred 320,000 years ago and the volcano has been inactive for a long time, hence the low likelihood of a volcanic eruption at Mount Muria [12,13]. The volcanic hazard assessment at the West Kalimantan site was also conducted within a 150 km radius of the planned nuclear power plant site. Several old Mesozoic volcanic rocks were found due to past magmatic volcanic activities that are no longer active within that radius. Consequently, the Kalimantan site is assured of safety from volcanic hazards that could disrupt the installation and operation of the nuclear power plant [14]. Using probabilistic lahar methods, the volcanic hazard assessment at the Serpong site was conducted within a 150 km radius of the Experimental Power Reactor (RDE) construction site. Volcanoes with lahar hazard potential reaching the RDE site originate from Mounts Gede and Salak. Probabilistic analysis results indicated a potential lahar volume of 60 million m^3 from Mount Salak spreading along 35.35 km, posing no impact on the RDE site located 41 km away. Similarly, the lahar range from Mount Gede extends 37.7 km without impacting the site 60 km away [15].

Currently, the substance related to volcanic aspects in SNI 18-2034-1990 is less relevant to the provisions of the applicable laws and regulations. It is besides, based on the National Standardization Agency of Indonesia (BSN) Regulation No. 6 of 2018 regarding the review of SNI (at least every 5 years [16]). So, it is imperative that SNI 18-2034-1990 is revised and standard renewal. Therefore, the purpose of this study is to revise the specific sections of SNI 18-2034-1990, especially the volcanic aspect that requires updating to ensure that stakeholders, especially those involved in nuclear power plant construction in Indonesia, have access to the most current and up-to-date standards. To achieve these goals, nuclear power plants in Indonesia are built to the highest safety and quality standards.

2. Methodology

The research employs a qualitative method of inductive procedures, including a literature review, secondary data collection (SNI 18-2034-1990, BCR 5 in 2015, and 4 in 2018), and analysis. The data acquired

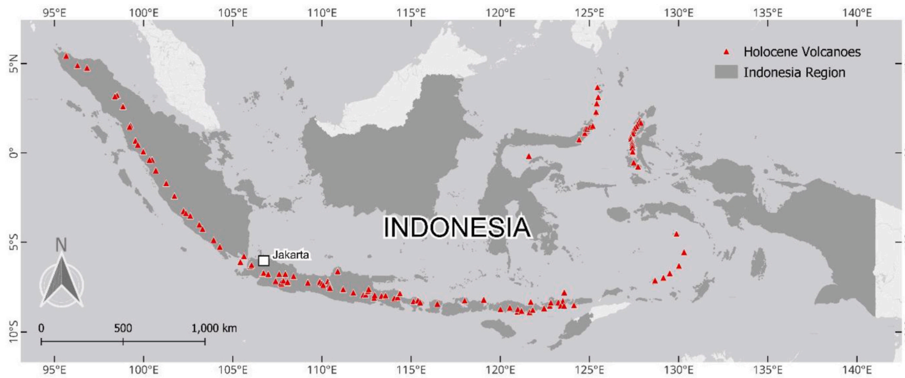

Fig. 2. Indonesia's Holocene Volcanoes (drawn from Ref. [31] database).

are gap analysis concepts from literature studies and in-depth focus group discussions (FGD) with related resource persons for aspects of volcanoes. Members of the FGD were qualified individuals who had previously conducted site studies.

The analysis approach uses descriptive analysis. Specifically, the gap analysis format suggested in Channon & Sammut-Bonnici's 2015 theory of gap analysis [17] to determine the standardization of volcanic features to ensure that they satisfy the appropriate criteria. This gap study will examine the requirements, appropriateness, and non-conformity of SNI 18-2034-1990 connected to volcanic issues with BCR regulations number 5 in 2015 and number 4 in 2018. If SNI fails to comply with regulations concerning the volcanic aspect, an action plan will be implemented. This gap analysis's action plan and results are significant for identifying the latest parameters in nuclear site evaluation and developing guidelines for determining the most current nuclear reactor site. Following that, recommendations for the formulation of the results will be made.

3. Fundamental principles of NPP safety aspects against potential volcanic hazards

Site evaluation requires information about dating certificates for rock samples from surrounding the volcano, such as the interpretation of volcanic material products in a 1 km radius from the site [18]. This information is required to assess the risk of eruption impacts on site selection. All knowledge concerning the potential impact of future eruptions is a reference in deciding reaction planning, operational plans, and the development and improvement of land use planning programs that do not already incorporate volcanic hazards [19]. The IAEA Guidelines on Volcanic Aspects are primarily concerned with the possible risk of volcanic activity from land volcanoes and tsunami hazards from marine volcanic activity. It is intended to emphasize that volcanic tephra is potentially the cause of volcanic hazards for nuclear facilities, which is an urgent concern potential volcanic hazard for nuclear reactors [20]. Aside from the danger of volcanic eruptions, another important aspect to note is the deformation of the volcano. In its development, it turns out that volcanoes can experience changes in shape, so it needs to be studied regarding the rate, duration, and process of deformation [21].

NPP must be constructed so that it is not disrupted by volcanic events that may occur, which can impair safety during the building, commissioning, and operation periods [22]. These comprise the collections of volcanological data and technical recommendations for volcanic hazard assessment for nuclear power facilities. It is vitally important for NPP to protect nuclear safety from volcanic phenomena [23–25].

Available numerical data and methods for predicting the capabilities of adjacent volcanoes that may erupt in the future and cause possibly dangerous events at those sites. Initial assessment of potential volcanic hazard phenomena using the filtering distance value approach [25].

In determining the site of the NPP, various parameters need to be considered, such as health, safety, and security parameters, including the magnitude and periodic of natural hazards, and radiological impact characteristics. Natural hazards that need to be considered are earthquakes, volcanoes, landslides, floods, tsunamis and other coastal hazards, and extreme meteorological events, among many others. This is by the site selection guidelines set by the IAEA [26]. Based on this, it can be concluded that the stages of determining the location of the NPP site are regional analysis, followed by the screening and comparison stage of potential sites, and the last is site screening determined by boundaries and under the effective control of management [27].

4. Result and discussion

SNI 18-2034-1990 is a standard for implementing nuclear reactor site evaluation activities. This standard serves as a guideline in site determination by implementing evaluation activities on aspects that affect site safety, operating conditions, and accident conditions that exceed the design basis. The aspects in question include aspects of seismicity, volcanoes, geotechnical, meteorological and hydrological, human-induced event aspects., and dispersion of radioactive substances. "The proposed site for a nuclear reactor must be tested taking into account the frequency and severity of natural and human-caused occurrences and phenomena that may impair the installation's safety," according to clause 2.1.2 [28]. Indonesia's geographical location, which is part of the Pacific Ring of Fire and has 117 Holocene volcanoes out of 130 active volcanoes (Fig. 2), should be assessed to comprehensively explain of the impact of volcanic features on nuclear power plant site selection. Thus, in 2015, BAPETEN, Indonesia's nuclear regulatory body, published BCR number 5 on the Evaluation of Nuclear Installation Sites for Volcanic Aspects. Later, BAPETEN produced a more comprehensive rule, BCR number 4 in 2018, which includes not only the volcanic aspect but also the seismic aspect, geotechnical aspect, meteorological and hydrological aspect, and human-induced event aspect [29,30].

BCR number 5, the year 2015, contains 12 articles that regulate the stages of evaluating nuclear installation sites for volcanic aspects, including.

- Compilation of volcanic data and information;
- Evaluation of potential volcanic products; and
- Volcano hazard evaluation

BCR number 5, the year 2015, also stated that probabilistic methods are used to determine the probability of an Active Volcano. Further evaluation is unnecessary if the probability of an Active Volcano in a geographical area is less than 10^{-7} per year, further evaluation is not necessary. In deterministic methods, the probability of an Active Volcano can be determined based on the quiet period, which is the

Table 1
Gap Analysis SNI 18-2034-1990 in comparison with BAPETEN Chairman Regulation number 4 in the year 2018 and BAPETEN Chairman Regulation number 5 in the year 2015.

No	BCR No. 4 the year 2018	BCR No. 5 the year 2015	Manual SNI 18-2034-1990	Result
1	**Article 17**	**Article 4** **Verse 1** **Verse 2**	No explanation	**Clause x.x.x** The organization shall evaluate an evaluation of the nuclear plant site for the volcanic aspect of the site and the surrounding area.
2	**Article 18**	**Article 5**	**Clause 2.1.3** **Clause 2.2.2** **Clause 2.2.3**	**Clause x.x.x** Collection of volcano data and information **Clause x.x.x** Volcano evaluation **Clause x.x.x** Determination of values of volcano design parameters
3	**Article 19** **Verse 1** **Verse 2**	**Article 6** **Verse 1** **Verse 2** .	**Clause 3.11.1**	**Clause x.x.x** Data collection of information on volcanic activity that occurred more than 10,000,000 years and/or volcanic activity that occurred less than 10,000,000 years must be carried out. **Clause x.x.x** Determining the age of volcanic activity requires collecting geological, geophysical and volcanic information in the geographical area around the site with a radius of at least 150 km from the site depending on geological and physiographic conditions. Geology, geophysics and volcanic information can be obtained from national and international volcano catalogs or databases. Geological, geophysical and volcanic information in the geographical area around the site is presented in a map with a scale of 1:250,000.
4	**Article 20** **Verse 1** **Verse 2** **Verse 3** **Verse 4** **Verse 5**	**Article 7** **Verse 1** **Verse 2** **Verse 3** **Verse 4** **Verse 5**	No explanation	**Clause x.x.x** a. Preliminary assessment; b. characterization of volcanic activity sources; and c. screening of volcanic products **Clause x.x.x** Preliminary assessment using disaster-prone maps established by the agency that organizes government affairs in the field of geology field must be carried out. **Clause x.x.x** Assessment characterization of the source volcanic activity should be carried out to determine the probability of eruption or volcanic activity identified at the initial assessment **Clause x.x.x** The organization shall conduct screening of volcanic products such as pyroclastic flows, lava flows, avalanches of robbery materials, landslides, slope failures, the opening of new vents, soil deformation, tephra ash, lahars, missiles, volcanic gases, tsunamis, and upright waves, and atmospheric phenomena. **Clause x.x.x** If an area with a radius of 5 km from the site is a disaster-prone area determined by government agencies in the field of geology field, the site is declared unfeasible.
5	**Article 21** **Verse 1** **Verse 2**	**Article 8** **Verse 1** **Verse 2** **Verse 3** **Verse 4** **Verse 5**	No explanation	**Clause x.x.x** Volcano aspect evaluation activities must be carried out by the organization if there is a potential occurrence of one of the volcanic products such as pyroclastic flows, lava flows, avalanches of robbery materials, landslides, slope failures, the opening of new holes, soil deformation, tephra ash, lahars, missiles, volcanic gases, tsunamis and upright waves, and atmospheric phenomena. **Clause x.x.x** The results of the volcano hazard evaluation are quantified into design parameter values.
6	**Article 22**	**Article 9** **Verse 1** **Verse 2**	No explanation	**Clause x.x.x** Provisions regarding Site Evaluation of Nuclear Installations for volcanic aspects are regulated in other relevant Government Regulations.

maximum period between one eruption and the next, the age trends and characteristics of rocks, and eruption time-volume trends.

BCR number 4, the year 2018, contains the same article as BCR number 5, 2015, regarding the volcanic aspect.

The results of the gap analysis from the FGD and literature study activities are shown in Table 1. Overall, this gap between BAPETEN and SNI regulations is discussed in depth and focused on volcanic aspects. Characterizing past volcanic eruptive activity forms the foundation for a long-term volcanic hazard assessment. It can be used to understand better the risk of eruption recurrence and the probability of future eruptions [32].

Article 19 Verse 1 BCR number 4 for the year 2018 defines the collection of volcanic data and information as data and information from volcanic activity that happened more than and or less than 10 million years ago. Furthermore, if the area within 5 km of the location is considered disaster-prone, the site will appear impractical. The Nuclear Regulatory Commission of the USA (US NRC) discussed the rationale for the period of interest and the rationale for the region of interest. US NRC staff consider the Quaternary Period (i.e., the last 2.6 million years) as providing sufficient margin for the historical period and that low-likelihood events have been captured in the geologic record, such that projections of future events can be reasonably based on this record [33]. Additional studies determined the potential volcanic hazards are indicated by either (1) a Quaternary volcano within the 320 km (200 mi) region around the proposed site or (2) a volcanic deposit within the 40

Table 2
The Recorded Eruption Data of Mount Kelud since 1848 illustrates the range of impacts caused by Lahar Eruptions.

Date of eruption	The crater lake's water (million m^3)	Tephra volume (million m^3)	Eruption duration (hours)	Damage radius (km)	Extent of eruption lahars (km)	Extent of pyroclastic flows (km)	Note/ Sources
May 16, 1948	48,7	–	4	Unknown data	27	Unknown data	[35]
3–4 January 1864	–	–	–	Unknown data	27	Unknown data	[35]
22–23 Ma y 1901	–	200	–	6	27	Unknown data	[35]
May 20, 1919	40	190	–	5–7	37,5	10	[35]
August 31, 1951	1,8	200	11,5	4-6,5	–	6,5	[35]
April 24, 1966	21,6	90	7	2–5	31	9	[35]
February 10, 1990	2,5	130	8	1–5	15	5	[35]

km (25 mi) vicinity of the proposed site from a Quaternary volcano located more than 320 km (200 mi) away. If neither of these conditions occurs, an organization would not be expected to asses of volcanic hazards."

In addition to the data and the distance from the volcano, a volcanic assessment must consider the characterization of the volcano itself. Assessment of volcanic characterization can help establish standard eruption patterns. For example, the volcanic products of Mount Kelud have a significant impact. This stratovolcano is known for its explosive eruptions located in the Central Zone, the most active among other mountains, situated on the borders of Kediri, Blitar, and Malang Regencies in East Java, Indonesia. The volcanic materials ejected during Kelud's eruptions include ash and gravel (lapilli, rocks, sand, and chunks up to 30 cm in size), accompanied by pyroclastic flows. The sand and gravel materials can reach distances of up to 20 km. The eruption on February 13, 2014, reached an estimated height of 17 km, significantly higher than the 1990 eruption of 8 km, with an ejected material volume of 100 million cubic meters. The spread of volcanic ash not only affected East Java, Yogyakarta, and Central Java provinces and reached parts of West Java, such as Banjar, Tasikmalaya, Ciamis, and even Bandung City. Large rock fragments fell within a 3 km radius from Kelud's summit, while sand and gravel scattered up to 100 km from Kelud's crater. Ashfall was widespread, particularly in the western regions of Java, including Central Java and parts of West Java. The volcanic ash eruptions occurred in two distinct phases, the first being an explosive eruption that destroyed the lava dome, resulting in varied patterns of pyroclastic material distribution influenced by prevailing wind directions. The formations can be observed through various deposits found after the eruption. Field surveys conducted by relevant parties have provided data showing the initial and subsequent eruption patterns, which can be seen through an isopach map. The map indicates the eruption results forming a 17–18 km high eruption column with pyroclastic material spreading westward towards the Sukabumi region and partly northward towards Surabaya. Volcanic ash spreading eastward is not as extensive, only reaching up to 5 km away from the peak due to strong winds blowing westward. The recorded eruption data of Mount Kelud since 1848 illustrates the range of impacts caused by Lahar eruptions [34–36] as shown in Table 2.

As a result, when analyzing a volcano, it is necessary to evaluate every aspect of geological processes that drive magma to ascend to the earth's surface [37]. It is not in the SNI or BCR publications, but it could be valuable in enhancing documents appropriate in Indonesia.

The study results show that the SNI 18-2034-1990 needs a new clause containing the organization for site evaluation and must conduct a nuclear installation site evaluation for the volcanic aspect of the site and its surrounding areas. A detailed explanation of volcanoes, the natural events of volcanoes, and the time range for collecting data on volcanic activity is needed. Special provisions are needed to assess the volcanic aspects in the category of natural phenomena. It completes the differences and similarities in the principles of hazard evaluation listed in BCR number 4 of 2018 and BCR number 5 of 2015 including the provision regarding the evaluation of nuclear installation sites for volcanic aspects. So those are all recommendations for changes to each item comparing the SNI 18-2034-1990 document to the BCR number 5 in the year 2015 and BCR number 4 in the year 2018.

5. Conclusions

After comparing the SNI 18-2034-1990 document using qualitative methods of inductive techniques related to volcanic aspects against BCR documents number 5 of 2015 and BCR number 4 of 2018, it found that the SNI 18-2034-1990 document is no longer compatible to be used as a reference for evaluating the location of the NPP because it does not provide detailed information for various aspects of natural events, one of which is the volcanic aspect. The gap analysis results indicate that recommendations are needed to update the SNI document 18-2034-1990. They are clauses about the organization's need to undertake volcanic site evaluations, stages of volcanic site evaluations, and explanations about volcanic data collection and information. Furthermore, clarifications regarding the appraisal of the potential of volcanic products are required, such as the characterization of sources of volcanic activity, the screening of volcanic products, and the determination of the radius of disaster-prone areas that do not meet the requirements. The results of this study will be a recommendation to revise SNI number 18-2034-1990, especially the volcanic aspect.

CRediT authorship contribution statement

Widjanarko: Writing – original draft, Visualization, Supervision, Project administration, Funding acquisition, Writing – original draft, Visualization, Supervision, Project administration, Funding acquisition. **Budi Santoso:** Writing – original draft, Resources, Project administration, Funding acquisition, Conceptualization. **Rismiyanto:** Visualization, Project administration, Funding acquisition, Visualization, Project administration, Funding acquisition. **Kurnia Anzhar:** Validation, Supervision, Methodology, Investigation, Formal analysis. **Joko Waluyo:** Supervision, Project administration, Funding acquisition. **Gustini H. Sayid:** Supervision, Project administration, Funding acquisition. **Khusnul Khotimah:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Funding acquisition, Conceptualization. **Nicholas Bertony Saputra:** Writing – review & editing, Writing – original draft, Resources, Investigation, Funding acquisition, Conceptualization. **Agus Teguh Pranoto:** Supervision, Project administration, Funding acquisition. **Hadi Suntoko:** Visualization, Validation, Resources, Formal analysis, Conceptualization. **Siti Alimah:** Validation, Supervision, Methodology, Funding acquisition, Formal analysis, Conceptualization. **Sriyana:** Validation, Investigation, Formal analysis, Data curation, Conceptualization, Validation, Investigation, Formal analysis, Data curation, Conceptualization. **Roni Cahya Ciputra:** Software, Resources, Data curation. **Alfitri Meliana:** Writing – original draft, Resources, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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