SITE SUITABILITY ANALYSIS FOR A NUCLEAR POWER PLANT USING GIS AND AHP TECHNIQUE - SRI LANKA

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KEY WORDS: Spatial data analysis, nuclear power plant, Analytical Hierarchical Process, GIS

ABSTRACT: Day by day, necessities of mankind are being increasing and people find new ways to make their lives more convenient. As a basic need, electricity plays a vital role in the society like other needs and it resulted an energy crisis in the present world. Therefore, it is essential to find viable alternatives for this energy crisis. Though, electricity has been generated according to the demand, still Sri Lanka is facing supply shortage which cannot be fulfilled with the prevailing power generation methods. Therefore, the concept of a 'New Power Plans' has been aroused to find solutions to the ever-increasing energy crisis. These power plans should be a good solution to minimize the emission of greenhouse gases and climate changes. One solution is to build a nuclear power plant in Sri Lanka. To build a nuclear power plant, any country has to fulfil some essential requirements. Some of these requirements are spatial in nature and others are social and economic requirements. For the spatial requirement analysis, GIS based environment is the most effective method. One of the spatial analysis, site selection plays a major and critical role. Thus, this study focuses on the applicability of GIS for selecting a suitable site for a nuclear power plant in Sri Lanka. This study was undertaken using two analysis techniques; AHP (Analytical Hierarchy process) and GIS. From the literature review, the study area was limited to the North part of Sri Lanka and secondary data and literature review were helpful for getting understanding about the social and economic requirements for proper site selection. The study reveals that the most suitable area for establishing a nuclear power plant is Kilinochchi district coastal area.

1. INTRODUCTION

1.1 Background

Discovery of electricity is one of the remarkable achievements of the man. Electrical energy plays a key role in increasing the standards of human life including the efficiency of day-to-day work, in addition to providing comfort and luxury. Hence, electricity plays a major role in our life. This energy source is crucial to the economic development of a country as it contributes to the effective functioning of all the development activities. It is almost impossible to survive in the present world without electricity.

There is a limited number of resources which can generate electricity. A few major categories which can generate electricity are coal, natural gases, renewable energy (hydro, wind, solar, biomass, geothermal) and nuclear energy. Among these categories, nuclear energy has specific advantages compared with other resources. Nuclear power is relatively cost-effective comparison to oil, gas and coal (World Nuclear Association, 2008). At present large-scale development projects utilize their own nuclear power plants to fulfil their energy requirements as a solution for this crisis.

Currently, 31 countries around the world are using nuclear power plants (International Atomic Energy Agency, 2017). Particularly Europe, North America, East Asia, and South Asia are very interested in the nuclear power plants for generating electricity. Most of the countries around Sri Lanka use nuclear energy to generate electricity (Lee, 1998, Priyadarshana, 2010).

Further, nuclear power does not emit greenhouse gasses, thus it doesn't contribute to the increase of earth surface temperature. Hence, nuclear energy gives a better solution to the climate crisis. In addition, nuclear power produces little amount of waste compare to the fossil fuel. According to the global power market indicators, nuclear power is more reliable than wind or solar power (Mueller, 2018).

The main energy generating method in Sri Lanka is hydropower. However, at present the electricity generation is not sufficient for Sri Lanka to reach the expected development. As a result, Sri Lanka is already facing a massive energy crisis. It is really hard to survive through the existing power plants. The annual increasing demand of the electricity in Sri Lanka is estimated as a percentage is 5.9% (Ministry of Power and Renewable Energy,2017).

In addition to hydropower, Sri Lanka considers other alternative methods like solar, wind, ocean currents, bio gases and etc. However, due to the unpredictability of the climate and the location of the country, the use of wind and solar power is restricted. Thus, nuclear power is one of the most appropriate alternatives to minimize the energy crisis in Sri Lanka. This is a new avenue in the development process of the country. Hence, using nuclear power will be a new experience to the citizens and it will pave way for rapid development with new investors involving in mega projects. However, cost and safety will be two major concerns when introducing nuclear power to Sri Lanka. Thus, it is essential to research on the safety of the biotic and abiotic resources of the country and the cost of maintaining nuclear power plants before it is implemented.

Considering the above background, this research is focused on analyzing the possibility of introducing nuclear power to Sri Lanka. The analysis is mainly focused on identifying the suitable locations for nuclear power plants with minimum effect to biotic and abiotic resources of the country. Sri Lanka is a small island with 65,612km^2 area. The country is unique in every aspect including climate, location, biodiversity and historical value. Therefore, before introducing a new energy source to the country, it is essential to consider this diversity of the country. However, if a nuclear power plant could be established in a proper location following the required guidelines, it will surely be the pathway for rapid development of the country. Therefore, this is the high time to introduce new energy source like nuclear power to Sri Lanka and eliminate the uncertainty in power generation.

Thus, the aim of this research is to identify suitable locations within the country to establish a nuclear power plant. Due to time and data constraints the site selection basically focused on spatial suitability including spatial features like topography, soil, land extent and population. The spatially selected locations should be analyzed with other requirements of a nuclear power plant before coming to a conclusion about the site.

The site suitability analysis was undertaken in Geographic Information System (GIS) environment. GIS is a combination of computerized mapping and database management system. GIS is enabled with assembling, storing, manipulating and displaying data. It also involves disciplines like cartography, geography, statistics, land surveying, remote sensing and etc. This system can be used for scientific investigation, resource management, and community education. In addition, GIS can be used for spatial decision support system. GIS is effective because of its accuracy, easy operation, great analytical capabilities and user friendliness.

1.2 Research Context

Site selection process for a nuclear power plant has a specific procedure. Although this topic is new to Sri Lanka, other countries including developed and developing countries have undertaken hordes of researches and have come up with specific standards. The standards have some differences to match with different countries, however there are common requirements to fulfill since nuclear power plants should be established in accordance with necessary safety measures. Site selection procedure has few criteria to be considered.

Region of Interest (ROI)is the first criteria to be considered. It is required to analyze the impact on the environment, and the safety of the nuclear power plant in this stage. Other criteria are exclusionary criteria, avoidance criteria and suitability criteria which are also called absolute factors, critical factors, and economic factors respectively. Under exclusionary criteria the factors like population, distance, water availability, plate boundaries and faults, seismicity, and foundation condition will be analyzed. Under the avoidance criteria flooding/Tsunami, environmental sensitivity areas, agriculture, meteorology, airports and national parks are considered. (C.Rizzo et al., 2015). To complete this stage there is a requirement of geological data, hydrological data, seismological data, geotechnical data, coastal flooding including tsunamis data, river flooding data, and data on human included events (IAEA,2015).

This process is complex because the required conditions are in several perspectives. A site selection process has to fulfil a number of objectives for proper selection. Thus, the site selection is one of the crucial tasks in nuclear power plant Projects.

If we have identified an appropriate location for the nuclear power plant with significant potential, it is helpful to minimize cost and the vulnerability. However, physical suitability analysis is not a simple mission in these kinds of projects. Sri Lanka has conducted only a smaller number of researches regarding nuclear power plants. These researches also have considered few criteria and factors introduced by the IAEA. Thus, this research tried to apply the criteria and factors introduced by IAEA. Further, this research uses AHP to select the suitable criteria for the study and the overlaying process was undertaken in GIS environment. It gives more reliability because of the faster decision-making process and it is simple to understand, repeatable, and provides evidence-based outcomes. Because of these benefits GIS has become the most applicable procedure for selecting sites.

1.3 Objectives

With the above background, following objective was set for the study.

To select a spatially suitable site for a nuclear power plant with minimum effect to biotic and abiotic resources of Sri Lanka through most critical criteria and factors selected through AHP technique.

2.0 Methodology

2.1 Study Area

Sri Lanka is located in between latitudes 5°55′ and 9°51′ N and longitudes 79°41′ and 81°53′ E and has a maximum length of 432 km and a maximum width of 224 km (Peiris and Arasaratnam, 2020). The country is an island surrounded by the Indian ocean. Sri Lanka is one of the countries with a large coastal zone.

There are very few past studies about selecting a suitable site for a nuclear power Plant in Sri Lanka. According to Thisirini's research undertaken in 2018, the best location was Delf island. The second-best site was selected as Luhugala in Digamadulla District (non- published data). Third and fourth sites are in Mannar district. According to Priyadarshna (2010), there were nine locations suitable for a nuclear power plant in Sri Lanka. His first priority was also given to the Delf island. As the second option Mannar Island was selected. Third location was near Palavi Nawaladi area. Alampil Mulathivu and Trincomalee North areas were selected as fourth and fifth sites respectively. They selected sites only considering basic selection criteria. According to expertise in Sri Lanka Atomic Energy Board, (SLAEB) it is not suitable to build nuclear power plant in an island like Delf. Further, pre-feasibility studies carried out by SLAEB has pointed out four zones which will be suitable for a nuclear power plant: Kilinochchi, Mannar, Digamadulla and Hambanthota districts (Jayakody, et.al., 2018).

All these researches have highlighted few common regions. Considering these past findings, the study area for the current research was narrowed down to Killinichchi and Mannar districts. From these two districts, 19 GN divisions with close proximity to the coastal belt were selected. The areas are low in population. The average area of the study is around 1425km^2. Figure 1 displays the study area.

Figure 1: Location of the Study Area

2.2 Data

The data for the study were collected from different institutions and through interviews. The spatial data were collected from the Survey Department of Sri Lanka as maps. Population data were collected from Census and Statistics Department of Sri Lanka. Topographic data was taken from USGS Earth Explorer (U.S. Geological survey) website. The secondary data collected from the previous studies carried out in Sri Lanka. Further, through focus group discussions with experts in Geological Survey and Mines Bureau, National Building Research Organization (NBRO) and Sri Lanka Atomic Energy Board (SLAEB) helped to improve the accuracy of the study.

Criteria for Site Selection

IAEA has introduced Specific Safety Guide (SSG) No 35 in IAEA, 2015. This guide has given a format for selecting the NPP site to any country. According to the SSG No. 35, whole process has been divided into two stages. First stage is site survey stage and the second stage is site selection stage. Under first stage the reginal and potential sites will be identified. Under the second stage, candidate sites will be identified from the selected regional sites. From the selected candidate sites a final suitable site will be identified considering other social and economic criteria.

2.2.1 Data Selected from Literature and Previous Studies for Regional Analysis

This study mainly focuses on the second stage which is site selection. The first stage was not undertaken due to time limitation and data issues. A suitable region for this study was selected based on the previous studies and analysis results of the following few criteria.

Grid connectivity (Figure 2)

For any power plant it is essential to consider the connectivity of power supply. The selected study area has 220kv and 132kv transmission lines. It is a good opportunity to minimize the cost of construction by means of power supply for the preliminary constructions. On the other hand, quality and the profit value can increase because of the convenience of the power transmission (Wu et al., 2020). Thus, the selected study area is suitable for further analysis for a NPP establishment.

Tectonic Plates

Sri Lanka is located on the Indo – Australia plate (Wikipedia Contributors, 2019). The moving speed of this plate is 3cm per year (Earth How, 2018). Tectonic plate movements cause some geological hazards like subsidence, unstable slope area, and tsunami. However, Sri Lanka is located in a considerable distance away from the major plate boundaries. (Approximately, 1000km-1500km away) (non-published data). Thus, Sri Lanka is having minimum natural hazards and thus suitable for building NPP.

Tsunami (Figure 3)

Tsunami was one main disaster in Sri Lankan history occurred in 2004. It happened due to 9.1 Earthquake in Sumathra coast (Taylor, 2014). However, the tsunami damage was minimum in the Batticalloa, Killinochchi and Mannar areas of Sri Lanka. That is the only Tsunami incident recorded in the recent past history of Sri Lanka and according to the damage assessment reports, the selected study area was not affected from that incident. Therefore, the study area is suitable for massive constructions like this project.

Precipitation (Figure 4)

The annual average precipitation is around 1250mm in the Northern province (Piratheeparajah, 2015). However, it can vary from place to place. Since the rainfall is not too high in the study area it will minimize natural disasters which will occur with high rainfall intensities. Thus, it is an additional advantage for this NPP construction.

Temperature (Figure 5)

The selected study area has been categorized under arid zones in Sri Lanka. The area has very high temperature. It is due to two main reasons; Indian subcontinent and location at the opposite side to the North East Monsoon direction (Nagamuthu, 2016). High temperature in the study area is also an additional advantage for constructing a NPP. Past researches also prove that high temperature areas are suitable for NPP. (Wu et al., 2020).

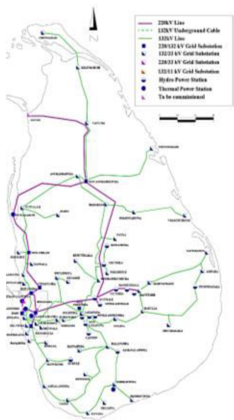

Figure 2: The Map of Sri Lanka transmission system in 2019. Source: (Ceylon Electricity Board)

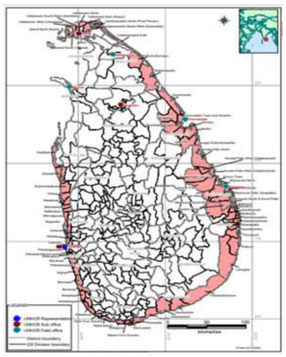

Figure 3: Tsunami 2004 Disaster Affected Divisions. Source: (United Nations High Commissioner for Refugees, 2004)

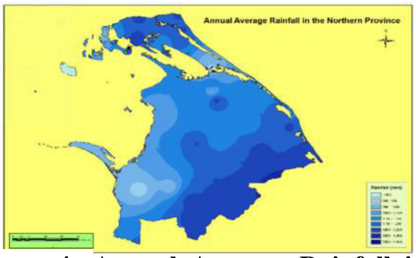

Figure 4: Annual Average Rainfall in the Northern Region of Sri Lanka. Source: (Piratheeparajah ,2015)

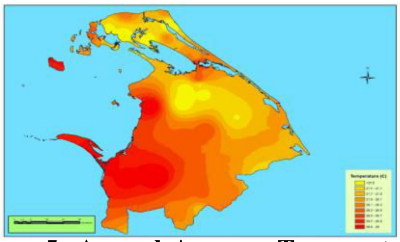

Figure 5: Annual Average Temperature of the Northern Region of Sri Lanka. Source: (Nagamuthu, 2016)

Thus, by considering available electricity network, tectonic plates, natural hazards like Tsunami, precipitation and temperature, the selected region for further site suitability analysis was a good selection. The selection was strengthened by the past studies on NPP in Sri Lanka.

2.2.2 Data Selected for Potential Site Suitability Analysis

Population

Construction of NPP is very crucial considering potential damages it can cause to the living beings. Thus, it is essential to select an area with low population and other living beings. According to the SSG (Specific Safety Guide) population is one of the factors to be considered in selecting potential site for NPP. (International Atomic Energy Agency, 2015). If the population density is more than 194 per square kilometer then these areas are not feasible to construct NPP (Barzehkar, et.al., 2016). Eluyemi et al (2020) in his study conducted in Niegeria, applied 40km and 20km buffer zones to the state capitals and villages(towns) to avoid highly populated areas. Similarly, research conducted in Turkey by Baskurt and Aydin in 2018 also applied a 25km buffer zone around the population centers. The population of Sri Lanka is around 21.44 million and the average population density is around 341 people per square kilometers (Worldometer, 2019). However, the population density of the selected study area is around 152 people per square kilometer. It is also an advantage for constructing a NPP in the study area.

Shoreline

Shoreline is a very significant factor in nuclear power plant construction. The main reason is supplying sea water for the cooling system of the nuclear power plant. For a reactor with 1000MW capacity, the cooling system needs water approximately 75 cubic meter per second (Baskurt and Aydin, 2018). Fresh water cannot be used for this cooling system, because fresh water is a scarce resource and cannot be wasted. Since Sri Lanka is an island, use of sea water for the cooling system is the best way to minimize the waste and the cost. Another important thing is when site is closer to the sea it will be very easy to transport nuclear waste and to exchange the nuclear material in safe way.

Geology

Geology is also a considerable factor for any construction. Fortunately, Sir Lanka is one of the countries free from volcanoes. Geology affects the structural engineering designs. There can be some zones with faults displacements, fractures, discontinues or joints. Thus, it is essential to select a suitable area with minimum geological effects. There are more than 50 geological types covering Sri Lanka. However, the study area has only seven types.

Soil

Soil type triggers the seismic activities (Abudeif, et.al., 2015). Therefore, it is important to consider the soil factor as well. Soil excavation is needed for finding places with liquefactions, collapse or subsidence (Abudeif, et.al., 2015). In Sri Lanka there are 23 soil types. Among them only 6 types can be found in this study area.

Freshwater

Any construction causes environment damages. However, it is required to find ways to minimize these environmental damages. Freshwater is one of the most vulnerable resources for such damages. There are some zones with highly sensitive aquifers (Abudeif, et.al., 2015). Thus, it is essential to identify such fresh water aquifers and avoid them as much as possible.

Land use

Most of the new development projects are constructed converting existing land use. Therefore, before starting a project the land use of the study area has to be investigated. There are different types of land uses in the study area. There will be a change in the use of land after the construction. The study area has mainly 10 types of land uses.

Slope

Slope of the surface is another important factor in huge construction projects to avoid any natural disasters like landslides and rockslides. Idris and Abd Latif, (2012) considered 20% slope as the best land for NPP construction. Barzehkar, et.al., (2016) considered slope less than 12% as the best land for NPP. Slope map of the study area was created using DEM downloaded from USGS Earth Explorer. The study area is almost flat and suitable for NPP construction.

2.3 Method

The method was undertaken in few steps.

a) Defining the problem
b) Dividing the problem into sub stages
c) Determining significant layers
d) Reclassifying the data and generating new raster layers
e) Weighting the input layers
f) Combining the seven layers
g) Final site analysis

Following flowchart displays the method as a summary.

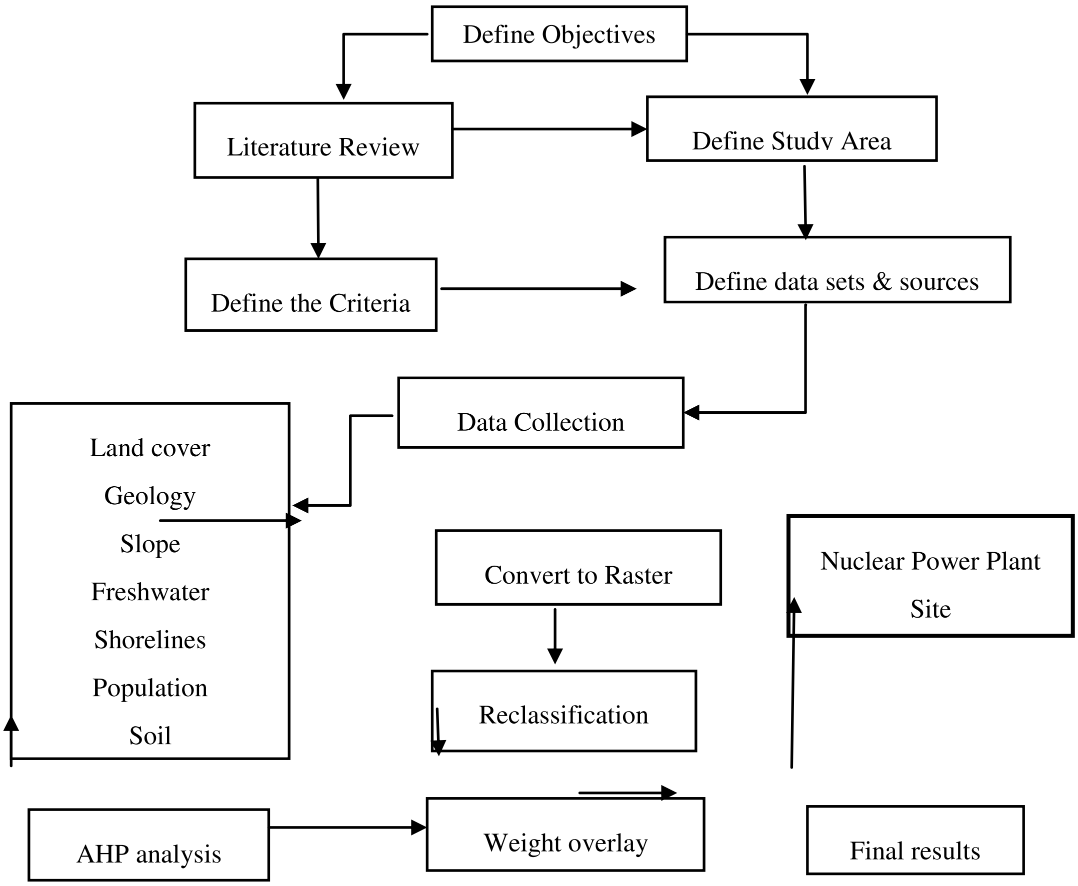

Figure 6: Flowchart of the Methodology

3.0 Results and Discussion

Pairwise Comparison between the Criteria

According to AHP method the values are ranked respect to the preference. The basic scale (1 to 9) of the AHP shows in table 1.

Table 1: Pairwise Comparative Analysis of Each Criteria

Preferences	Numeric Value
Extremely Preferer	9
Very Strongly Preferer	7
Strongly Preferer	5
Moderate Preferer	3
Equally Preferer	1
Moderately	1/3
Strongly	1/5
Very Strongly	1/7
Extremely	1/9
Less important between the above intervals	(2,4,6,8) (1/8,1/6,1/4,1/2)

(Source: Barzehkar, et.al., 2016)

An online calculator was used for pairwise comparison (https://bpmsg.com/ahp/ahp-calc.php). Literature and expert's opinion were considered to give the values for the matrix. Figure 7 displays the decision matrix and Figure 8 shows the priorities given by the AHP.

Decision Matrix

The resulting weights are based on the principal eigenvector of the decision matrix:

	1	2	3	4	5	6	7
1	1	8.00	6.00	4.00	3.00	1.00	1.00
2	0.12	1	8.00	7.00	6.00	5.00	3.00
3	0.17	0.12	1	6.00	5.00	4.00	3.00
4	0.25	0.14	0.17	1	7.00	5.00	4.00
5	0.33	0.17	0.20	0.14	1	4.00	3.00
6	1.00	0.20	0.25	0.20	0.25	1	2.00
7	1.00	0.33	0.33	0.25	0.33	0.50	1

Principal eigen value = 11.222
Eigenvector solution: 14 iterations, delta = 4.4E-8

Figure 7: Decision Matrix

Priorities

These are the resulting weights for the criteria based on your pairwise comparisons:

Cat		Priority	Rank	(+)	(-)
1	Shoreline	34.5%	1	43.9%	43.9%
2	Population	25.4%	2	22.3%	22.3%
3	Landuse	13.4%	3	12.1%	12.1%
4	Freshwater	10.1%	4	8.7%	8.7%
5	Soil	5.7%	5	4.9%	4.9%
6	Geology	5.6%	6	7.3%	7.3%
7	Slope	5.3%	7	7.3%	7.3%

Number of comparisons = 21
Consistency Ratio CR = 52.5%

Figure 8: Priority Given by AHP

Following equation explains the AHP selection criteria.

$$\text{Consistency Index; CI} = (\lambda max - n)/(n-1) \quad (1)$$

n = the number of the criterion

λmax = the biggest eigen value

$$\text{Consistency Ratio; CR} = CI/RI \quad (2)$$

RI = constant corresponding to the mean random consistency index value based on n (Source: Zhou and Wu, 2012)

Modeling in ArcGIS

The selected and prioritized criteria were converted into raster then reclassified and modeled in ArcMap modeling interface. The final suitability model is based on the weighted index model (Parry, et.al., 2018). The tool weighted overlay concludes several factors which were processed here. In the output raster layer in higher values of favorable results in several factors were assumed by this tool (Atia and Shahnawaz, 2017). In the weighted overlay map appropriatness is increasing with higher numbers. Figure 9 displays the result of weighted overlay process. The areas in dark green depict the more appropriate zones. Red color areas show inappropriate areas for building a nuclear power plant. Figure 10 displays the potential areas for building a nuclear power plant.

Suitability Equation

$$S = \sum_{k=1}^{n} w_i c_i \quad (3)$$

S is suitability, c_i is criterion score of i , w_i weight of criterion
Source: (Siefi et al., 2017)

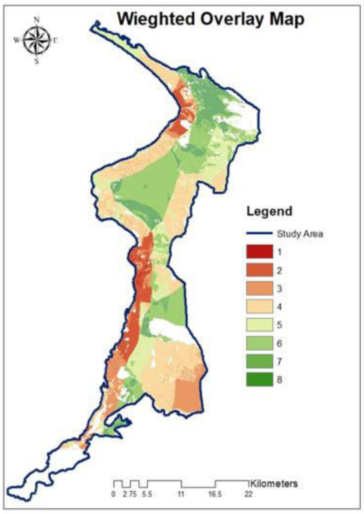

Figure 9: Result of Weighted Overlay Process

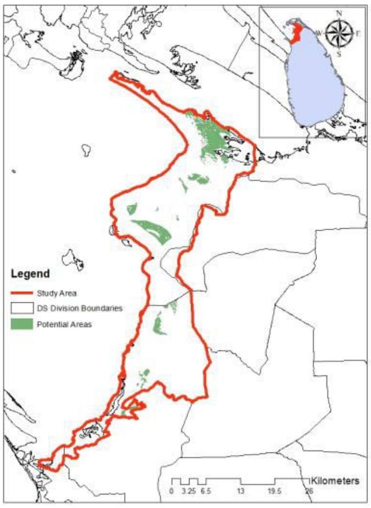

Figure 10: Potential Areas for Nuclear Power Plant

4.0 Conclusion

Demand for the electricity in Sri Lanka is estimated as 70,000 GWh (UNDP, 2017) in 2050. Sri Lanka has eight major power plants that supply energy to Sri Lanka grid system. These power plants are either hydro power or coal power plants. Currently, some wind power plants were also established in Sri Lanka. However, the existing supply is not enough to fulfill the electricity demand of Sri Lanka. Therefore, there is a requirement of another energy source. Nuclear power plays specific role in energy world. This topic is a novel topic to Sri Lanka and there are only few researches available regarding this subject. The main objective of this study is mainly focused on finding out the spatially suitable sites for a nuclear power plant with minimum effect to biotic and abiotic resources of Sri Lanka.
Through literature review the relevant 'criteria' to be used in this analysis were selected. According to those articles 'criteria' vary in different perspectives. Each literature piece has followed a specific set of 'criteria' within the GIS environment.
The analysis was undertaken using modeling facility in ArcMap. The selected criteria were overlayed by giving weights according to the priority given by the AHP analysis. The final map displays few areas which satisfied the considered selection criteria. The most appropriate areas are located in Ponnavile, Kollakurichchi and Cheddiyankurichchy in Kilinochchi district. These sites were selected considering the spatial factors. Thus, the selected sites are spatially suitable sites for an NPP. However, this selection did not include any social or economic feasibility consideration. Therefore, for the final selection it is required to consider the social condition of the selected sites and the economic feasibility of the selected sites. The previous studies in Sri Lanka regarding the NPP were not followed IAEA factors. However, in this research a maximum number of criteria explained in IAEA were selected and applied.

5.0 Recommendations

For any massive construction there should be an EIA (Environmental Impact Assessment). Thus, for the selected sites it is recommended to do EIA and social and economic analysis. Then it will give the final best sites fulfilling all physical, environment, social and economic feasibilities.
After selecting a site fulfilling above criteria, it is required to do soil analysis, geological analysis and soil excavations underground. In a NPP construction there should be an acceptable bed rock in underground.

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