GIS-based multi-criteria analysis for nuclear power plant site selection in West Kalimantan

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Abstract. Nuclear power is set as the highest priority to slow global warming, so the construction of a nuclear power plant (NPP) using nuclear reactors as a source of heat energy is initiated to produce pollution-free electricity. Bengkayang and Mempawah Regencies in West Kalimantan provinces are selected as prospective NPP locations based on the exclusion and discretionary criteria. The exclusion criteria consist of the geological structure, types of bedrock, the existence and sufficiency of the cooling water, proximity to the population center, and terrain shape. Meanwhile, the discretionary criterion is proximity to the road network. This study aims to map and analyze the exclusion and discretionary criteria for potential NPP. The multi-criteria analysis in this study includes screening analysis, regional suitability analysis, and descriptive spatial analysis. It is performed using the Geographic Information Systems (GIS) technique on spatial data information. The screening process produced six potential locations to be used as NPP. Five locations are in Bengkayang Regency, precisely in Sungai Raya Kepulauan District and Sungai Raya District. Another location is in Mempawah Regency, precisely in Sungai Kunyit District.

1. Introduction

The current supply of electrical energy is still dominated by non-renewable fossil energy (43% petroleum, 28.7% coal, 22% natural gas, and 6.2% renewable energy) [1]. Electric Steam Power Plant (PLTU) is still the largest contributor to electricity supply of 16,897.00 MW, Gas Power Plant (PLTG) is 3,616.47 MW, Gas and Steam Power Plant (PLTGU) is 8,894.11 MW, Diesel Power Plant (PLTD) is 2,292.49 MW, and Hydroelectric Power Plant (PLTA) is 3,410.62 MW [2]. Of the various kinds of power plants, the largest sources are oil and coal. New and renewable energy, such as nuclear energy, has been announced as a substitute for fossil energy sources. Nuclear power is set as the highest priority to slow global warming, so the construction of a Nuclear Power Plant (NPP) using nuclear reactors as a source of heat energy is initiated to produce pollution-free electricity [3].

Presidential Regulation Number 5 of 2006 concerning the National Energy Policy states that 5% of nuclear energy is used for power generation until 2025 [4]. This policy is strengthened in Law Number 17 of 2007 concerning the Long-Term Development Plan for 2005-2025 [5]. This law mandates the use of nuclear energy as power plants in 2015-2019 with strict conditions. According to Government Regulation Number 79 of 2014 concerning National Energy Policy, the target for new and renewable energy in the national energy mix in 2025 is 23% [6]. In the West Kalimantan Provincial Medium-Term
Development Plan (RPJMD) 2013-2018, NPP as a type of power generation technology has been included as a source of EBT to meet the electricity needs of the region [7].

The NPP location needs to be properly selected and evaluated adequately so that plant planning can ensure that structures, systems, and components which important for safety must continue to operate against normal conditions and abnormal operating conditions arising from internal and external events [8]. However, NPP construction still has many obstacles related to public acceptance of nuclear technology to date [9]. The problem that often arises is the determination of the location of the NPP itself. The generator's location has become a persistent problem. Construction is constantly being canceled due to location conflicts, so a solution is needed to choose the NPP's best location. The IAEA guidelines state that prospective NPP locations are obtained at the regional analysis stage. By the safety principle of nuclear technology, NPP's location selection must meet various predetermined safety requirements [10]. The criteria stipulated in the regulation state that a good location must be protected from natural external events that are destructive (natural external events). These natural events are active faults, volcanic eruptions, large shallow earthquakes, subsurface material support, river and coastal flooding, and extreme weather. Besides, external events can also arise because of human activities (human-induced events), including explosions in chemical plants, military facilities, and aircraft crashes. Natural events can be considered through historical data, analysis, and studies of their damage [11]. The screening method is used to produce a thematic map of NPP's potential locations, which can help determine the location conflicts of potential NPP in a simple way. This research is useful to help stakeholders carry out further research on the potential locations of NPP produced. This study aims to map and analyze the exclusion and discretionary criteria for potential NPP. This study's multi-criteria analysis includes screening analysis, regional suitability analysis, and descriptive spatial analysis using Geographic Information Systems (GIS) technique on spatial data information.

2. **Methodology**

2.1. **Study area**

West Kalimantan is a strategic area to build an NPP for several reasons: the soil and rocks are relatively stable with a low seismic rate, both tectonic and volcanic earthquakes. Likewise, from a demographic point of view, with low population conditions and a large area, the potential impact of radiation on the population per area is relatively small [11]. Bengkayang Regency and Mempawah Regency were chosen as potential NPP locations because they were close to industrial development sites, especially the construction of the Smelter Grade Alumina (SGAR) factory and Kijing Port in Mempawah Regency. Besides, in Bengkayang Regency and Mempawah Regency, there were Mempawah Substation and PLTU PBSB Substation (Parit Baru Site Bengkayang) so that with the construction of NPP it could supply electricity for the needs of the area so that it could reduce electricity consumption from neighboring countries. These two districts were selected as candidates for the NPP location based on the exclusion and discretionary criteria. Exclusion criteria consisted of the geological structure, rock type, presence and availability of cooling water, proximity to population centers, and terrain, while discretionary criteria were proximity to the road network. Therefore, the NPP is expected to anticipate the demand for electricity, which is projected to increase.
2.2 Screening
In this study, the screening method was chosen to determine the potential location of NPP. The screening process uses a grid with the fishnet tool covering 400 hectares for one grid. The screening was carried out starting from the exclusion criteria, then the results of the exclusion criteria screening process were filtered with discretionary criteria. The results of the discretionary criteria screening process are potential locations for NPP [12–17].

Table 1. Research variable.

| No.  | Variable                                | Suitable                                                                 | Unsuitable                                                                 |
|------|-----------------------------------------|--------------------------------------------------------------------------|---------------------------------------------------------------------------|
| 1    | Geological Structure                    | Located >5.000 meters from capable faults                               | Located <5.000 meters from capable faults                                 |
|      |                                         | Igneous rock                                                             | Sedimentary rock, Alluvium rock                                           |
| 2    | Rock Type                               | Located <8.000 meters from the river                                     | Located >8.000 meters from the river                                       |
| 3    | Existence and Sufficiency of Cooling Water (river) | Located >8.000 meters from the population center                         | Located <8.000 meters from the population center                           |
| 4    | Proximity to Population Center          | Wavy and Wavy-Bumpy                                                     | Flat, Bumpy-Hilly, Hilly-Mountainous, Steep Mountain                     |
| 5    | Terrain Shape                           | Located <5.000 meters from Road Network                                  | Located >5.000 meters from Road Network                                   |
| 6    | Proximity to Road Network               |                                                                           |                                                                           |

Exclusion criteria were used to select unsuitable locations based on variables relating to problems, events, phenomena, or hazards for which there is no generally feasible technical solution. Discretionary criteria are associated with variables related to problems, events, phenomena, hazards or other considerations for a technical solution. In this study, the exclusion criteria used were geological.
structure, rock type, presence and availability of cooling water, proximity to population centers, and terrain. The discretionary criterion in this study is the proximity to the road network.

3. Results and discussion
The screening process was carried out with exclusion criteria consisting of the geological structure, rock type, existence and sufficiency of cooling water, proximity to population centers, terrain shape, and discretionary criteria, namely proximity to road network resulting in six grids of potential NPP. The six grids are in Bengkayang Regency and Mempawah Regency. Five grids are in Bengkayang Regency, and one other grid is in Mempawah Regency. Based on figure 2, the six grids are 9K, 11O, 13O, 13P, 17O, and 20M. The shaded grid indicates that the grid is not suitable for the location of the NPP. Meanwhile, the unshaded grid shows that the location is feasible to become a potential location for NPP.

9K grid is in the west of Sungai Raya Kepulauan, Bengkayang Regency. The screening results of the exclusion and discretionary criteria show that the 9K grid is included in the potential location of the NPP. The 9K grid has a fairly safe distance from the existence of geological structures, has strong rock types, and is not far from the existence and sufficiency of cooling water because it is in the Raya River's reach. The 9K grid is also far from the center of the population, has flat and choppy terrain, and has a location close to arterial roads because Jalan Ahmad Yani crosses the 9K grid.

11O grid is in the southern district of Sungai Raya Kepulauan Bengkayang Regency. The screening results of the exclusion and discretionary criteria show that the 11O grid is included in the NPP's potential location. The 11O grid has a safe enough distance from geological structures, has strong rock types, and is not far from the existence and sufficiency of cooling water because it is in the Raya River's reach. The 10K grid is also far from the center of the population, has choppy terrain, and has a location close to arterial roads because Jalan Ahmad Yani crosses the 11O grid.

13O grid is in the north of Sungai Raya District, Bengkayang Regency. The exclusion and discretionary criteria' screening results show that the 13O grid is included in the NPP's potential location. The 13O grid belongs to a fairly safe distance from the existence of geological structures, has strong rock types, and is not far from the existence and sufficiency of cooling water because it is in the Duri River's reach. The 13O grid is also far from the center of the population, has flat and choppy terrain, and has a location close to arterial roads because Jalan Ahmad Yani crosses the 13O grid.

13P grid is in the north of Sungai Raya District, Bengkayang Regency. Based on the screening results of the exclusion and discretionary criteria, it shows that the 13P grid belongs to a fairly safe distance from the existence of geological structures, has strong rock types, is not far from the existence and sufficiency of cooling water because it is in the reach of the Duri River, is far from the center of the population, has flat and choppy terrain, and has a location close to arterial roads because there is Jalan Ahmad Yani that crosses the 13P grid. So that the 13P grid is included in the potential location of the NPP.

17O grid is in the south of Sungai Raya District, Bengkayang Regency. Based on the screening results from the exclusion and discretionary criteria, it shows that the 17O grid is a safe enough distance from the existence of geological structures, has strong rock types, is not far from the existence and sufficiency of cooling water because it is in the reach of the Duri River, is far from the center of the population, has flat and choppy terrain, and has a location close to arterial roads because there is Jalan Ahmad Yani that crosses the 17O grid. So that the 17O grid is included in the potential location of the NPP.

20M grid is in the west of Sungai Kunyit District, Mempawah Regency. Based on the screening results of the exclusion and discretionary criteria, it shows that the 20M grid is included in a fairly safe distance from the existence of geological structures, has strong rock types, is not far from the existence and sufficiency of cooling water because it is in the reach of the Duri River, is far from the center of the population, has flat and choppy terrain, and has a location close to arterial roads because there is Jalan Ahmad Yani that crosses the 20M grid. So that the 20M grid is included in the potential location of the NPP.
4. Conclusion

Mapping nuclear power plant potential locations in Bengkayang and Mempawah districts based on the exclusion and discretionary criteria resulted in notable potential locations. These locations are reasonably safe distance more than 5 kilometers from the presence of geological structures, have a strong rock type in the form of igneous rock, are not far from the existence of cooling water no more than 8 kilometers, far from the population center more than 8 kilometers, have flat to wavy terrain, and have a location close to arterial road no more than 5 kilometers.

The screening process carried out to determine potential locations resulted in six potential locations to be used as nuclear power plant locations. Five locations are in Bengkayang Regency, precisely in Sungai Raya Kepulauan District and Sungai Raya District. Another location is in Mempawah Regency, precisely in Sungai Kunyit District.

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