Jurnal Pengembangan Energi Nuklir
Laman Jurnal: jurnal.batan.go.id/index.php/jpen

Preferred Site Selection Using GIS and AHP: Case Study in Bangka Island NPP Site

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INFORMASI ARTIKEL

Riwayat Artikel:
Submitted:
6 July 2021
Receive in revised:
9 July 2021
Approved:
12 July 2021

Keyword:
Nuclear power plant
Preferred site
Site vicinity
Geographic information system
Analytical hierarchy process

ABSTRACT

PREFERRED SITE SELECTION USING GIS AND AHP: CASE STUDY IN BANGKA ISLAND NPP SITE. Industrial growth affects the increasing demand for electricity in various places, this also occurs on the island of Bangka. So far, electricity supply has only been obtained from fossil fuel power plants with inadequate capacity, unstable flow and depending on fuel supplies from outside the island. For this reason, it is necessary to build a Nuclear Power Plant (PLTN) which is believed to be reliable and able to overcome these problems. In order to prepare a safe and economical nuclear power plant site, influential parameters such as population density, cooling system, land clearing, cut and fill, and granite for the foundation have been analyzed. The novelty of this analysis lies in 2 methods which gradually used before come up with a final decision, namely spatial analysis and pairwise comparison using Geographic Information Systems (GIS) and Analytical Hierarchy Process (AHP), respectively. The scope of study area is based on the site vicinity (1:5.000) scale, located in the districts of West and South Bangka. The siting process refers to the rules set by the International Atomic Energy Agency (IAEA). Based on the final results of the analysis using the expert choice program, the numerical weights for West Bangka and South Bangka were 0.709 and 0.291, respectively, with a consistency value of 0.03. From this, it can be concluded that the best preferred site is located in West of Bangka Island.

ABSTRAK

PEMILIHAN *PREFERRED SITE* MENGGUNAKAN GIS DAN AHP: STUDI KASUS TAPAK PLTN DI PULAU BANGKA. Pertumbuhan industri berpengaruh terhadap meningkatnya kebutuhan listrik di berbagai tempat, hal ini juga terjadi di pulau Bangka. Selama ini pasokan listrik hanya diperoleh dari pembangkit listrik berbahan bakar fosil dengan kapasitas yang tidak memadai, aliran yang tidak stabil dan bergantung pada pasokan bahan bakar dari luar pulau. Untuk itu perlu dibangun Pembangkit Listrik Tenaga Nuklir (PLTN) yang diyakini handal dan mampu mengatasi permasalahan tersebut. Untuk mempersiapkan lokasi PLTN yang aman dan ekonomis, parameter yang berpengaruh seperti kepadatan penduduk, sistem pendingin, pembukaan lahan, cut and fill, dan granit untuk pondasi telah dianalisis. Kebaruan pada kajian ini terletak pada pengambilan suatu keputusan akhir yang dilakukan secara bertahap menggunakan 2 metode yaitu *spatial analysis* dan *pairwise comparison* dengan menggunakan sistem Informasi Geografis (SIG) dan Analytical Hierarchy Process (AHP). Ruang lingkup kajian ini dilakukan berdasarkan skala *site vicinity* (1:5.000) pada daerah yang terletak di Kabupaten Bangka Barat dan Selatan. Proses penentuan tapak mengacu pada aturan yang ditetapkan oleh Badan Tenaga Atom Internasional (IAEA). Dari hasil akhir analisis menggunakan program *expert choice* diperoleh bobot angka untuk Bangka Barat dan Bangka Selatan masing-masing sebesar 0.709 dan 0.291, dengan nilai konsistensi 0.03. Dari hasil analisis dapat disimpulkan bahwa *preferred site* terbaik terletak di Bangka Barat.

Kata kunci: Pembangkit listrik tenaga nuklir, *Preferred site*, *Site vicinity*, Sistem informasi geografis, *Analytical hierarchy process*

1. INTRODUCTION

Economic and population growth may raise the electricity energy demand. This is mostly occur in many provinces in Indonesia. This trend also impact to the island of Bangka. Recently, the existing systems of electricity in Bangka Belitung Province are divided into two separate systems, which are Bangka Island and Belitung Systems. This system mostly supply by diesel power, and a few of renewable energy such as solar panel and pico hydro. However, these energy supply only generate small capacity, work intermittently and depend on fuel supply from outside of the island. Based on the study of the State Electrical Company for Bangka Belitung in the year of 2012, the electricity demand was increasing rapidly, meanwhile the supply was in stagnancy [1]. Nevertheless, until 2012 the electrification

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indicate that only 87.78% village was electrified. To make it worse, there are only 15 out of 64 villages in West Bangka Regency has no electricity supply at all [1]. For all of this reasons, it is necessary to build a Nuclear Power Plant (NPP) which is believed to be reliable and able to overcome these issues. There are some of NPP technologies that suitable to fulfil the electricity demand such as APR1400, AP1000, VVER, and ATMEA1. However, since the lack of information among these reactors, only AP1000 is considered to be the adequate ones. The AP1000 is a two-loop Pressurize Water Reactor (PWR) that able to generate a net power output of 1117 MWe. Furthermore, the design of this reactor is less expensive than another design reactors because it requires a smaller number of components, such as pipes, wires, and valves inside the installation [2]. All of the study in this paper including the site and non-site parameter refer to this reactor technology.

To support the preparation of the NPP development which comply with safety rules, it is necessary to carry out a siting process based on the recommendations of the International Atomic Energy Agency (IAEA). Site survey activities in the area of interest received enormous spatial data in the form of parameters that must be quantified in certain value and weights. The parameters that are considered to be significant are population density, transmission line, land availability, nearest seaport, land clearing, cut and fill, and seismicity. These parameters were chosen based on the premise that they will have a huge influence in defining the decision from the safety and economic aspect point of view. Geographic Information System (GIS) and Analytical Hierarchy Process (AHP) are applied to analyze spatial data and weights, respectively. The GIS is applied in this study to process and analyze the enormous spatial data, while the AHP contributes to define the relation among those by assigning the weights to come up with the final decision.

In concept, AHP is to define a goal which involve many parameters and translate into weighted. The next step is to score each parameter and calculate a weighted score for each criteria. The process is similar to a weighted score from a spreadsheet, but with a couple of important differences. AHP was developed in 1970s. Since then, the knowledge on good decision-making increased significantly and scientists have developed lots of new decision making methodologies such as project prioritization and selection, procurement, site selection, technology selection, strategy development as well as evaluating different design options.

The area of interest is obtained based on general criteria through data collection, identification of interpretations and field confirmation in a limited scope. The selection of coastal areas are based on the premise that the development of NPP project requires access to heavy equipment transportation via ships and the need for cooling water from the sea water as well as to foster industrial development in the area. From the site survey activities in 2012, it was decided that the interest area was situated in the West and South coastal areas in the island of Bangka. The scope of study area is based on the site vicinity (1:5.000) scale, located in the districts of West and South Bangka. The objective of this research is to select the preferred site for constructing a Nuclear Power Plant between two alternative locations which are situated on the West of Bangka (hereinafter referred to as WB) and on the South of Bangka (hereinafter referred to as SB).

2. METHODOLOGY

2.1. Siting Process

Siting is the process of surveying and selecting of a site to build an NPP (Figure 1 and 2). Selection of an appropriate tread is one of the elements of the concept of defense in depth to prevent accidents. This siting process is a part of the whole process which is siting and site evaluation process (Figure 1) [3].

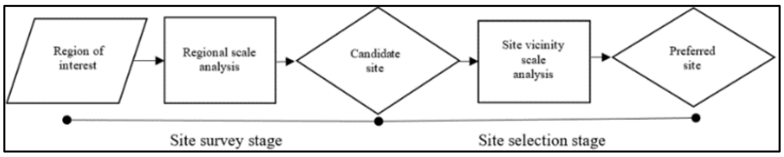

Figure 1. Siting process.

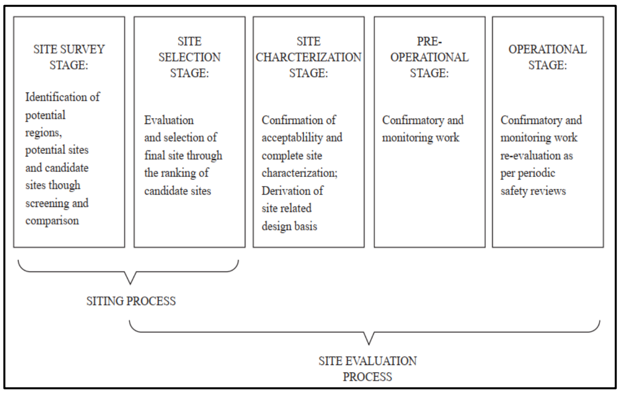

Figure 2. Siting and site evaluation process [3].

In site survey activities, a large area is studied to find potential sites and to identify one or more candidate sites. In the site selection activity, unsuitable sites will be rejected and the remaining candidate sites will then be assessed by screening and comparing them on the basis of safety and other considerations then lead to the determination of the candidate site [3]. The scope and scale use in this activities is categorized into regional scale (1:150.000), near regional (1:50.000), site vicinity (1:5.000) and area of interest scale (1:1.000) [4]. For this study, a site vicinity scope in the scale of 1:5.000 is used. Primary and secondary data mainly obtained from the document of Nuclear Power Plant Siting Project at Bangka Island Bangka Belitung Province in the year of 2012 such as master plan, geology, topography, infrastructure, and seismic hazard assessment as well as demography.

2.2. Geographic Information System (GIS)

GIS is a platform for collecting, managing, and analyzing data. GIS gathering spatial and non-spatial data. It processes spatial data and its attributes into visualizations and put it into the maps [5]. Abundance of primary and secondary data has been successfully obtained from the Nuclear Power Plant site survey activities in the Island of Bangka. These data consist of spatial data in the form of maps with regional scales along with their attributes. The GIS has been performed to conduct the spatial analysis for calculating distance, wide area for land clearing, volume for cut and fill, overlaying the depth of bed rock, as well as positioning the electricity network. These spatial analysis methods has been used for this research for:

2.2.1. Population density.

This is include define the location based on the satellite imagery map of population density per village in radius of 80 km. The data is obtained from the Statistical Agency (BPS) refers to the year of 2011. The new existing public record data were collected from the local government.

2.2.2. Cooling System

The cooling systems used in condenser for both WB and SB NPPs is once-through cooling system that needs large amount of water for cooling the used steam from turbine. Therefore, the recommended location should be close to the sea water as a media for cooling system. Non-radioactive waste produced by NPPs includes high temperature wastewater from tertiary cooling system, waste oil spills or substances on the plant construction process and household waste[2]. Wastewater from tertiary cooling system must be treated before disposing into the sea. Oil spills and household wastes can contaminate soil and groundwater so that the waste management and grouping types of generated waste are needed to avoid leak-age of the waste from the tank.

The water requirement for primary cooling system is about 17,400 gallon per minute (GPM), while the water (seawater) demand for the tertiary cooling system is about 1.35 million GPM [2]. Very large water needs for the cooling system has the potential to cause depletion of natural resources. A very abundant seawater resource in Bangka is the reason that sea water should be used for the cooling system. The use of ground water in the cooling system (mainly tertiary) should be avoided because it can interfere with the human needs for groundwater and cause degradation of the quality of the environment such as seawater intrusion and land subsidence. Sea water intrusion occurs when the amount of ground water is reduced causing disruption of the balance between the amount of fresh groundwater and salty groundwater. This will cause the movement of salt water/sea towards the land so that the ground water in the land turned into salt water. Construction of NPPs could affect marine results due to construction of water intake and discharge for the cooling system facilities which needs quite large sea area and create the region as a restricted area. It can reduce the area of fishing for fishermen so it will affect the level of fishermen productivity [2].

2.2.3. Land clearing

To identify the type of land cover and its range can be done from available land cover maps derived from the Quick Bird imagery. The type and extent of land clearing for NPP site can be identified by overlaying the land cover map with the location of the NPP. Land clearing in the initial stages of land preparation can be done by the two main ways is by slashing and burning manually or by mechanical means using large equipment such as bulldozers. The spatial analysis to calculate the area for land clearing is successfully done by overlaying land use map and NPP site map [6].

2.2.4. Cut and fill

The NPP site requires an area of 420 x 420 square meters to place the reactors and other supporting facilities. Filling material will be used for particular location in which the surface height is less than the reference height. As for the land, the land surface elevation shall exceed the land surface excavation references. Cut and Fill should be conducted efficiently and effectively to reduce the cost of work [2]. The method of cut and fill calculations by means of converting contour map of the LIDAR to raster format, with ground level serve as a reference point for the cut area, and overlay contour maps with location map using cut and fill tool in ArcGIS software. The filling material will be used for particular location, in which the surface height is less than the height reference. The land surface elevation shall exceed the land surface excavation references. Cut and fill of land improvement should be conducted efficiently and effectively to reduce the cost of work for the excavation and landfill.

2.2.5. Granite for foundation

Granite layer formation has been assessed by the geotechnical drill on the site, and the result data from the borehole that contains the granite rock layer is overlaid to the map. This granite layer considered to be a stable foundation for the NPP to be constructed [2].

2.3. Analytical Hierarchy Process

The AHP is one of the methods of Multi Criteria Decision Analysis (MCDA). This method is applied when many parameters involve in determine a decision. This is a theory of measurement through pairwise comparisons and relies on the judgment of experts to derive priority scales or weights [7]. As many as 9 colleagues who have a deep understanding and have involved in site survey in the Island of Bangka are invited to be participated as a respondent to fill out the questioners for providing weights. It is these weights that measure intangibles in relative terms. The comparisons are made using a weight of absolute judgment that represents, how much more, one element dominates another with respect to a given attribute.

2.3.1 Evaluation of criterion weights

A weight can be determined as a value assigned to some parameters of its importance relative to other parameter under consideration. The larger the weight, the more important they have [7]. A many of techniques are available to define of weights. In simple cases, assignment of parameter weights can be applied by dividing 1.0 among the parameters. When many parameters are involved and many discrete apply, it becomes complicated to make weight evaluations on the set as a whole. In this case, the weights are then normalized to 1 [8].

The techniques for the development of weights mainly consist of ranking methods, which are the simplest methods for assessing the importance of weights which is every criterion under consideration is ranked in the order of the decision maker's preferences; rating methods, which require the estimation of weights on the basis of predetermined scale; pairwise comparison methods, which involve pairwise comparison to create a ratio matrix; trade-off analysis methods, which make use of direct trade-off assessments between pairs of alternatives [9]. In this study the criterion weights were evaluated using the pairwise comparison, which belong to AHP method.

2.3.2. Application of the AHP method in spatial decision making

2.3.2.1. Problem Decomposition

There are five steps to elaborate the AHP methods [10], begins with the problem decomposition, which is is the step by which an objective (Goal) is determined further systematically into structures that make up a series of systems to achieve goals rationally (Figure 3).

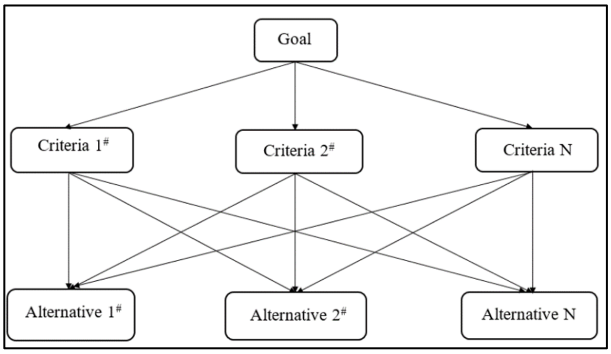

Figure 3. Hierarchy structure of AHP.

2.3.2.2 Scoring/Comparing of the elements

After the decomposition process has been completed and the hierarchy is well established. Then pairwise comparison assessment (weighting) will be applied in each hierarchy based on level relative importance. The scale of the pairwise comparison was introduced by Saaty[7] in Table 1.

Table 1. The fundamental scale of absolute number

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgment slightly favour one activity over another
4	Moderate plus	
5	Strong importance	Expericence and judgment strongly favor one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation

Calculating the criteria scores apply by means of comparing each alternative with pairwise comparison with respect to a specific criterion to obtain the scores of alternatives. The Eigen vectors is obtained after normalizing the judgmental matrices.

In weighting the level of importance or the estimated comparison use reciprocal axiom, it means that if an element of A is more essential (5) than element B, then B is 1/5 more essential than element A. If element A is the same importance with B then the value of each of them is = 1.

2.3.2.3 Matrix Arrangement and Consistency Test.

When the weighting process or 'filling out the questionnaire' has been completed, the next step is preparation of paired matrices to normalize the weight of the level of importance of each element in their respective hierarchies. If the questionnaire has been filled out by some experts, then we will unify the opinions of the experts using equations geometric mean:

$$GM = \sqrt[n]{(X1)(X2)\ldots(Xn)} \quad (1)$$

Where, GM: Geometric Mean, X1= Expert 1, X2 = Expert 2, Xn = Expert n. Then arrange a comparison matrix. For local priorities and consistency of comparisons or calculating the criteria weights, Saaty used the lambda max technique to obtain criteria weights by applying the pairwise comparison method, alternatives are compared pairwise with respect to each criterion to obtain weights [7]. Every matrix has a set of Eigen values and for every Eigen value there is a corresponding Eigen vector. In Saaty's lambda max technique, a vector of weights is defined as the normalized Eigen vector corresponding to the largest eigenvalue λ max. .Once the judgmental matrix of comparisons of criteria with respect to the goal has been evaluated, the local priorities of criteria are obtained and the consistency of the judgments is determined. It has been generally agreed that priorities of criteria can be estimated by finding the principal Eigen vector w of the matrix A. That is:

$$Aw = \lambda_{max}\,{}^{\omega} \quad (2)$$

When the vector is normalized, it becomes the vector of priorities of the criteria with respect to the goal. λmax is the largest Eigen value of the matrix A and the corresponding eigenvector w contains only positive entries. The consistency of the judgmental matrix can be determined by a measure called the consistency ratio CR defined as:

$$CR = \frac{CI}{RI} \quad (3)$$

Where RI is the random index, and CI is the consistency index which provides a measure of departure from consistency. The consistency index is calculated as:

$$CI = \frac{\lambda max - n}{n-1} \quad (4)$$

Where λ *max* is the largest Eigen value of the matrix A and n is the number of criteria. RI is the consistency index of a randomly generated reciprocal matrix from the 9-point scale, with reciprocals forced. Saaty [7] has provided average consistencies (RI values) of randomly generated matrices (up to size 11x11) for a sample size of 500. The RI values for matrices of different sizes are shown in Table 2. The consistency test was carried out on each questionnaire answer / expert who assessed or provide weighting. The benchmarks use CR (Consistency Ratio) which is a comparison between CI (Consistency Index) with RI (Ratio Index). The value of the index ratio (RI) is based on the order of the comparison matrix used in Table 2.

Table 2. The average consistencies of random matrices.

Size	RI
1	0
2	0
3	0.58
4	0.9
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

If the CR of the matrix is higher, it means that the input judgments are not consistent, and hence are not reliable. In general, a consistency ratio of 0.10 or less is considered acceptable. If the value is higher, the judgments may not be reliable and have to be elicited again. Determination of suitable alternatives, is done by defining the normalized Eigen Vector by averaging the sums of each row on the matrix.

2.3.2.4 Prioritization in each hierarchy

Prioritization in each hierarchy is carried out through an iteration process (matrix multiplication), this weighting stage is carried out using computer assistance program namely Expert Choice.

2.3.2.5 Define a conclusion

The final result of the analysis is obtained by multiply the value of prioritization in each hierarchy and the value of Eigen vector. The higher number of the value has, the more suitable for candidate site of NPP.

3. RESULT AND DISCUSSION

3.1. Spatial analysis with GIS

3.1.1. Population density

In the WB area, in the year of 2011, Muntok district has a total population of 46.786 and occupied area of 505.94 km^2. The density population of Muntok was 92 people per km2, while population density at Tanjung village (where NPP site is located) was 581 people per km^2, therefore the population density of Tanjung village was more than the density in Muntok district. This density is higher than the maximum density for the location of the NPP that is 195 people per km^2. The land acquisition cannot be avoided [4].

In the SB, Simpang Rimba district has a total population of 21.948 and they occupied the area of 362 km^2. The density population in Simpang rimba was 61 km^2, while the density at Sebagin village (where NPP is located) was 40 people/km^2 [4]. Therefore the population density of Sebagin village was less than those in Simpang rimba district. This density is below than the maximum density for the location of NPP which is 195 people/km^2 [11]. The more the density of the population, the less advantage it has, related to the land acquisition, people evacuation and public acceptance resistance, and environmental issue.

3.1.2. Cooling System

In the WB, intake points of water and water discharge are taken from seawater of the Bangka Strait opposite to Western Sumatra. The intake pipe distance from the main land to the sea is about 1.041 km towards the West (Figure 4) [2].

Intake points of water and water outtake (discharge) are taken from seawater of the Bangka Strait opposite to Southern Sumatra. The intake pipe distance from the main land to the sea is about 1.676 km towards the West (Figure 5) [2].

Figure 4. Cooling system of WB [2].

Figure 5. Cooling system of SB [2].

Both of the locations having a depth of 10 m for intake with the diameter of the pipe between 5 m (1000 MWe) - 6.4 m (1350 MWe) for each reactor. A levee is designed to quite lengthen water flow within the pond to get opportunity for the heated waters to transfer heat to atmosphere before flowing out of the pond. This long distance and discharge are affected by the structure of the less steep seabed, the turbidity of the seawater is quite low. Based on the spatial analysis from both area for cooling system installation related to the contour, slope and bathymetry as well as turbidity of seawater, the WB area has a shorter cooling system pipe than those in the SB. It means that the WB has more advantage, since the shorter length of pipe cooling system give less maintenance as well as electricity consume for the seawater pump. The out take water temperature from the cooling system is relatively assumed to be the same, since both of the site operate the same water cooling system. However, the more length cooling pipe to the sea give less adverse effect to the environment since it will neither disrupt the coral reef in the near coastal nor the activity of fisherman who subsist on fishery.

3.1.3. Land Clearing

Based on the analysis using ArcGIS software, the area of land clearing at WB (Figure 6) and SB (Figure 7) [6] shows in the maps. Based on the calculation using the ArcGIS, the total area of land clearing in WB and SB shows in Table 3 and Table 4 [6]. In this case, the total area is only calculated at the reference plant (site no.3# indicated with the red arrow in Figure 6 and Figure 7) to make an apple-to-apple comparison.

Figure 6. Land clearing of WB [6]

Figure 7. Land clearing of SB [6]

In addition, the reference also considered to be the zero point from each site, and serve to be a pioneer for the subsequent NPP construction in adjacent location. Once the NPP at this reference point is successfully constructed, means become a good example for the subsequent plants.

Table 3. Land clearing area at WB reference plant.

No	Land Use	Area (m^2)
1	Secondary Forest	15.452.39
2	Pat	4.297.58
3	Mix	106.619.34
4	Open Area	7.842.28
5	Bush	50.239.55
Total		**182.451.14**

Table 4. Land clearing area at SB reference plant.

No	Land Use	Area (m^2)
1	Secondary Forest	156.090.24
2	Rubber Plantation	23.900.61
3	Open Area	2.230.10
Total		182.220.95

Based on the calculation, it can be concluded that the land clearing area in the reference plant at the SB area has less area than those in the WB. The less land clearing are provides more advantage for the site preparation, related to the budget for hire the worker and heavy equipment as well as a shorter time consume. In addition, land clearing causes species death and habitat loss, but also exacerbates other threatening processes, reduces the resilience of threatened species populations to survive future perturbations such as climate change.

3.1.4. Cut and Fill

Based on the calculation of analysis spatial by means of overlay between contours layer with NPP site layer, cut and fill area in both location in WB and SB is shown in Figure 8 and Figure 9 [6]. The blue color on the picture shows the area to be excavated and the others small black color indicates areas to be back filled.

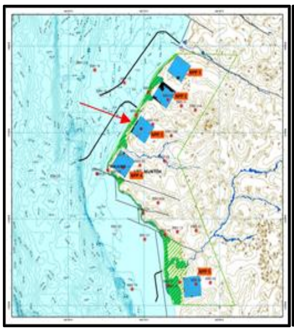

Figure 8. Cut and fill area of WB [2].

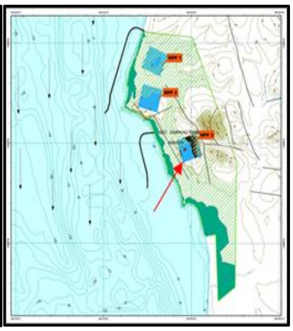

Figure 9. Cut and fill area of SB [2].

The result of calculation for volume of material for cut and fill in WB and SB show in Table 5 and Table 6 [6]. The underlying reason for calculating cut and fill only in the reference plant (site no.3#, indicate with red arrow in the Figure 8 and Figure 9) is exactly as same as already mentioned in the land clearing aspect.

Table 5. Cut and fill volume in WB.

Site	Cut (m^3)	Fill (m^3)
1#	2.208.533	-5.862
2#	1.354.333	-154.935
3#	2.384.221	-2.454
4#	2.265.010	-2.297
5#	2.270.950	-316
Total	10.483.047	-165.864

Table 6. Cut and fill volume in SB.

Site	Cut (m^3)	Fill (m^3)
1#	524.530	-85.292
2#	1.473.280	-50.797
3#	4.094.443	-6.299
Total	6.092.253	-142.388

Based on the area calculation, it can be informed that cut and fill area at the reference plant in WB area has less area than those in the SB. The less total area to be cut and filled, provides more advantage for the site preparation, especially in case of the budget for hire the worker and heavy equipment as well as a shorter time consume. In addition, cut and fill may lead to disturb the natural habitat and topsoil of a given site and this poses risks to the integrity of the natural ecosystem. Cut and fill construction alters drainage patterns and soil structure.

3.1.5. Granite for Foundation

Dominance distribution of rock types in the site vicinity of WB is granite, rhyolite reaching 79,78 % of the site vicinity of WB Regency, and it spreads in Air Putih Village, Baru River, Daeng River, and Tanjung [2].

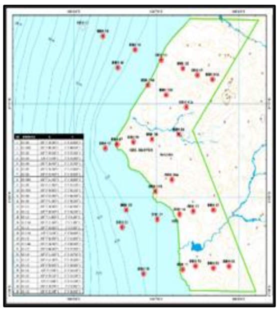

Figure 10. The borehole location in WB [2].

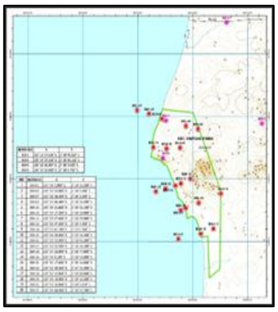

Figure 11. The borehole location in SB [2].

The results of soil test in WB shows that granite layer depth is 51.41 m depth at the location BBH 01; 70.5 m depth at the location BBH 02; 52.3 m depth at the location BBH 03; and 2 m depth at the location BBH 04 (Figure 10). Effect of soil bed rock depth will affect the structure of the foundation of each reactor to be located. The less shallow will give more advantages. Sites with competent bedrock generally have sites with competent bedrock generally have good foundation conditions. Alternatively, it is good foundation conditions. Alternatively, it is prudent to select sites having low liquefaction prudent to select sites having low liquefaction and subsidence potential [12]. The results of the investigation in SB shows that there is no layer of granite soil at the site but soil bed structures instead (Figure 11). The depth of the granite, not only has significant effect in reducing the civil work and able to hold strongly the NPP foundation in, but also give less negative effect to the environment related to the excavation works.

3.2. Pairwise comparison with AHP

The method of pairwise comparison is performed by expert choice software. The parameters are decomposed into a hierarchy include the criteria along with their alternatives [7] (Figure 12).

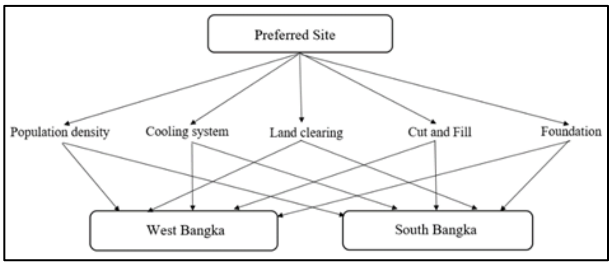

Figure 12. Hierarchy for Selecting Preferred Site in Bangka.

As many as ten respondents are participated to fill out the questioners, based on the analysis by pairwise comparison supported by expert choice software, the combination results among the respondents and consistency number is described in Table 7

Table 7. Criteria comparison by all respondent.

	Pop. dens	Cool. syst	Land clear.	Cut and fill	Foundati on
Pop.d ens	1	0.9117	2.9338	1.3313	0.2361
Cool. syst	1.0968	1	3.2311	3.1509	0.8135
Land clear	0.3408	0.3094	1	0.5248	0.1983
Cut and fill	0.7510	0.3173	1.9051	1	0.2123
Foun dtion	4.2341	1.2292	5.0404	4.7087	1

The value of inconsistency of the calculation is 0.03 means that it fulfil the requirement which is under 0.1. Based on the calculation, the most important criteria with respect to goal to be concerned according to the respondents is the foundation aspect (figure 13). This rank is taken in a qualitative manner regardless the factual value from the analyzed data, or in another word this data is taken based on the intuition from the respondents. However, this data results the Eigen vector as a multiplication number in the final analysis.

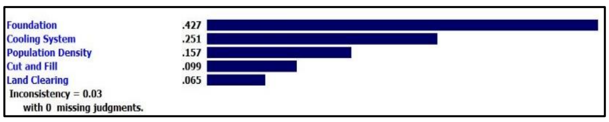

Figure 13. The rank of importance among the criteria.

The weights of each parameter is obtained from the factual spatial analysis that has been described in the previous spatial analysis report. The result of this study is important to give the priority for the parameter to be concerned when the adjustment should be taken in case there is no more site is available. From the table 8, the importance of each criteria has a different value in each site, this intricate data has been successfully simplified using the Multi Criteria Decision Analysis.

Table 8. The importance of criteria in each site.

Criteria	WB	SB
Foundation	0.889	0.111
Cooling system	0.833	0.167
Population density	0.111	0.889
Cut and fill	0.875	0.125
Land clearing	0.333	0.667

After went through some calculations under the expert choice software, it can be concluded in the Figure 14 that the WB has the more weights than SB, with overall consistency is 0.03.

Figure 14. Final value of weights between WB and SB.

The final decision informs that the most suitable preferred site is located at the WB, indicated as the red area pointed with the red arrow in Figure 15.

Figure 15. The location of NPP preferred site in WB [2].

4. CONCLUSION

Based on the final results of the analysis using the expert choice program, the numerical weights for West Bangka and South Bangka were 0.709 and 0.291, respectively, with a consistency value of 0.03. Therefore, it can be concluded that the site in the West Bangka is more suitable than those in the South Bangka for the preferred site to build the NPP. However, further assessment with additional parameters and judgments from the experts should be conducted in subsequent study to have more detail result. In addition, updating data should be taken into consideration, since the data is obtained in the year of 2012.

ACKNOWLEDGEMET

The authors are grateful to all the co-worker for their willingness to be a respondent to fill out the questioners as an important contribution in the analysis.

REFERENCES

[1] National Nuclear Energy Agency. *NPP Siting Project at Bangka Island Bangka Belitung Province, Inrastructure Final Topical Report*. Jakarta, 2013.

[2] National Nuclear Energy Agency. *NPP Siting Project at Bangka Island Bangka Belitung Province, Masterplan Final Topical Report*. Jakarta, 2013.

[3] IAEA Safety Standard Series No.SSG-35. *Site Survey and Site Selection for Nuclear Installations*. Jakarta, 2015.

[4] National Nuclear Energy Agency. *NPP Siting Project at Bangka Island Bangka Belitung Province, Demography Topical Report*. Jakarta, 2012.

[5] PT. Geomatic-JICA. *Modul Pelatihan Sistem Informasi Geografis ArcGIS*. Tim SIG PT. Geomatik-Konsultan. Makassar, 2010

[6] National Nuclear Energy Agency. *NPP Siting Project at Bangka Island Bangka Belitung Province, Geology and Topography Topical Report*. Jakarta, 2012.

[7] Saaty, T.L.. *Decision Making With The AHP*. Int. J. Services Sciences, Vol. 1, No. 1, Katz Graduate School of Business, University of Pittsburgh, pp.83-98, 2008.

[8] Abudeif, A.M., et. al.. *Multicriteria Decision Analysis Based On Analytic Hierarchy Process In GIS Environment For Siting NPP In Egypt*. Annals of Nuclear Energy 75, Elsevier, pp. 682- 692, 2015.

[9] Malczewski J.. *GIS and Multi criteria Decision Analysis*. John Wiley & Sons, Inc. New York, 1999.

[10] Wibowo, H. S.. *Modul Pelatihan: Analytic Hierarchy Process*. Pusat Pendidikan & Pelayanan Masyarakat Universitas Indonesia. Jakarta, 2018.

[11] United States-Nuclear Regulation Commission. *Regulatory guide 4.7: General Site Suitability Criteria for Nuclear Power Stations*. Washington DC, 1975.

[12] United States-Nuclear Regulation Commission. *Regulatory Guide 1.132: Site Investigations for Foundations of Nuclear Power Plants*. Washington DC, 1977.