REGIONAL SCALE SCREENING OF SELECTED REGIONS OF BANGLADESH TO IDENTIFY POTENTIAL SITES FOR THE DISPOSAL OF LOW AND INTERMEDIATE LEVEL RADIOACTIVE WASTE

by

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Disposal of radioactive wastes has emerged as a vital issue for Bangladesh as the country is actively working to have a nuclear power plant operating in the country by 2023-2024. The current study aims to find potential sites for a near-surface disposal facility using a geographic information system software and multi-criteria analysis method. Previously six regions (Region-1 to Region-6) were identified upon performing continental scale screening of the whole territory of Bangladesh. In the current study, regional scale screening has been performed of Region-1 and Region-2 using five criteria divided into fifteen sub-criteria: earthquakes, wind speed, rainfall, cultivated-vegetated land, forests, buildings-facilitie-built up areas (area), buildings-facilities-industries-institutions (Point), population density, medium-broad road and railway, narrow road, monument, power line, ground water table, surface water body, and lastly flooding were used in the analysis. The suitability map and relative importance weighting of these sub-criteria were determined by using the geographic information system and multi-criteria analysis method. The overlay analysis was performed of suitability maps of each sub-criterion and found the final suitability map of Region-1 and Region-2. These suitability maps were divided into six categories: the excluded area, most suitable, suitable, moderately suitable, unsuitable, and completely unsuitable. Nineteen potential sites with a maximum and minimum area of 7.90 km^2 and 1.15 km^2 were identified from these most suitable and suitable areas. Detailed field investigation and site characterization are needed to be performed on selected potential sites to choose a final disposal site for the low and intermediate levels of radioactive waste.

Key words: radioactive waste, near-surface disposal, site selection, geographic information system, multi-criteria analysis

INTRODUCTION

Bangladesh is committed to the peaceful use of nuclear energy. Currently, Bangladesh is operating a number of nuclear and radiological facilities including a 3 MW TRIGA Mark II research reactor (RR), radioisotope production facility, semi-commercial food irradiation facility, nuclear medicine facilities as well as using sealed radioisotope sources in the field of medicine, industry, agriculture, research, education *etc.* for the socio-economic development of the country. The operation and maintenance of these facilities produces various types of radioactive wastes (RW). The uses of radioactive materials in the country are increasing day by day. Furthermore, Bangladesh is actively working to embark upon a nuclear power program to improve its energy mix and the first nuclear power plant (NPP) of the country is expected to come into operation by 2023-2024. The operation and maintenance of the NPP will generate a large amount of RW. Consequently, the generation of RW is expected to be increased significantly in the near future. Thereby, the modest amount of low and intermediate level radioactive waste (LILW) is being generated from the operation and maintenance of all these nuclear facilities currently in operation in the country and it will be significantly increased after starting the operation of the NPP.

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The RW may have a detrimental health effect on living beings if not managed properly. The RW management activities include collection, segregation, characterization, treatment, conditioning, storage and disposal. Disposal is the final step in the LILW management process. There are several disposal options for RW, such as landfill, surface, near-surface, intermediate depth, borehole and deep geological disposal [1]. Appropriateness of the disposal facility not only depends on types of RW but also on socioeconomic conditions, available technology and safety features. The option of near-surface disposal has already been practiced in different countries [2, 3] and also has been anticipated as a suitable option in Bangladesh for the disposal of LILW [4]. The objective of this study is to find potential disposal sites from selected regions of Bangladesh for LILW. Previously, five data criteria (geology, hydrology, climatology, pedology, and socio-economy), geographic information system (GIS), and multi-criteria analysis (MCA) method were used for continental scale screening of the whole territory of Bangladesh to select the excluded area, completely unsuitable, unsuitable, moderately suitable, suitable and most suitable area [4]. A total of six regions (Region-1 to Region-6, fig. 1) were selected for subsequent study based on the most suitable area category. The current study aims to find out potential sites for a near-surface disposal facility (NSDF) from Region-1 and Region-2. The screening on of Region-1 and Region-2 has been performed in the same way as continental scale screening with some more refined data, such as 1:25000 and 1:50000 scale vector data of criteria/sub-criteria. The GIS software in combination with the MCA method has been utilized in various studies for site selection studies [5-9]. The GIS software has a high ability to manage a large volume of spatial data and consider many factors from a variety of sources [10]. It efficiently stores, retrieves, analyzes and displays information according to user-defined specifications [11]. The MCA method helps to make a decision in case of complex decision-making problems. The principle of the method is to divide the decision-making problems into smaller understandable parts, analyze each part separately and then integrate the parts in a logical manner in order to produce a meaningful solution [12]. The analytic hierarchy process (AHP) is the preferred decision-making method among different MCA methods. The AHP method is used to estimate the consistency weightings of criteria that resulted from constructing the matrix of pairwise comparisons [8]. The GIS software provides effective management and presentation of the data, and the AHP method delivers consistent ranking of the criteria. Therefore, combined utilization of GIS and MCA has been proved to be a powerful tool to solve the site selection problem [13]. This study utilized fifteen sub-criteria in the GIS environment to prepare raster files and the AHP method for weighting the sub-criteria. The GIS based simple additive weighting (SAW) method provides a suitability map of the Region-1 and Region-2, which indicates some area as excluded, completely unsuitable, unsuitable, moderately suitable, suitable and most suitable for LILW disposal and it also delivers suitability indexes of these selected areas. These most suitable and suitable areas provides potential sites for further analysis. A detailed field survey as well as site characterization need to be performed on selected potential sites to select the final site for the disposal of LILW.

MATERIALS AND METHODS

Study area

The regions in the study marked as Region-1and Region-2 in fig. 1 have areas of 2123.25 km^2 and 675.31 km^2, respectively. Figure 1 shows a total of six potential regions throughout Bangladesh found after continental scale screening [4]. The continental scale screening was performed using five data criteria, namely hydrology, geology, climatology, pedology, and socio-economy and those were further divided into 14 sub-criteria. The GIS software and the MCA method were utilized to produce a suitability map and weighting of each sub-criterion, respectively. Finally, GIS added the SAW method which was applied to perform overlay analysis among suitability maps of each sub-criterion. The overlay analysis provides a final suitability map for the establishment of NSDF in Bangladesh. These six potential regions (Region-1 to Region-6) were identified from this final suitability map considering the most suitable area. Among these regions, Region-1 and Region-2 is situated in between the Ruppur nuclear power plant (RNPP) currently under construction and probable future sites (Khulna, Barguna, Patuakhali, Noakhali and Feni districts) for the second nuclear power plant of the country [14]. A waste disposal site situated in the vicinity of NPP is preferable [15]. Furthermore, the current policy of the country is to develop and operate a single disposal facility to safely hosting all RW generated in the country [16]. Therefore, considering previous facts and transport distance of RW from potential waste generation points, Region-1 and Region-2 were considered for further analysis. This study was performed considering Region-1 and Region-2 to find potential sites.

Input data

Earlier continental scale screening was conducted using five main criteria subdivided into fourteen sub-criteria: population density, seismic faults, ground water table, lakes and rivers, river bank erosion, earthquakes, agricultural land use, rainfall, air-

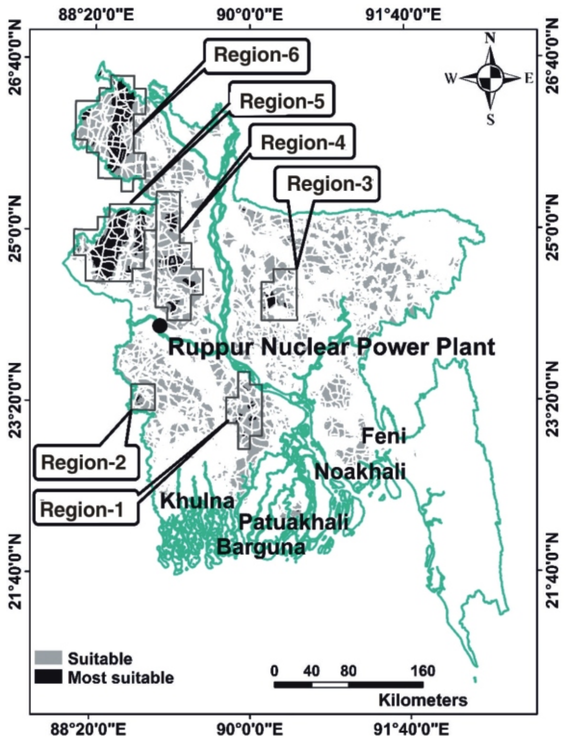

Figure 1. Location map of Region-1 and Region-2 in Bangladesh

ports, cyclones, forests, transport, wind speed, and thunderstorms. This study comprises five main criteria divided into fifteen sub-criteria: earthquakes, wind speed, rainfall, cultivated-vegetated land, forests, buildings-facilities built up areas (area), buildings-facilities-industries-institutions (Point), population density, medium-broad road and railway, narrow road, monument, power line, ground water table, surface water body, and lastly flooding. Previously 1:1000000 scale vector data were used for continental scale screening because this screening was performed over a large area *e. g*., over the total territory of Bangladesh. This continental scale screening was done using GIS software, the MCA method and GIS based SAW method which facilitated the identification of six potential regions as mentioned earlier. Therefore, the current study utilized 1:25000 and 1:50000 scale data of the sub-criteria to screen the smaller areas, *e.g*., Region-1 and Region-2. This regional scale screening with large scale data indicates the precision of the data and the study. All these data were collected from the governmental organization of Bangladesh.

Methodology

The process of selecting a site for the RW disposal facility typically comprises the conceptual and planning stage, area survey stage, site characterization stage and site confirmation stage [17] though almost a similar approach has been used by others for repository siting [18]. The near-surface disposal facility was anticipated as a suitable disposal option for the disposal of LILW in Bangladesh. As mentioned earlier, the continental scale screening procedure from the area survey stage has already been performed and six regions have been selected as potential for further study. Region-1 and Region-2 from these six regions were considered for this study. This regional scale screening was accomplished using the GIS and MCA method. The data of each sub-criterion was collected from reputed national organizations and prepared to a suitable raster according to grading, tab. 1, utilizing GIS. The MCA method (AHP) provides weighting of each sub-criterion for overlay analysis. The overlay analysis was performed among the prepared raster of each sub-criterion according to the weighted value of each sub-criterion. The GIS based SAW method was utilized to perform this overlay analysis. This overlay analysis produces the final suitability map of Region-1 and Region-2. The final suitability map was divided into most suitable, suitable, moderately suitable, unsuitable, completely unsuitable and excluded area, respectively. Finally, potential sites were selected from these most suitable and suitable areas.

RESULTS AND DISCUSSION

This section describes the construction of the grading and suitability map for each sub-criterion along with the applications of the MCA and SAW method on Region-1 and Region-2 to get the suitability map.

Evaluation criteria

A waste disposal site should have long term stability to protect the public and environment. The protection would be ensured if the following factors are considered during the area survey stage (continental/regional/area screening) in the site selection process. A disposal site should:

- Not be located adjacent to a settlement area.
- Be constructed on an uncultivated area.
- Not be built adjacent to a road and railway.
- Be away from surface and ground water.
- Be away from an earthquake fault line.
- Be away from a populated and protected area.
- Be away from historical and cultural sites.
- Be constructed in a low rainfall, thunderstorm and wind speed area.
- Be away from a flood and cyclone affected area.
- Be away from an industrial area and major infrastructure systems, like power transmission lines.

Upon considering the above factors and sub-criteria used in the continental scale screening, a total of five criteria divided into fifteen sub-criteria were considered in this study. Table 1 shows the criteria,

Table 1. Grading of sub-criteria used in this study

Criteria	Sub-criteria	Classification guideline (Classification was done according to international practice and expert's' judgment based on the environmental setting of the region under study)	Classification considering the study area	Grading (x_{ij}), 0 – Excluded area 1 – Completely unsuitable, 2 – Unsuitable, 3 – Moderately suitable, 4 – Suitable, 5 – Most suitable
Geology	Earthquakes (Magnitude on the Richter's scale)	According to [4], different magnitudes represents different amounts of shock, such as 2.5-slight, 4-strong, 5-very strong, 7-disastrous, 8.5-catastrophe and >8.5-great catastrophe. The site should be located in an area of low seismic activity [17].	>8.5 7-8.5 5.5-7 4-5.5 2.5-4	1 2 3 4 5
Climatology	Wind speed (Knots)	Strong winds can lead to anticipated operational occurrences, incidents or accidents [19]. The classification of the wind speed sub-criterion was done based on the minimum and maximum values of this sub-criterion in the area under study [4, 13].	>6 5-6 4-5 3-4 2-3	1 2 3 4 5
	Rainfall [mm]	A NSDF should be situated in a low rainfall area [4]. The classification of the rainfall sub-criterion was done based on the minimum and maximum values of this sub-criterion in the area under study [4, 13].	>2000 1850-2000 1700-1850 1550-1700 1400-1550	1 2 3 4 5
Pedology	Cultivated-vegetated land [km]	According to [4], agricultural land is not suitable for a radioactive waste repository site. A repository site should be built in a less vegetated area [20]. Experts' judgment was used to grade this sub-criterion.	0-0.5 0.5-1 1-1.5 1.5-2 >2	1 2 3 4 5
	Forests [km]	A radioactive waste repository site should not be built in a forested area [4, 20] and should be 500 m away from any forest [4].	0-0.5 0.5-1 1-2 2-3 3-4 >4	0 1 2 3 4 5
Social/ economical	Buildings-facilities built-up areas (area) [km]	A waste disposal site for hazardous waste such as soil contaminated by depleted uranium (DU) should be located at least 500 m away from the a permanently populated area [21].	0-0.5 0.5-1 1-2 2-3 3-4 >4	0 1 2 3 4 5
	Buildings-facilities-industries-institutions (Point) [km]	Besides a permanently populated area, according to [15], areas of industrial, tourist or other interests are to be avoided for a LILW disposal site.	0-0.5 0.5-1 1-2 2-3 3-4 >4	0 1 2 3 4 5
	Population density (per sq. km)	The [4] was used to classify the population density sub-criterion.	>2000 1000-2000 500-1000 100-500 0-100	1 2 3 4 5
	Medium-broad road and railway [km]	The [4] was used to classify the medium-broad road and railway sub-criterion.	0-1 >10 8-10 5.5-8 3-5.5 1-3	0 1 2 3 4 5
	Narrow road [km]	Like the medium-broad road and railway a buffer distance of 0.5 km was considered as an excluded area for a narrow road according to experts' judgment.	0-0.5 >7 5-7 3.5-5 2-3.5 0.5-2	0 1 2 3 4 5
	Monument [km]	The protection of cultural heritage from a RW repository should be maintained [22]. Therefore, a 500 m buffer was considered as an excluded area for the monument sub-criterion.	0-0.5 0.5-1 1-2 2-3 3-4 >4	0 1 2 3 4 5
	Power line [km]	Electric power is an important facility meaning that the distance to power transmission lines is a parameter to be considered but very close to a transmission line may increase risk associated with high-voltage [21]. Therefore, a 200 m buffer distance was assigned a rating of zero.	0-0.2 >4 3-4 2-3 1-2 0.2-1	0 1 2 3 4 5
Hydrology	Ground water table [m]	The [4, 5] were used for the classification.	0-5 5-10 10-20 20-30 >30	1 2 3 4 5
	Surface water body [km]	Sites very near to a river or lake should be avoided along with wetlands and marshes [21]. Grading was done according to [4].	0-1 1-2 2-4 4-6 6-8 >8	0 1 2 3 4 5
	Flooding	Grading of this sub-criterion was done using ref. [17, 23] and experts' judgment.	Severe/moderate flash/river flooding and severe/moderate tidal surge Low flash/river flooding Not flood prone	0 1 5

sub-criteria and grading used in the analysis. The criteria, sub-criteria and grading of each sub-criterion were specified according to the published reports as well as experts' judgment based on environmental setting of the region under study.

Geological criterion

The geological criterion comprises the earthquake sub-criterion. The earthquakes data from 1918 to 2019 were collected from the Bangladesh Meteorological Department (BMD). An earthquake with high magnitude can hamper the entity and long term safety of the waste disposal facility. The grading and suitability map for the earthquake sub-criterion is illustrated in tab. 1 and figs. 2 and 3, respectively. Figures 2 and 3 indicates that Region-1 and Region-2 are safe in regard to this sub-criterion for NSDF, respectively.

Climatological criterion

This criterion contains the wind speed and rainfall sub-criteria. The point data of wind speed and rainfall sub-criteria were collected from the BMD. Thirty- two years (1988-2019) of point data both for wind speed and rainfall sub-criteria were collected for this study but a few stations had less than 32 years of data. According to [17], the effect of unexpected extreme meteorological conditions should be adequately considered in the design and licensing of the disposal facility. Therefore, high wind speed and rainfall was graded as low. The grading of this criterion was made considering the environmental conditions of the study area and the international practices (tab. 1). All sub-criteria of the climatological criterion are spatially presented in figs. 2 and 3.

Pedological criterion

The pedological criteria consist of cultivated-vegetated land and forests sub-criteria. The 1:25000 scale vector data for these sub-criteria were collected from the Survey of Bangladesh (SOB). Bangladesh is mainly an agricultural country, therefore a major part of the land is used as cultivated and vegetated land. Thus, cultivated and vegetated land, to the extent possible, would be considered as unsuitable for a radioactive waste disposal facility which is depicted in figs. 2 and 3. The repository site should not be built on a forested area [20], because this would create an adverse effect on the environment and endanger species. The grading of the forests sub-criterion was kept the same as the grading used in continental scale screening for the forests sub-criterion [4]. The grading and suitability map for the forests sub-criterion is illustrated in tab. 1 and figs. 2 and 3, respectively.

Socio-economic criterion

The buildings-facilities-built up areas (area), buildings-facilities-industries-institutions (Point), population density, medium-broad road and railway, narrow road, monument and power line sub-criteria forms the socio-economic criterion. Institutions indicate governmental, educational, religious and medical institutions. The 1:25000 scale vector data of these sub-criteria were collected from SOB. A published article has considered buildings, industries, institutions and municipal offices in the site selection process for high level radioactive waste disposal [24]. Buildings, industries, institutions and municipal offices indicates a populated area. A waste disposal site away from a populated area could increase public acceptance and decrease public health risk. In this study buildings-facilities-built up areas and the buildings-facilities-industries-institutions sub-criterion were considered separately because those two sub-criteria were presented as an area and point respectively. A waste disposal site in a densely populated area increases the probability of a harmful effect on human beings. Therefore, the least populated area was preferred in this study and graded with the highest value. A waste disposal site next to a road and railway would decrease security of the public and NSDF, on the other hand away from a road and railway it could increase the construction cost of the plant road. Therefore, a 1 to 3 km buffer was considered as most suitable and 0 to 1 km as the excluded area for the medium-broad road and railway sub-criterion. The narrow road sub-criterion was graded in the same way as the medium-broad road and railway sub-criterion. Cultural heritage includes monuments, therefore, a 500 m buffer was considered as an exclusion area for the monument sub-criterion to protect the cultural heritage. Buffer distance of 0.2 to 1 km and 0 to 0.2 km was considered as most suitable and an excluded area for the power line sub-criterion because a waste disposal site requires electricity but a power line too close to the disposal site may create complications. All grading associated with socio-economic criteria is shown in tab. 1. Figures 2 and 3 show all suitability maps calculated for a different sub-criterion related to the socio-economic criterion.

Hydrological criterion

The hydrological criterion will play an important role regarding the siting of NSDF in Bangladesh because of the elevated level of the underground water table and a good number of surface water bodies. This water is one of the important considerations that could hinder long term safety of a disposal facility. The hydrological criterion has been divided into three sub-criteria to attribute separate importance. The 1:25000 scale data of the surface water body sub-crite-

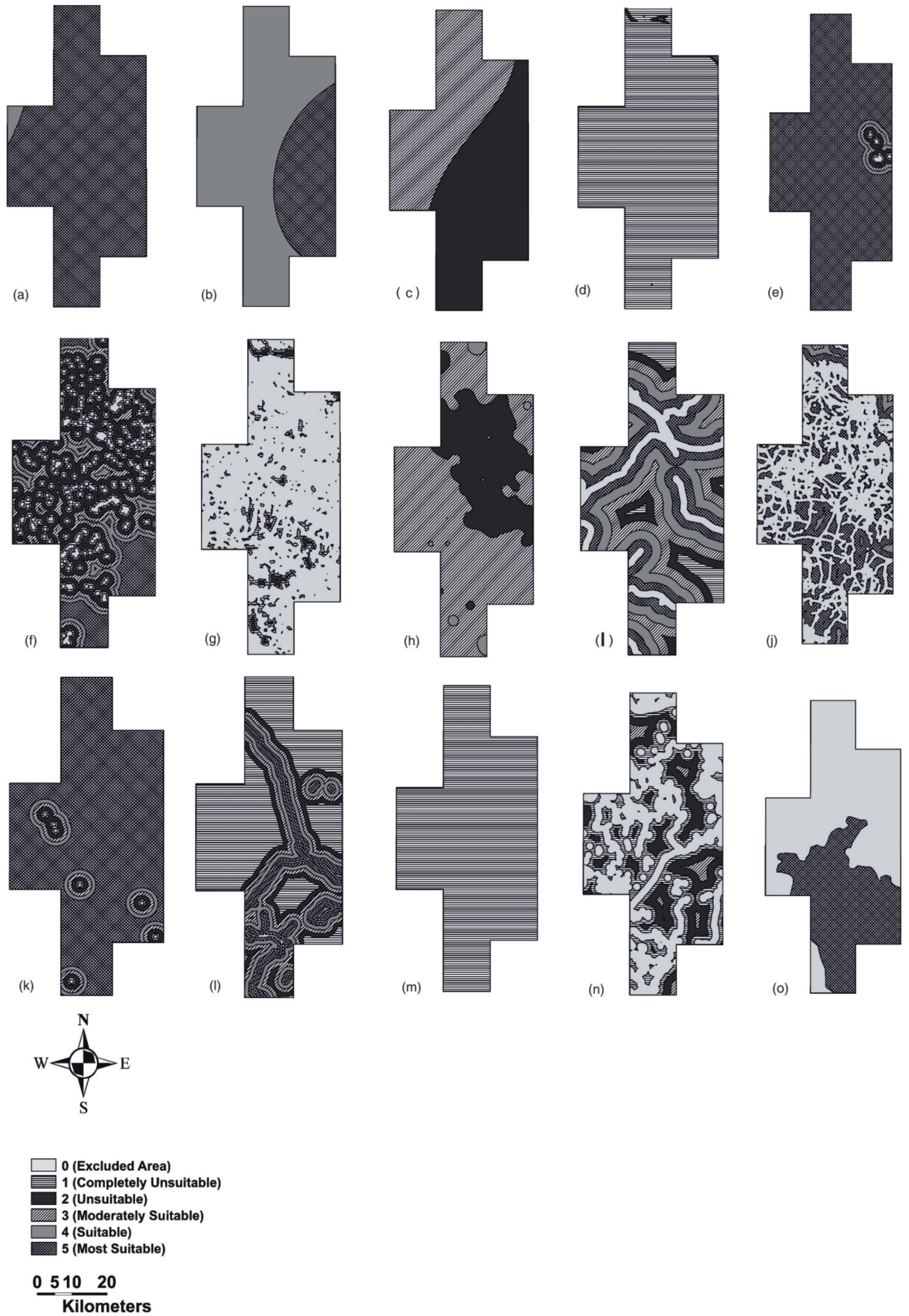

Figure 2. Suitability maps of (a) earthquakes, (b) wind speed, (c) rainfall, (d) cultivated-vegetated land, (e) forests, (f) buildings-facilities-built up areas (area), (g) buildings-facilities-industries-institutions (Point), (h) population density, (i) medium-broad road and railway, (j) narrow road, (k) monument, (l) power line, (m) ground water table, (n) surface water body, and (o) flooding sub-criteria for Region-1

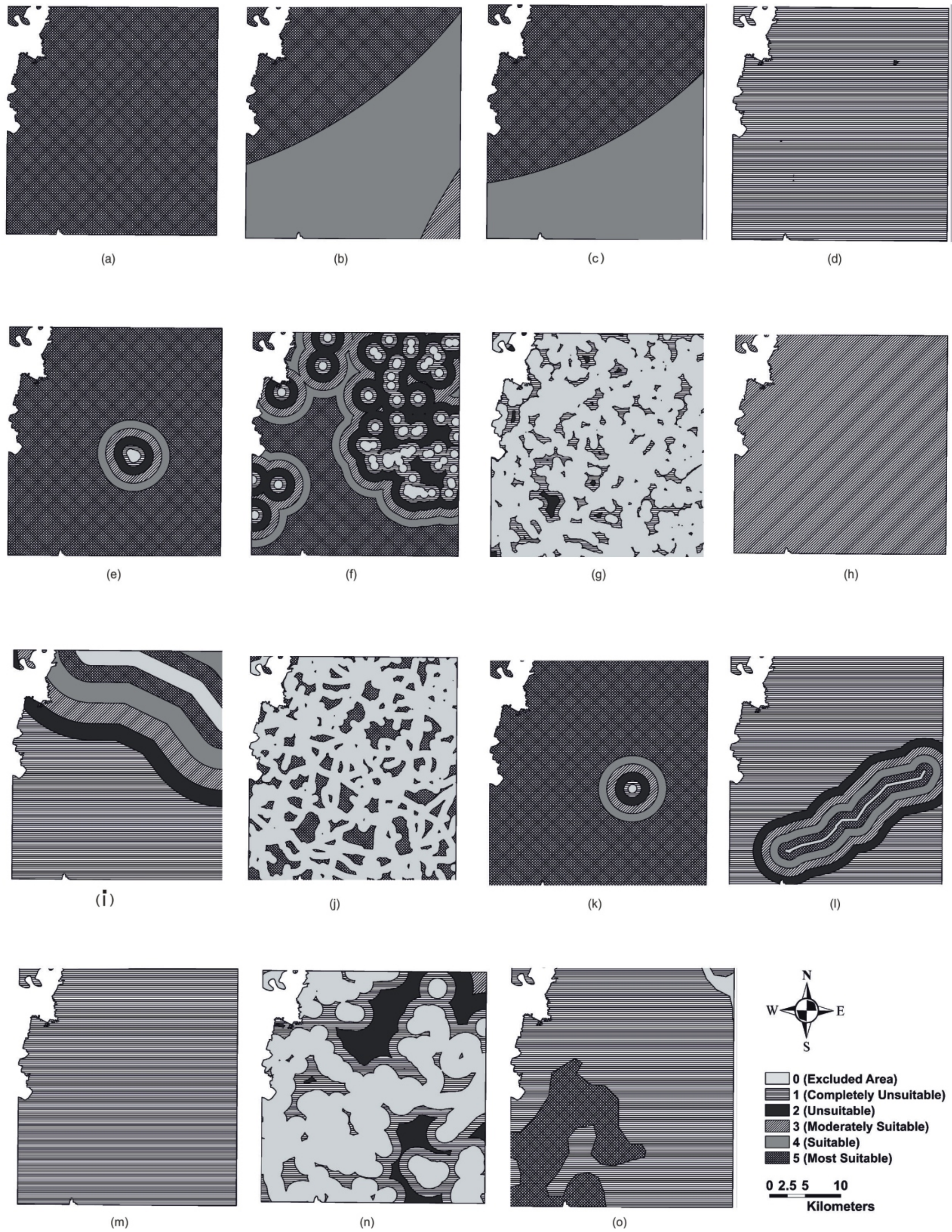

Figure 3. suitability maps of (a) earthquakes, (b) wind speed, (c) rainfall, (d) cultivated-vegetated land, (e) forests, (f) buildings-facilities-built up areas (area), (g) buildings-facilities-industries-institutions (Point), (h) population density, (i) medium-broad road and railway, (j) narrow road, (k) monument, (l) power line, (m) ground water table, (n) surface water body, and (o) flooding sub-criteria for Region-2

rion was collected from SOB, besides 1:50000 scale data for flooding was collected from the Water Resources Planning Organization (WARPO). The distance between the water table and the surface is known as the groundwater table. Nine years (2010-2018) of groundwater table data were collected from the Bangladesh Water Development Board (BWDB). A few stations have less than nine years' data. The ground water table changes throughout the year, therefore, the least value of the ground water table within 2010 to 2018 for each station was considered for safety. People in Bangladesh excessively depend on underground water for drinking and other purposes. Therefore, to make the contamination of groundwater risk minimal, a higher depth of the groundwater table was preferred. Bangladesh is prominent for inland fish production throughout the world. Plenty of surface water bodies gives the opportunity for fish farming, irrigation, household use and other purposes, therefore, the surface water body was graded as an excluded area. Floods in Bangladesh have become a common disaster due to its geographical position. The flood-prone area is not suitable for waste disposal and according to some reports NSDF should be away from the flooding [17, 23] zone. Therefore, severe and moderate flooding areas in Region-1 and Region-2 were considered as an exclusion area. Table 1 and figs. 2 and 3 show the grading and suitability maps of the hydrological criterion. Figures 2 and 3 represents a significant area of the Region-1 and Region-2 as an excluded area or completely unsuitable for the hydrological criterion.

Multi-criteria analysis

The MCA technique helps to make decisions while working with severawl objectives [4]. The AHP is one of the most common MCA methods used in this study. The pairwise comparison and consistency test are advantageous features of this method. In this study, the relative importance weight of each sub-criterion was evaluated using the AHP method. The pairwise comparison of each sub-criterion with respect to others was made on a scale 1 to 9, tab. 2, according to the experts' opinion and published research [4, 25]. Table 2 shows the importance values used in the pairwise comparison matrix (PCM), moreover 1.1-1.9, 2.1-2.9, 3.1-3.9 *etc*. values were used to indicate intermediate importance between 1-2, 2-3, 3-4 *etc*. The inconsistency of the PCM was measured with the help of the consistency ratio (CR) defined as

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \tag{1}$$

$$\text{Consistency index (CI)} = \frac{\lambda_{\max} - \mathrm{n}}{\mathrm{n} - 1} \tag{2}$$

where $\lambda_{\max}$ is the principal eigenvalue and n indicates the number of sub-criteria. The principal eigenvalue is the sum of the products between the column total of the PCM and the corresponding value of the weight. The constant parameter RI is known as the random consistency index. The RI_{15} indicates the value of RI for fifteen sub-criteria and it is 1.59 [26]. The less than 10 % value of CR indicates consistency of the PCM [27]. The calculated value of CR in the current study has been found to be 0.03 % which indicates the appropriateness of the judgment.

After determination of the relative importance weight and suitability map of each sub-criterion, the overlay analysis was performed using the GIS based simple additive weighting method. The formula utilized in this method is as follows [25]

$$S_i = \sum_{i=1}^{n} x_{ij} w_j \tag{3}$$

where S_i is the suitability index for area i, w_j – the relative importance weight of the sub-criterion j, x_{ij} – the grading value of area i under sub-criterion j, and n – the total number of sub-criteria. The values of x_{ij}, tab. 1, and w_j, tab. 3, were utilized to calculate the suitability index of the final suitability map, fig. 5. The lowest and highest value of the suitability index were 1.989 and 3.30142, respectively, without the excluded area. Figure 4 shows the excluded area and residual area of the Region-1 and Region-2. This excluded area of Region-1 and Region-2 is comprised of the excluded ar-

Table 2. Preference values used in the AHP method [28]

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgment slightly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Demonstrated importance	An activity is strongly favored and its dominance is demonstrated in practice
9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgments	When compromise is needed
Reciprocals of the above nonzero	If activity i has one of the above nonzero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	

A – Population density, B – Buildings-facilities-industries-institutions (point), C – Buildings-facilities-built up areas (area), D – Ground water table, E – Earthquakes, F – Flooding, G – Surface water body, H – Medium-broad road and railway, I – Cultivated-vegetated land, J – Monument, K – Forests, L – Rainfall, M – Narrow road, N – Power line, O – Wind speed.

eas for all the sub-criteria. This residual area was divided to produce the final suitability map based on the equal interval classification of the suitability indexes. The final suitability map comprises six types of areas such as excluded, most suitable, suitable, moderately suitable, unsuitable and completely unsuitable, fig. 5.

This regional scale screening as shown in fig. 5 depicts different parts of Region-1 and Region-2 as an excluded area, most suitable area, suitable area, moderately suitable area, unsuitable area and completely unsuitable area, which respectively, indicates 2046.07 km^2, 29.147 km^2, 42.022 km^2, 5.97 km^2, 0.036 km^2, and 0.0004 km^2 of the total area of Region-1 and 651.162 km^2, 3.107 km^2, 6.294 km^2, 10.989 km^2, 3.736 km^2, and 0.022 km^2 of the total area of Region-2. Waste disposal sites with a smaller area are not economically acceptable [29]. In addition, Bangladesh is currently interested in developing and operating a single disposal facility to safely hosting all RW generated in the country [16]. Therefore, areas greater than one square kilometer were considered as potential sites for the further study. Figure 6 and tab. 4 show the potential sites map and details of the potential sites, respectively.

The reconnaissance field survey, site characterization and site confirmation need to be performed on potential sites to identify the final disposal site.

CONCLUSIONS

Bangladesh is currently producing a small amount of RW. However, the amount will be drastically increased in the near future after starting the operation of the NPP currently under construction. The proper management of RW including disposal is necessary to ensure safety of the public, future generations and the environment. Disposal is considered as the final step of waste management activities. The suit-

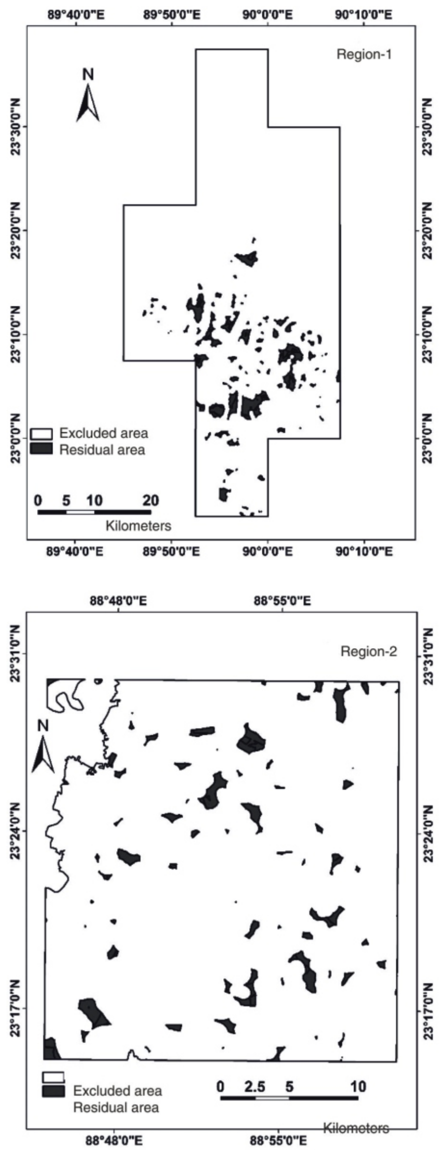

Figure 4. Excluded area and residual area map of Region-1 and Region-2

Table 3. Pairwise comparison matrix and relative importance weights of the sub-criteria

Sub-criteria	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	Weights w_j
A	1	1.1	1.2	1.3	1.4	1.4	1.5	2	2	2.2	2.5	2.8	3	3.2	3.5	0.11428
B	0.91	1	1.1	1.2	1.3	1.3	1.4	1.8	1.8	2	2.3	2.5	2.7	3	3.2	0.10463
C	0.83	0.91	1	1.1	1.2	1.2	1.3	1.7	1.7	2.1	2.2	2.3	2.5	2.8	3.1	0.09743
D	0.77	0.83	0.91	1	1.1	1.1	1.2	1.6	1.6	1.8	2	2.2	2.3	2.4	2.6	0.08890
E	0.71	0.77	0.83	0.91	1	1	1.1	1.4	1.4	1.6	1.7	2	2.1	2.2	2.3	0.08052
F	0.71	0.77	0.83	0.91	1	1	1.1	1.4	1.4	1.6	1.7	2	2.1	2.2	2.3	0.08052
G	0.67	0.71	0.77	0.83	0.91	0.91	1	1.3	1.3	1.4	1.6	1.8	1.9	2	2.1	0.07388
H	0.50	0.56	0.59	0.63	0.71	0.71	0.77	1	1	1.3	1.2	1.4	1.5	1.6	1.6	0.05739
I	0.50	0.56	0.59	0.63	0.71	0.71	0.77	1	1	1.3	1.2	1.4	1.5	1.6	1.6	0.05739
J	0.45	0.50	0.48	0.56	0.63	0.63	0.71	0.77	0.77	1	1.1	1.2	1.3	1.4	1.5	0.04965
K	0.40	0.43	0.45	0.50	0.59	0.59	0.63	0.83	0.83	0.91	1	1.1	1.2	1.3	1.3	0.04592
L	0.36	0.40	0.43	0.45	0.50	0.50	0.56	0.71	0.71	0.83	0.91	1	1.1	1.2	1.2	0.04119
M	0.33	0.37	0.40	0.43	0.48	0.48	0.53	0.67	0.67	0.77	0.83	0.91	1	1.1	1.2	0.03854
N	0.31	0.33	0.36	0.42	0.45	0.45	0.50	0.63	0.63	0.71	0.77	0.83	0.91	1	1.1	0.03583
O	0.29	0.31	0.32	0.38	0.43	0.43	0.48	0.63	0.63	0.67	0.77	0.83	0.83	0.91	1	0.03383

λ_{max} = 15.006, CI = 0.00044, RI_{15} = 1.59, and CR = 0.00028 <<0.1

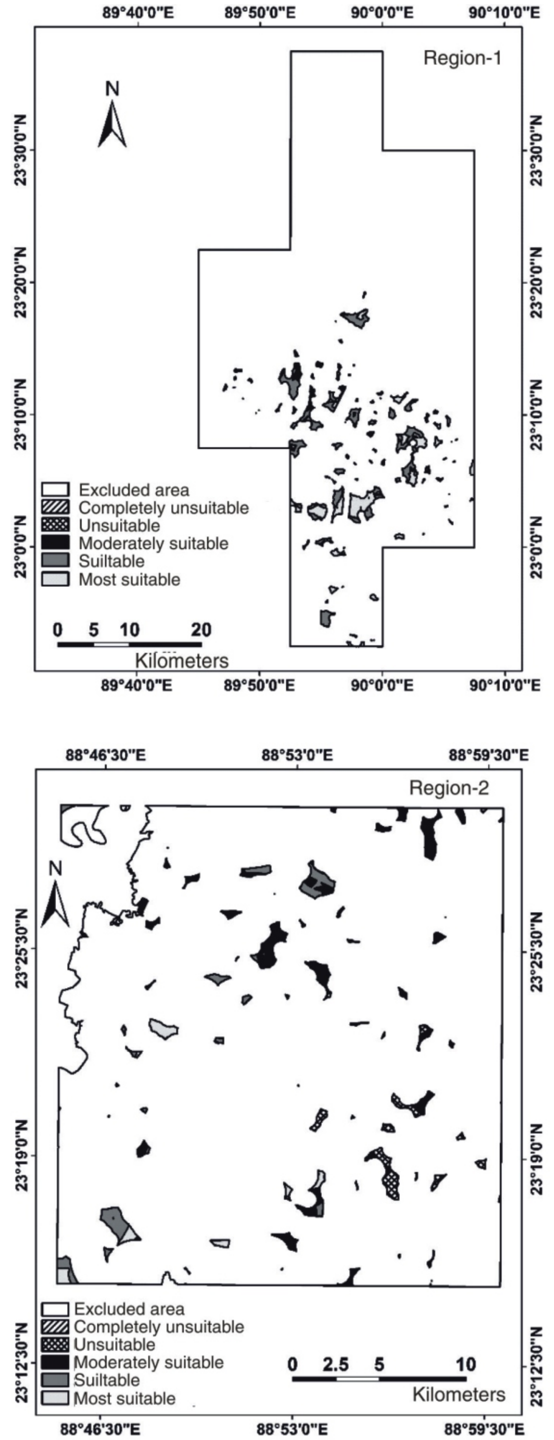

Figure 5. Suitability map of Region-1 and Region-2 for the NSDF siting

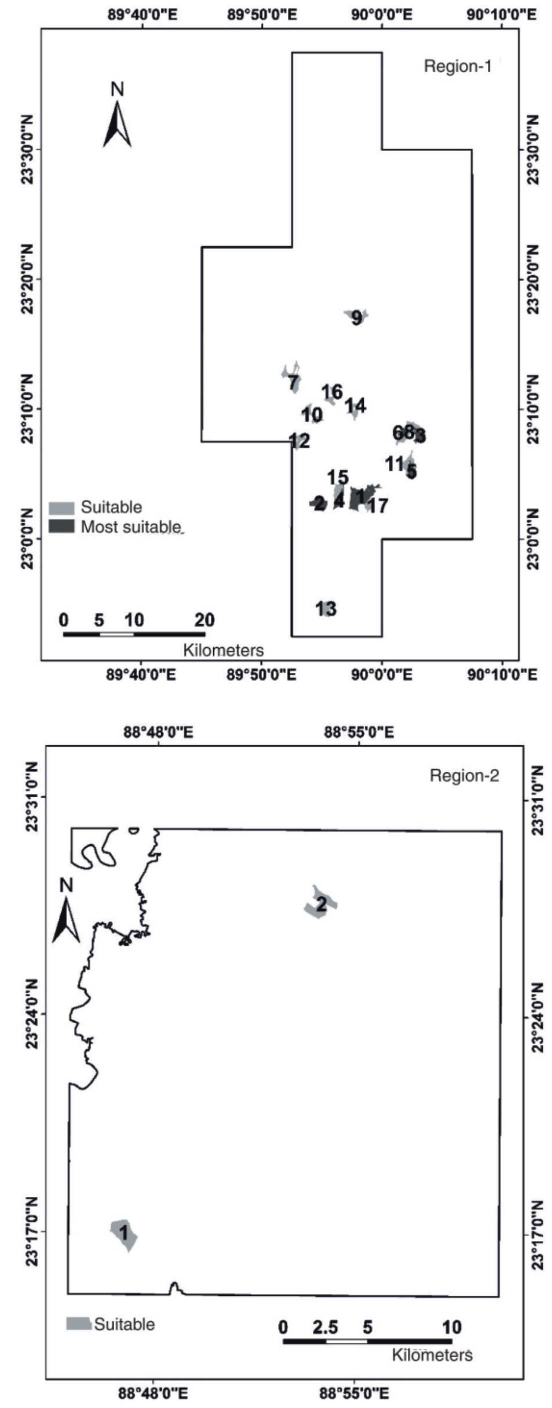

Figure 6. Potential sites map of Region-1 and Region-2

ability of a disposal option for a country depends not only on the types of RW but also on socioeconomic conditions, available technology and safety features.

Near-surface disposal has been anticipated as the preferred option for the disposal of LILW in Bangladesh. Research activities have already been initiated in this regard to find suitable sites for this purpose [4]. This work is the continuation of the ongoing research activities in the country as stated in the earlier section of the manuscript.

The continental scale (in 1:1000000 scale) screening in the previous study identified six potential regions (Region-1 to Region-6) which could be considered for further analysis to find out suitable sites for near-surface disposal facilities. From the six aforementioned regions, Region-1 and Region-2 have been selected for the current study based on some suitability criteria of these two regions over others. Regional scale (mostly in 1:25000 scale) screening has been performed in the current study with large scale data which provides precision of the data and the study. This regional scale screening identified 42.02 km^2 and 29.14 km^2 areas of Region-1

Table 4. Nineteen selected potential sites from Region-1 and Region-2

Site number	Region	Category	Latitude	Longitude	Area [km^2]
1	Region-1	Most suitable	23° 3' 18.24"	89° 58' 16.83"	7.903979
2		Most suitable	23° 2' 43.05"	89° 54' 47.17"	2.969646
3		Most suitable	23° 8' 0.72"	90° 3' 2.9"	2.402077
4		Most suitable	23° 3' 3.75"	89° 56' 28.21"	2.301824
5		Most suitable	23° 5' 16.17"	90° 2' 27.24"	1.774464
6		Most suitable	23° 8' 10.83"	90° 1' 46.48"	1.152137
7		Suitable	23° 12' 24.76"	89° 52' 35.15"	4.923788
8		Suitable	23° 8' 16.86"	90° 2' 11.05"	3.879479
9		Suitable	23° 17' 13.42"	89° 57' 54.62"	3.435391
10		Suitable	23° 9' 35.69"	89° 54' 9.71"	2.753719
11		Suitable	23° 5' 49.64"	90° 2' 12.35"	2.592529
12		Suitable	23° 7' 35.59"	89° 52' 59.05"	2.494583
13		Suitable	22° 54' 38.51"	89° 55' 23.85"	2.468154
14		Suitable	23° 9' 55.88"	89° 57' 42.2"	2.198926
15		Suitable	23° 3' 49.05"	89° 56' 20.77"	2.043595
16		Suitable	23° 10' 57.36"	89° 55' 49.04"	1.921544
17		Suitable	23° 2' 35.91"	89° 58' 52.17"	1.255698
18	Region-2	Suitable	23° 16' 57.55"	88° 46' 56.81"	1.689431
19		Suitable	23° 27' 37.01"	88° 53' 41.09"	1.550514

and 6.29 km^2 and 3.10 km^2 areas of Region-2 as suitable and most suitable, respectively. Nineteen potentials sites with areas of 7.90 km^2 to 1.15 km^2 were identified for further analysis from these suitable and most suitable areas.

As mentioned earlier, the current study is the continuation of the previous research work designed to find potential disposal sites for the disposal of LILW. The GIS and the MCA method were applied to screen Region-1 and Region-2 to find potential sites. The current research work is the first of this type that has been performed in the country. The current methodology also has been applied for the first time in the case of Bangladesh to find out potential sites for the construction of a disposal facility for RW. Thus this research work will pave the way for the policy makers to resolve the RW disposal problem in Bangladesh.

The current study has been conducted based on a well-established methodology and the results are precise, however, it may be done using a different methodology as per requirement. The success of such studies is dependent to some extent on the input data collected from various sources. A field survey should be implemented on these nineteen potential sites to select preferred sites for a further and rigorous study. Characterization of the preferred sites is necessary to get more specific data of the sites in order to confirm and identify a final and a standby site for the construction of a NSDF.

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AUTHORS' CONTRIBUTIONS

The concept of this study was put forward by Md. I. Ali and D. Paul. Data collection and scanning was done by K. N. Sakib and Md. A. Haydar. Md. S. Alam and Md. I. Ali helped to write this article. All the authors contributed to the data analysis and in the preparation of the manuscript.

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ПРИКАЗ СКРИНИНГА ОДАБРАНИХ ОБЛАСТИ БАНГЛЕДЕША РАДИ ИДЕНТИФИКАЦИЈЕ ПОТЕНЦИЈАЛНИХ МЕСТА ЗА ОДЛАГАЊЕ РАДИОАКТИВНОГ ОТПАДА НИСКОГ И СРЕДЊЕГ НИВОА

Одлагање радиоактивног отпада постало је витално питање за Бангладеш, јер земља активно ради на томе да до 2023-2024. године буде држава која управља нуклеарном електраном. Овај рад треба да прикаже потенцијалне локације постројења за површинско одлагање, користећи софтвер географског информационог система и методу вишекритеријумске анализе. Раније је идентификовано шест региона (Регион-1 до Регион-6) током вршења скрининга континенталних размера на целој територији Бангладеша. У садашњој студији извршен је скрининг регионалних размера у Региону-1 и Региону-2, користећи пет критеријума у анализи подељених у петнаест поткритеријума: земљотреси, брзина ветра, кише, обрађено и засађено земљиште, шуме, зграде-објекти-индустрије-институције, густина насељености, средње широки путеви и железница, уски путеви, далеководи, подземне воде, површинско водно тело и поплаве. Мапа погодности и пондерисање релативне важности ових поткритеријума утврђени су применом географског информационог система и методе вишекритеријумске анализе. Извршена је анализа са мапама погодности сваког поткритеријума и установљена је коначна карта погодности Региона-1 и Региона-2. Ове мапе погодности подељене су у шест категорија подручја: искључена, најпогоднија, погодна, средње погодна, непогодна и потпуно непогодна. Од најпогоднијих и погодних подручја идентификовано је деветнаест потенцијални локација са максималном и минималном површином од 7.90 km^2 и 1.15 km^2. На одабраним потенцијалним локацијама потребна су детаљна испитивања на терену и карактеризације локације ради одабира коначног одлагалишта ниског и средњег нивоа радиоактивног отпада.

Кључне речи: радиоактивни отпад, одлагање на површини, избор локације, географски информациони систем, метода вишекритеријумске анализе