



GIS-Based Identification of Potential Optimal Locations for Disposal of Radioactive Waste in Mongolia

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How to cite this paper: Uranchimeg, B., Helmut, Y. and Mizunoya, T. (2024) GIS-Based Identification of Potential Optimal Locations for Disposal of Radioactive Waste in Mongolia. *Open Access Library Journal*, 11: e11753.

<https://doi.org/10.4236/oalib.1111753>

Received: May 28, 2024

Accepted: July 28, 2024

Published: July 31, 2024

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Abstract

Mongolia has no well-developed national radioactive waste management strategy and insufficient infrastructure to manage the existing radioactive waste inventory or the expected future waste arisings. The low- and intermediate level of radioactive waste is generated from radioisotope applications in medicine, research, agriculture, geology, mining, and industries. Most radioactive waste is disused sealed radioactive sources which are stored at the long-term storage center. Besides, since the beginning of uranium prospecting in 1945, more than 12 uranium deposits, 100 hundred uranium occurrences, around 1400 anomalies have been discovered within Mongol-Priargun, Gobi-Tamsag, Northern Mongolian metallogenic provinces. Currently, The Badrakh Energy is a responsible for mining company committed to the development of the Zuuvch Ovoo uranium deposit in the Dornogobi region. The Zuuvch Ovoo project is the most advanced uranium mining development project since 2009. The past studies do not focus on the potential optimal locations for the disposal of radioactive waste. The study aims to create a geographic information system (GIS) based analysis to screen all study area of Mongolia to construct the map on the potential optimal locations. The selected criteria founded on international practice are divided into two main data criteria: environmental and socio-economy. These were used in the GIS analysis and were further sub-divided into fourteen parameters. The research employed GIS analysis to provide a practical and spatial component. The paper has not been carried out in Mongolia, and it can be used as a reference point in further study.

Subject Areas

Nuclear Chemistry

Keywords

Mongolia, Disposal, Radioactive Waste, Criteria, Geographic Information System (GIS), Uranium

1. Introduction

Many resources mentioned that the sources could be divided into waste for Nuclear Power Plant, from research, industry, medicine, agriculture, mining and other related sectors using radioactive material which are mainly generating low-level to high-level radioactive waste [1]. About 130 operable nuclear power reactors in Asia, out of which 35 are under construction, and several countries are planning to build an additional 70 - 80. Many are proposed, for example, India, China, Malaysia, Laos, etc., and even in Mongolia. The growth in the number of nuclear power plants in the Asian region requires good management of nuclear and radiation waste for protection from environmental concerns [2]. Many nuclear technologies countries' effort to control waste's environmental impacts has arranged on legislation to limit the environment and ensure that solid wastes are routed to appropriate landfill or other burial management sites [3].

Mongolia is a landlocked country in Central Asia with a large area of approximately 1.5 million square kilometers of territory without any nuclear industries. Mongolia is rich in mineral resources such as copper, gold, silver, rare, and particularly uranium minerals [4]. Since the beginning of uranium prospecting in 1945, more than 12 uranium deposits, 100 hundred uranium occurrences, around 1400 anomalies have been discovered within Mongol-Priargun, Gobi-Tamsag, Khentei-Daur, Northern Mongolian metallogenic provinces. The total of geological resources is over 180,000 tonnes with stands 11th by known uranium resources worldwide [5].

Currently, The Zuuvch Ovoo project is the most advanced uranium mining development project with Mongolian and France governments, started from 2009. Even though, the uranium pilot test done successfully, there are no low-level radioactive waste management activities at site [6]. Besides, the radioactive wastes as disused sealed radioactive sources (DSRS) are mostly generated from medicine, research, industry, mining, military and other users. These wastes are not well characterized and are stored at long-term storage facility without any radioactive waste management [7]. Like Mongolia, many countries have been developing safe radioactive waste disposal management to avoid any chance of radiation exposure to people or any environmental pollution.

Using ArcGIS 10.8, it is possible to identify the current situation and identify areas that are either potential or not potential for radioactive waste disposal locations. Mongolia is the first country to conduct this study, and it will be applicable to its future efforts in managing radioactive waste.

2. Data and Method Selection Criteria

2.1. Study Area

The study area covers the entire territory of Mongolia (**Figure 1**), with a longitude 46.8625°N and latitude 103.8467°E. The difference between the mean temperatures of January and July can reach 80°F (44°C), and temperature variations of as much as 55°F (30°C) can occur in a single day [8]. In the last decades, the meteorological disaster as dust storm, zud (heavy snow), flood, cold rain, earthquake, desertification, and wildfire occurred in Mongolia [9].



Figure 1. Location of Mongolia map.

2.2. Data Selection Criteria

International practices' data selection criteria consider the main environmental and social-economic parameters, including sub-divided transportation, population distribution, hydrology, sensitive zone, and morphology [10]. Before further steps can be recognized, the location shall not be endangered by environmental factors and human-induced events. Moreover, the exclusion maps criteria and additional criteria were used in few Mongolian National Standard, International experiences and the International Atomic Energy Agency (IAEA) [11] some suggestions are shown in **Table 1**. Meanwhile, the Mongolian National standards did not belong well to the hazardous and radioactive waste substances, and there were not many criteria attached in the study.

Table 1. International site selection criteria experiences.

No	Country name	Experience	References
1	International Atomic Energy Agency, IAEA	1) Siting of Near Surface Disposal Facilities, Safety series; 2) Near Surface Disposal Facilities for Radioactive Waste, Specific Safety Guide No. SSG-29 3) Site Survey and Site Selection for Nuclear Installations, Specific Safety Guide No. SSG-35, 2015. 4) Selection of technical Solutions for the Management of Radioactive waste, IAEA-TECDOC-1817, 2017	[11]-[14]

Continued

2	Australia	Australian Government, Department of Industry, Sciences, Energy and Resources. The following information is consistent with that used in various other countries such as France, the United Kingdom, and Canada.	[15]
3	Indonesia, Java Island	In Review site evaluation Activities for RW disposal Facility in JAVA Island, report of IAEA, considered on; 1) Prohibited area such as water recharge area or water resource area (aquifer), conservation area, wildlife protection, and national park; 2) Monument/Cultural heritage protected under the regulation. 3) Existing or future planning of particular land use; 4) Resident area with population density > 1000 people per square mil.	[16]
4	Iran	<u>Qazvin Province</u> is from 100 km city. Shahid Rajae Thermal Power Plant is located 25km east of Qazvin. About 15 - 20 tons/year with a high concentration of Heavy metals. Criteria are 1). Lake and pool—min 305 meters; 2) River or channel—92 meters; 3) Retention period flood—100 years; 4) Avoiding from wetland; 5) Do not cumulate birds in sensitive area around the airport. 6) Some of the evaluation criteria (national environmental regulations, and standards were considered.) for example; Fault—500 m; Mines and local industry—min 1000 m; Forest, garden—has to be 500 m; Wetland, rivers branches have to be—1000 m; Streams—2000 m; National parks—3000 m; Wild life refuges—2000 m; Protected area—1000 m; Cities—min 2000 m; Village and residential communities—1500 m; Roads—300 m; Highway—500 m; Rail roads—500 m. <u>Salafcheghan is in</u> 185 km from Tehran. This zone is economic for employment, stabilization, economic, population, services, and infrastructure. Study area is Qom province which consists of criteria, for example; Floodways—80 - 160 m (less to high) if higher than itself more suitable; Surface waters—1000 - 2000 m; Fault—200 - 1000; Slope—10 - 20; Groundwater depth—10 - 20 m; Groundwater—400 - 800 m; Access road—min 300 m; Social-economical; Residential areas—1000 - 3000 m; Industries—1000 - 1500 m; Power line—min 200 m; Agriculture (flora)—min 300 m.	Iran is well developed about Radioactive waste disposal facility which are described. [17];
5	Malaysia	Less vegetation area; Clay rich soil; low precipitation; low landslide potential; less influence of groundwater; elevated area between 50 - 300 m from mean sea level, free flood area; urban area—5000 m; forest, national park and surface water—shouldn't be built environment; slope—15 - 26 degree; rainfall 1000 mm.	[19]; and [20]
6	Bangladesh	Earthquakes—2.5 - 4 magnitudes; Seismic faults—5 km; Wind speed—2 knots; Thunderstorms—25 - 50 days per year; Rainfall—1400 - 2000 mm; Airports—domestic—min 12 km, International—min 15 km; Population density—min 2000/km ² ; Transport—1 km from national road or railways; Groundwater table—below 30 m; River bank—10 km; Lakes and rivers—1 km.	[21]

Continued

7	Turkey (Solid waste) no Radioactive	The aquifer has an average thickness of 2 m; Surface-water—Thus, all streams are buffered by a distance varying from 100 to 300 m; Slope and Topography—5° - 20°; Soil-silt and clay; Road buffer—no less than 100, 350 m; Ecology-Buffer zones of 300 m and 200 m; Settlement—A buffer zone of 2 km around residences; Water supply well—A safe distance of 365 m; 2 km distance from border supplies neither.	[22]
8	China	China has own Act on Sites for Establishment of low-Level Radioactive Waste final Disposal Facility that considered for a site of disposal facility must not be located in any of the following areas: 1) The area where active faulting or geological conditions could endanger the safety of the disposal facility; 2) The area where the geochemical conditions are unfavorable for effectively suppressing the diffusion of radioactive nuclides, and it is likely to endanger the safety of the disposal facility; 3) The area where the hydrologic conditions of surface water or groundwater are likely to endanger the safety of the disposal facility; 4) Area of high population density; 5) Areas that cannot be developed according to the law. The range of the areas listed in the preceding paragraph and the standard for recognition shall be prescribed by the competent authority jointly with other relevant government agencies within six months after this Act takes effect.	[23]
9	Russia	Regional criteria They characterize the location of sites within the region, their affinity with certain geological blocks, relations with the regional faults, general geomorphology, position in geophysical fields, seismic and geothermal effects, uplift and subsidence of blocks, probability of flooding the territory, cryogenic state of rock.	[24]

2.3. Method Selection Criteria

In recent years, the number of articles conducted and employed standard the Geographic Information System (GIS) uses digitized data representing siting criteria to generate composite maps showing areas more or less potential for siting [25]. For the last 15 years, the Geographic Information System has been developing globally to analyze many kinds of things. A geographic Information System is a framework for gathering, managing, and analyzing data. Most agencies and organizations in virtually every sector use GIS to maps that communicate, perform analysis, share information, and solve complex problems worldwide—the data relating to position on Earth's surface. The GIS technology applies geographic science with tools for understanding and collaboration. It helps people reach a common goal: to gain actionable intelligence from all types of data. For example, create the map, data information, analysis of spatial, and work virtually everywhere [26].

3. Data Collection

3.1. Data Collection and Preparation

There are no studies for the potential locations that were conducted in Mongolia.

Some data has been collected from national agencies [9] [27] and international [10] [28] and scored by international practices. The data was classified into a polygon, polyline, point, and raster as DEM (Digital Elevation Model). The all data selected and collected, and it classified into main and sub-criteria's shown in **Table 2**. The study is constructed by the methodology scheme shown in **Figure 2**.

Table 2. Selected criteria.

Main criteria	No	Sub-criteria	No	Exclusion criteria
Socio-economic	1	Population	1	Cities
		Distribution	2	Villages and Towns
	2	Transportation	1	Airport
			2	Road
			3	Railway
	3	Land-use	1	Farm, Farmland, Residentials, Industry
Environmental	1	Hydrology	1	River
			2	Lakes
			3	Well
	2	Sensitive zone	1	Forest
			2	Protected Area
	3	Morphology	1	Elevation
			2	Slope
3			Earthquake	

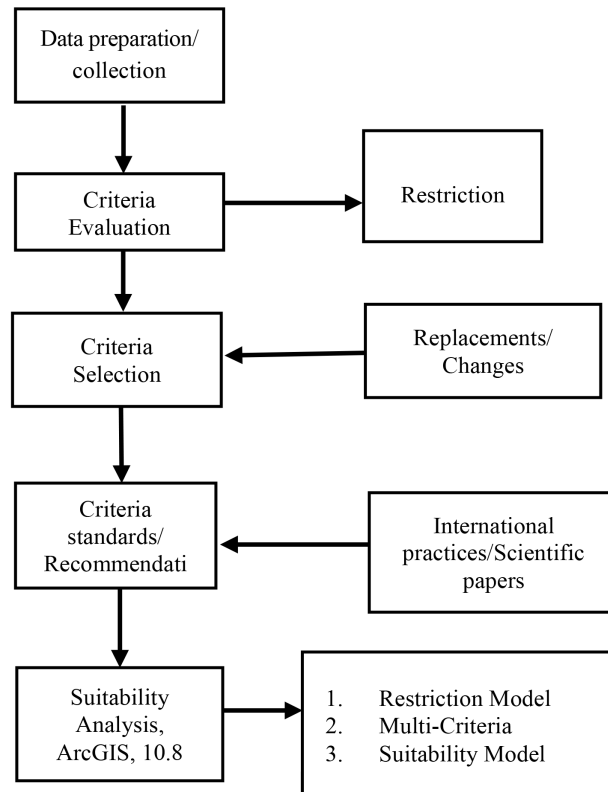


Figure 2. Methodology scheme.

3.2. Preparation for Geographic Information System Modeling

This study area is used in the latest Geographic Information System version, ArcGIS 10.8. It was mapped for Restriction Model and Multi-Criteria Model for Suitability Analysis calculated by raster calculator. The GIS works for mapping and modeling, Multi-Criteria Model (MCM) and restriction analysis to solve the model that these models were named by suitability analysis. GIS applications give a geographical study, which allows for practical and proposed waste disposal locations. Several publications consider the application for landfill GIS modeling issues. Published articles were executed by a variety of scientific journals publishers such as ScienceDirect [29], SpringerLink ([30], ASCE [31] and Scopus database ([32], which made through the multi-criteria and GIS, landfill, suitability analysis, landfilling, disposal and MCDA [33].

a) Site Suitability Analysis Using Arc GIS

Suitability analysis in a GIS context is a geographic or GIS-based process used to determine the appropriateness of a given area. Suitability can be performed by raster and vector methods. This analysis is identifying restriction maps and suitability areas. For creating a suitability raster for identification of the potential optimal location for disposal of radioactive waste, it has been proposed the equation as following.

$$S = \sum_{i=1}^n W_i \times C_i \prod_{j=1}^n r_j$$

S = suitability for the potential optimal location

W_i = Weight for the criteria's i , C_i

C_i = Criteria for suitability (example: slope, land use, distance, etc.)

r_j = Restriction criteria (examples: water, land use, protected areas, etc.)

This part is going to representing the restriction analysis for potential optimal location in the maps. To criteria, this study uses slope, elevation, place, forest, lakes area e.g. However, in the restriction raster analysis $\prod_{j=1}^n r_j$ Component, there were different constraints considered as well as its buffers. The buffers were applied to restrict the social-economic and environmental criteria based on international recommendations. The Restriction analysis created for Boolean raster layer will represent the restriction to develop the potential optimal locations for radioactive waste disposal. All restrictions included a minimum buffer zone. For producing the tutorial, the restriction raster, Boolean rasters much pasture that contains zeros and ones where zero represents the restricted cell to develop and represents a cell viable to set potential optimal location for disposal of radioactive waste.

b) Restriction Model for Potential Optimal Location for Disposal of Radioactive Waste based on criteria

According to International literature review, the criteria are mainly divided into Social, Economic and Environmental, which also split sub-criteria. This study considered mainly sub-criteria as transportation, population distribution, and land use to main social-economic. Besides, sub-criteria hydrology, sensitive

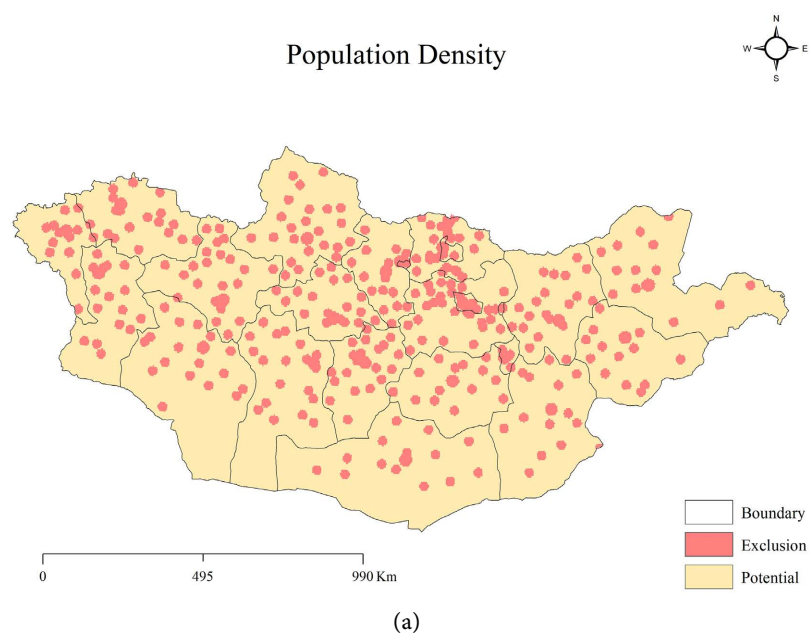
zone and morphology have been divided by main environmental criteria. Under divided sub-criteria. In additional, the reclassification is classified into Mongolian morphology based on several studies. Besides, International studies mentioned that elevation between 1000 - 1500 and slopes between 15 - 26 degrees. The source was posted in the original UN Office for the Coordination of Humanitarian Affairs (OCHA) from missions to principled humanitarian action in partnership with national and international actors to alleviate human suffering in disasters and emergencies [34]. Final multi-criteria model will be used in map of covered earthquake photo which are created by ArcGIS shapefile as vector. Those all criteria were calculated by raster calculator as suitability.

4. Results and Discussions

According to map construction and verification, the restriction analysis was conducted, resulting in restriction maps for overall potential locations for future basic study scenarios and support policy-maker support. However, this study aims not to identify the exact location for the potential location for disposal of radioactive waste.

4.1. Restriction Model for Potential Optimal Location for Disposal of Radioactive Waste Based on Social-Economic Criteria

a) The population distribution: The population distribution restriction was applied to protect the people in the study area. A distance was buffered by far away 20 kilometers from potential optimal locations to dispose of radioactive waste. The population density in Mongolia is five people per mi². 67.2% of the population lives in the urban city of Ulaanbaatar (2,203,469 people in 2020) [35]. The population distribution is scattered on the map is shown in **Figure 3**.



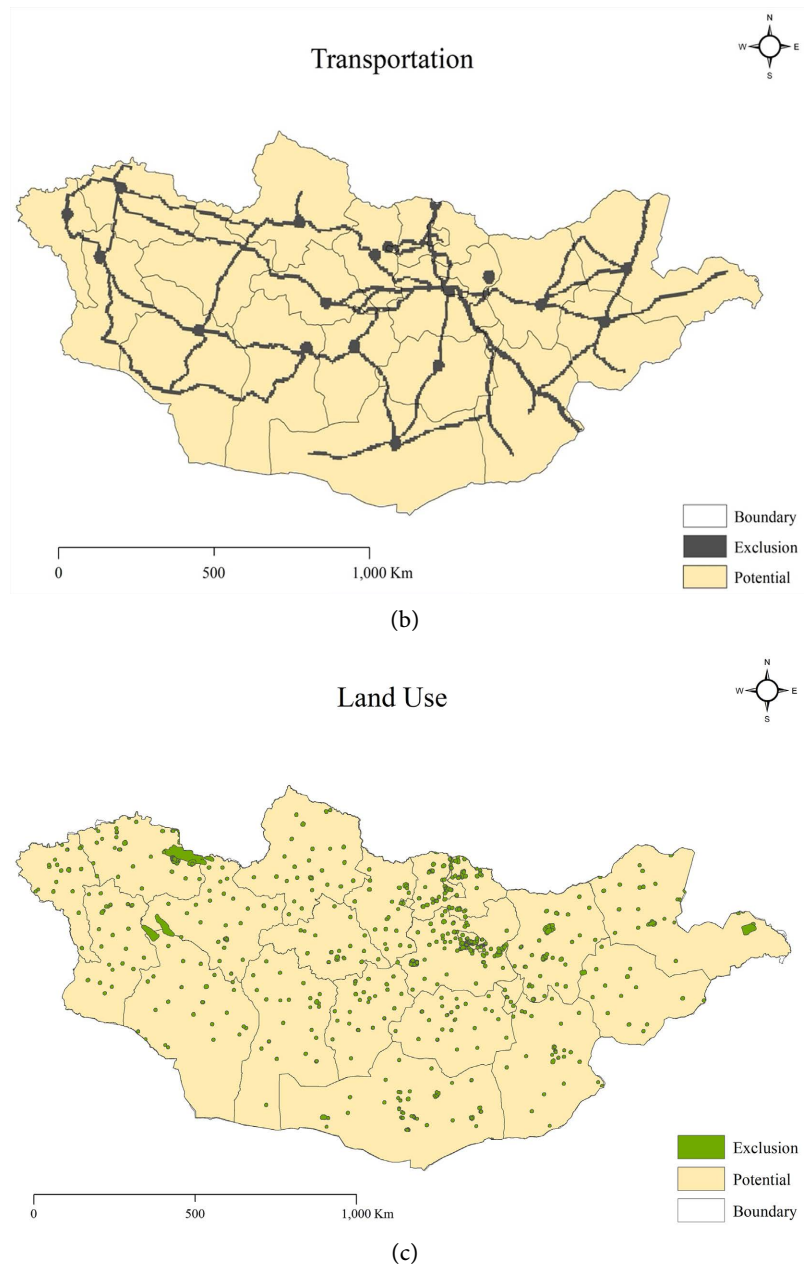


Figure 3. Restriction model for potential optimal location for disposal of radioactive waste based on social-economic criteria.

b) The transportation locations observed in this map were protected to address the commercial factor as the economic criteria shown in **Figure 3**. The restriction map was applied to protect the road networks, airports, and railways. In addition, it provides the safe, secure, and reliable transport of radioactive materials and sources from imported points to end-user due to protect the negative radiation impact. Nearby transport accidents may affect the disposal of radioactive waste management facilities [36].

c) This restriction analysis was applied to protect the existing land use ensure that the potential optimal area is not situated in the current land use areas. Land

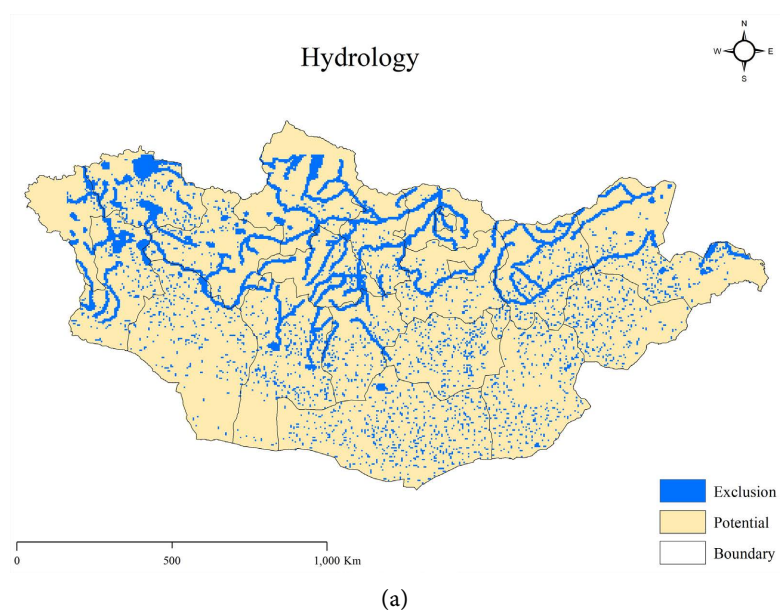
use data included mainly residential areas in urban cities and around farms, farmyards, military, and industries. It is shown in **Figure 3**.

4.2. Restriction Model for Potential Optimal Location for Disposal of Radioactive Waste Based on Environmental Criteria

a) The water resources of Mongolia are highly vulnerable depends on climatic conditions. The main sub-criteria as hydrology include wells, rivers and lakes, which exist to address the environment. The restriction map shows that collected Lake data is the primary source of drinking water in Mongolia, and it is in mountain areas containing cold water. Hydrology map shows that well and rivers are covered in existing locations which shown in **Figure 4**, and it shall be protected from hazardous substances. Lakes and Rivers may be affected by the pathway for the dispersion of radioactive materials and wastes and a potential source of flooding.

b) According to international practice, the study selected protected areas and forest applied to severe protect the sensitive zone from any negative impact of hazardous. Therefore, the protected area includes the fresh lake, mountain, and national zoo are 20 km far away from any hazardous facilities and industries. As observed, the protected area is covering the study area. Fires must avoid the forest, and protected areas are special attention. The restriction areas may be affected by fire-fighting. A map is shown in **Figure 4**.

c) An elevation map shows that Mongolian elevation and slope are classified into several categories [37] that shown in **Figure 4**. It was used by Digital Elevation Model (DEM) data. The country has an average elevation of 1580 meters. For suitable elevation for potential optimal locations, 800 - 1000 (7 - 12 degree of slope) meter is hills, and 1001 - 1500 (12 - 30 degree of slope) meter is low mountains to Mongolian elevation and international recommendations.



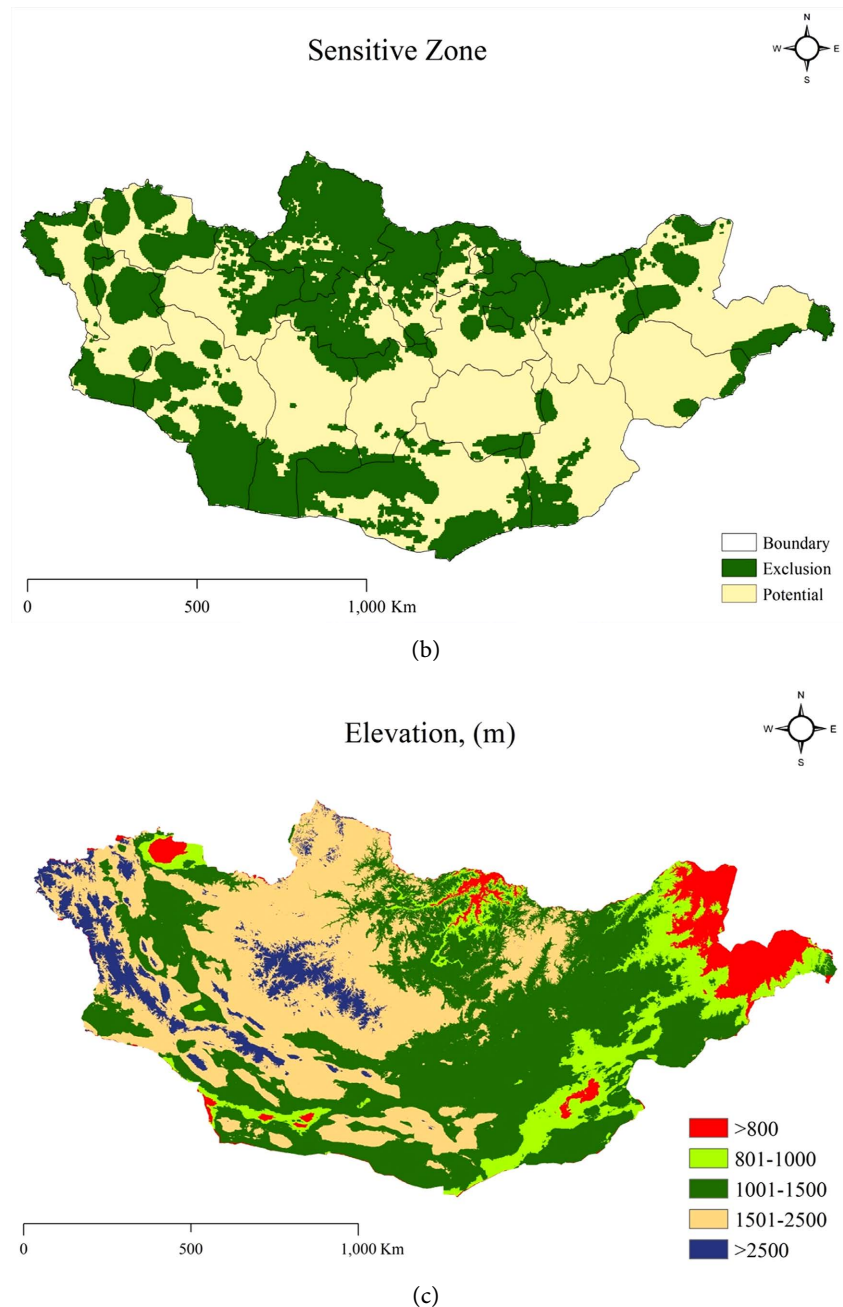


Figure 4. Maps restriction model for potential optimal location for disposal of radioactive waste based on environmental criteria.

4.3. Final Restriction Model for Potential Optimal Locations for Disposal of Radioactive Waste Based on Sub-Criteria

The restriction map shows that all the main criteria recommended by international practices in Figure 5. Raster calculator analyzed from the buffer to raster and its created restriction and allowed potential locations in the map. As a result, Mongolian western and southern regions might be potential optimal locations for radioactive waste disposal. But this map has shown that only allowed areas without specific locations.

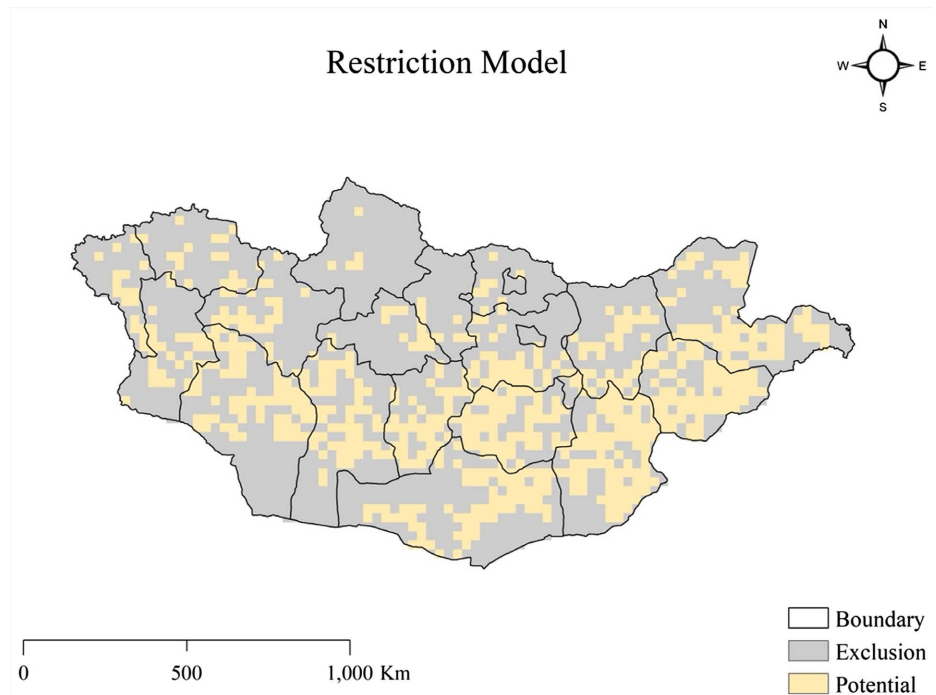


Figure 5. Final restriction model for potential optimal locations for disposal of radioactive waste based on sub-criteria.

4.4. Multi-Criteria Model for Potential Optimal Locations for Disposal of Radioactive Waste

a) Raster calculations have calculated the Final Multi-Criteria Model map that shown the potential locations to potential locations from less potential. The population distribution was used places, rivers, and forest's shapefiles, and slope and aspects used the Digital Elevation Data. The aspect identifies the downslope direction of the maximum rate of change in value from each cell to its neighbors. Aspect can be thought of as the slope direction. The slope direction is used in minimum 90 and maximum 270 degrees based on Multi-Criteria Analysis in ArcGIS [38]. Therefore, the green-colored potential location is expansive, and red-colored locations are less in the map showed in **Figure 6**.

b) In 2019, there were 45,757 earthquakes in Mongolia and the border areas. The 66 earthquakes of magnitude 3.5 and above, of which the public felt 20. The around 1000 earthquakes around Ulaanbaatar and some other serious earthquakes have occurred along with Northern and Central Mongolia [39]. Therefore, the study considered the earthquake zone, which is a risk. In addition, international practices recommend that site selection criteria be considered history of earthquake condition and estimate the maximum potential earthquake within the geological settings [40].

The map shown in **Figure 6** that Mongolian Northern, Western, and southern regions have a higher risk than the Central region; besides, the eastern region is lower risk. If the countries have plant to construct the facility, earthquakes shall be evaluated by assessments, recommended by IAEA, seriously.

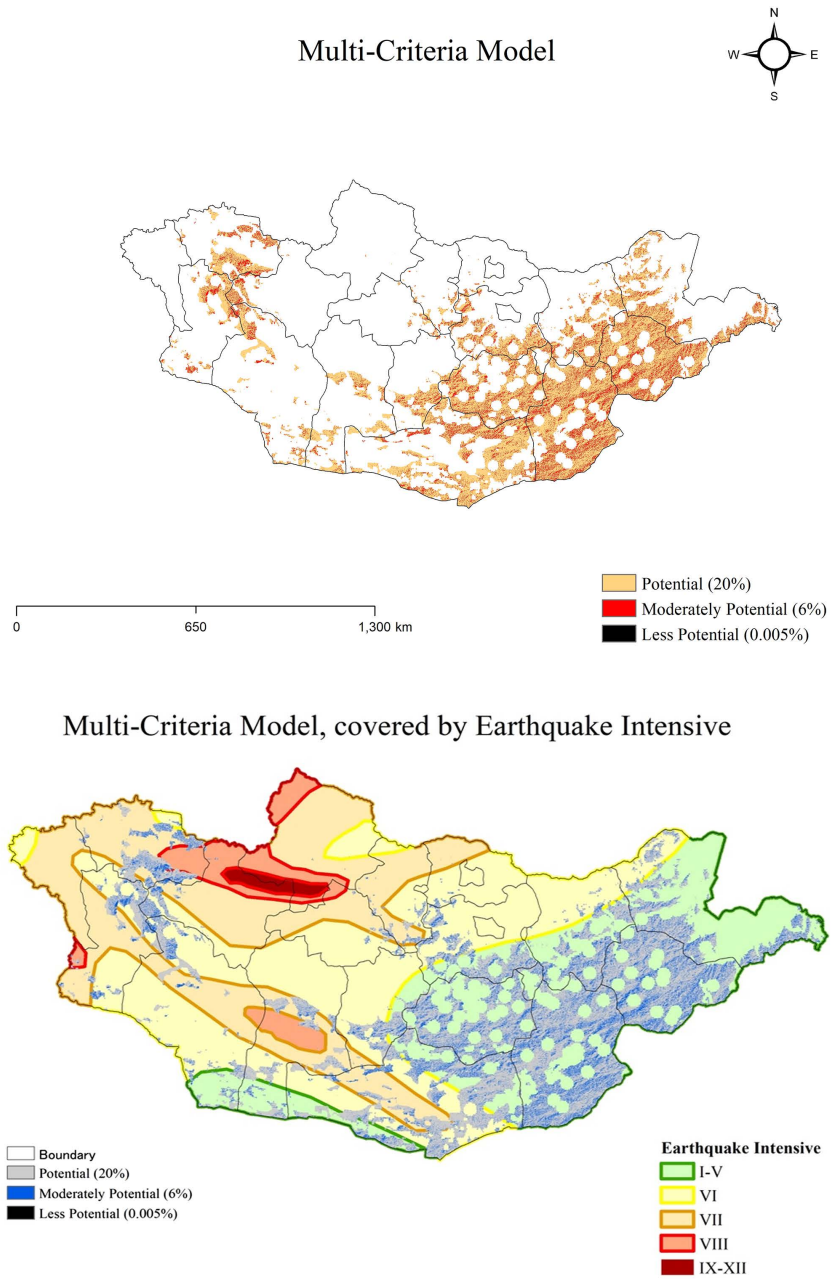


Figure 6. Multi-criteria model for potential optimal locations for disposal of radioactive waste.

5. Limitation

This study did not consider exact potential locations for disposal of radioactive waste and their management and cost component. Thus, this study can be further developed and improved by assessing the potential optimal locations involved at every step for disposal of radioactive waste management. Moreover, further studies can also be achieved with other management waste as this would be an essential source of the material. In addition, this study could provide additional value using ARC GIS 10.8.1 network analysis. Besides, the policy and

strategy of radioactive waste management could be future work of policymakers who will be updated or approved about radioactive waste. This study will continue the part ARG GIS analysis could be future work.

6. Conclusion

Collected data were classified to suitability criteria and processed to identify potential optimal locations. The analysis was completed by dividing these criteria into sub-criteria as a parameter. In combination with the raster method, GIS software was used to generate the potential optimal maps based on these data. Finally, identified locations are a potential map in the restriction model combining sub-criteria, which was 68% of the exclusion, an area of total Mongolian shown in the map. Besides, in the initial introductory multi-criteria model analysis, an area of total Mongolian, approximately 20% was identified to be the potential, over 6% were identified to be moderately potential, and an area of about 0.005% was identified to be less potential for disposal of radioactive waste in the map. Selection of criteria, collection of relevant data, and screening all Mongolia based on these criteria is to identify potential optimal locations for disposal of radioactive waste will be investigated in further study.

Conflicts of Interest

The authors declare no conflicts of interest.

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