KATHMANDU UNIVERSITY

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REPORT ON SITE SUITABILITY ANALYSIS FOR WASTE DISPOSAL SITE SELECTION USING GEOGRAPHIC INFORMATION SYSTEM AND MULTI-CRITERIA DECISION ANALYSIS: A CASE STUDY OF POKHARA-LEKHNATH METROPOLITAN CITY

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1. INTRODUCTION

1.1 Background

Waste is a surplus material discharged and discarded from daily human life activities, which leads to hostile impacts on human health and the environment (HUNDU, n.d.). Increasing population, rapid economic growth and the rise in community living standards are the major triggering factors for excessive waste generation in the world. Though, some source reduction, recycling and waste transformation are methods widely used to manage waste, there is always a residual matter even after the recovery process that must be disposed somewhere.

Site selection for waste disposal is a difficult task to accomplish as it depends upon different factors and regulations and a minor negligence may hamper the biophysical environment and the ecology of the surrounding area. Several techniques for site selection for different kinds of wastes and different kinds of environment are recommended as per the research of different authors (Al-Ansari, 2013) (Al-Ansari et al., 2013). However, most of such siting techniques combine MCDA and GIS as their major approach.

Suitability Analysis using GIS based MCDA can be thought as a process or technique that transforms and combines geospatial data and value judgments as per the decision makers' preferences to obtain information for decision making. The result of these technique is the evaluation of the suitability for the entire study area based on a particular suitability ranks, which is useful in order to make an initial rating of the suitable zones.

1.2 Problem Statement

The disposal of garbage is one of the prominent problems today. The challenges of waste management are manifold. Despite of various reuse and recycle systems, the waste production can't be minimized to zero.

Pokhara Lekhnath Metropolitan City is struggling to manage garbage of the town. The city has a capacity to manage a maximum 90 tons of garbage, against 200 tons produced here, every day (*Pokhara-Lekhnath Metropolis Facing Garbage Woes*, 2017). The location of ultimate disposal sites of this city represents the unconsciousness about the environmental and public health hazards arising from disposing of waste in improper location. Hence, proper garbage disposal is the basic need today. A proper siting of waste disposal location by using GIS based MCDA uses logical procedures incorporating different factors and criteria that addresses the biophysical and ecological aspects of environment. The study carried out here provides a basic framework of working procedures for waste disposal site selection.

1.3 Objectives

The key objective of this project was:

- To map the potential areas suitable for dumpsite in Pokhara Lekhnath Metropolitan City integrating MCDA with GIS to determine the suitable sites for waste disposal.

The secondary objectives incorporated:

- Determining criteria that influences the siting of location of waste disposal and
- Use of MCDA and GIS environments as an analysis technique.

1.4 Scope

This project dealt with determining suitable sites for waste disposal in Pokhara Lekhnath Metropolitan City. This study incorporated only few of the major factors influencing the disposal site like transportation network, water bodies, settlement areas, etc. that were openly accessible from the internet. Nevertheless, this study did not address all the factors and criteria of community-based standards and guidelines for waste disposal of the local municipality. Most of the values assumed in this study are based on the reference of researches of various authors.

2. LITERATURE REVIEW

2.1 Suitability Analysis

Suitability Analysis is the process and procedures used to establish the suitability of a system – that is, the ability of a system to meet the needs of a stakeholder or other user. In the context of GIS, suitability analysis refers to check the appropriateness of an area as per the defined objective.

GIS is a very powerful and robust tool to support decision making, problem solving and planning processes related to social development, environmental protection and management as well as economic boosting purpose. The power of GIS lies in its ability to put together diverse geo-data of varied types as well as manipulating it coming up with optimal results used in decision making thereby facilitating the best operations for environmental management (Nas et al., 2010). GIS is crucial to locating dumpsite owing to its ability to reduce the cost and time. Spatial decision problems typically involve a large set of feasible alternatives and multiple, conflicting and incommensurate evaluation criteria (Malczewski, 2006). Such decision problems give rise to the integration of GIS and MCDA. MCDA provides a rich collection of techniques and procedures for structuring decision problems, and designing, evaluating and prioritizing alternative decisions.

2.2 Multi-Criteria Decision Analysis Methods

As the name suggests, multi means more than one and decision is a choice between the alternatives. Multi-criteria decision analysis provides a set of strategies, procedures and calculation for organizing choice issues, planning process, assessing, prioritizing from the multiple set of alternatives. MCDA also has the power of decreasing the time period and expenses by narrowing down the possibilities (Malczewski, 2006). MCDA is concerned with structuring and solving decision problems involving multiple criteria and is summarized under four major operations namely Criteria selection and preference modelling, weight determination, aggregation and validation.

i. Criteria Selection and Preference Modelling

Criteria selection refers to understanding the problem or objective and determining set of criteria and constraints that have influence over the problem. The number of criteria depend upon the amount of detailing required. Preference modelling focuses on understanding preferences of decision makers in regard to the objective. Preferences can be inter-criteria and intra-criteria. Intra-criteria preferences are the judgments that refer to relative values attached to different levels of performances within the same criteria. Inter-criterion preference is judgments that refer to the relative importance attached to4 the information carried by each single criterion. The criteria need reclassification during which buffer distances are allocated and ranks are assigned depending upon their respective influences.

ii. Weight Determination

The criteria weights usually provide the information about the relative importance of the considered criterion. The importance of each criterion can be weighted by several methods and AHP is one of the most common methods. AHP is a pairwise comparison method applied for all the considered criteria within the analysis. Criteria are usually not more than 7. It then assigns weight to each criterion based on their relative importance. A matrix is constructed, where each criterion is compared with the other criteria, relative to its importance, on a scale from 1 to 9 where 1 applies to equal preference between two factors; 9 applies to a particular factor being extremely favored over the other A consistency ratio is then found in order to check how consistent the judgments have been with respect to large samples of purely random judgments. If CR is over 0.1, the judgment is said to be inconsistent and needs to be repeated.

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

iii. Aggregation of Criteria

Aggregation refers to the process of synthesizing a collection of numerical values into a unique representative or meaningful value in order to conclude or to come to a decision (Chou, 2013). Weighted linear combination technique is usually applied for aggregation of criteria in order to provide a concluding evaluation to each criteria and preferences. It is given by,

$$\mathrm{S} = \sum \mathrm{w_i x_I} * \pi \mathrm{c_j}$$

Where,

S = composite suitability score

w_i = weights assigned to each factor

x_I = factor scores

c_j =constraints

Σ = sum of weighted factors

Π = product of constraints

Weighted Overlay is also one of the most common methods for aggregation of criteria. Weighted overlay tool in GIS allows to input the raster, set scale values to each alternative within the criterion, apply weight to all criteria and delivers the final output raster. When the Weighted Overlay tool is being used for suitability modeling, higher values generally indicate that a location is more suitable.

iv. Validation

Validation refers to the assessment of the reliability of the output. It involves removal of logical fallacies, sensitivity analysis and field verification. Sensitivity analysis is performed to check how the result is altered with respect to change in weights. Besides, field verification during validation phase helps to verify the areas obtained in the GIS to that of real field areas. The changes occurred in the real field areas in comparison to areas obtained in GIS needs to be detected and adjustments should be made accordingly.

3. MATERIALS AND METHODOLOGY

3.1 Study Area

Pokhara Lekhnath Metropolitan City was taken as the study area for determining suitable sites for waste disposal as a part of this project. Pokhara Lekhnath Metropolitan City lies between coordinates of latitudes 28°05′ N and 28°21′ N, coordinates of longitudes 83°48′ E and 84°09′ E. This is the largest metropolis of the country where elevation ranges from 827m to 1740m and occupies an area of 464.24 square meters (*The Largest Metropolitan City*, n.d.).

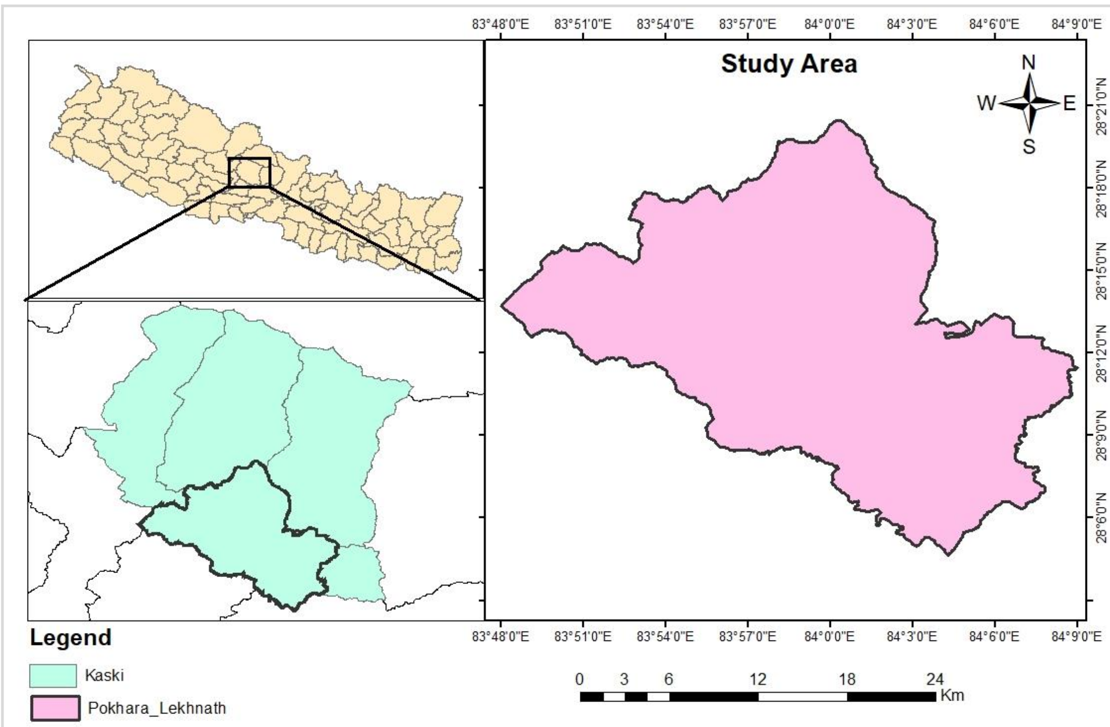

Figure 1. Map Showing Study Area for Waste Disposal Site Selection

3.2 Materials Used

3.2.1 Data used

The datasets available on the internet were used as the secondary data throughout the project. The datasets of roads, rivers, settlements and lakes were retrieved from Open Street Maps (*OpenStreetMap*, n.d.). The DEM file was retrieved from Unites States

Geological Survey (Earth Resources Observation And Science (EROS) Center, 2017). and the land use dataset was acquired from the website of ICIMOD (ICIMOD, 2013).

3.2.2 Software used

ArcGIS Desktop Software and Online AHP Calculator (*AHP Calculator - AHP-OS*, n.d.) was used for mapping and analysis procedure.

3.3 Study Method and Analysis Procedure

It was planned to locate the suitable waste disposal site where garbage would be buried.

3.3.1 Criteria Identification

Firstly, the evaluation criteria required for waste disposal site selection in Pokhara Lekhnath Metropolitan City were identified. Although a lot of criteria were defined by the standards and guidelines of the municipal waste management authority, only six of them were taken onto account for this study purpose, namely, transportation routes, water bodies (river and lakes), settlements areas, slope and landuse. Also, Agricultural land and Waterbody were counted as the constraints for waste disposal.

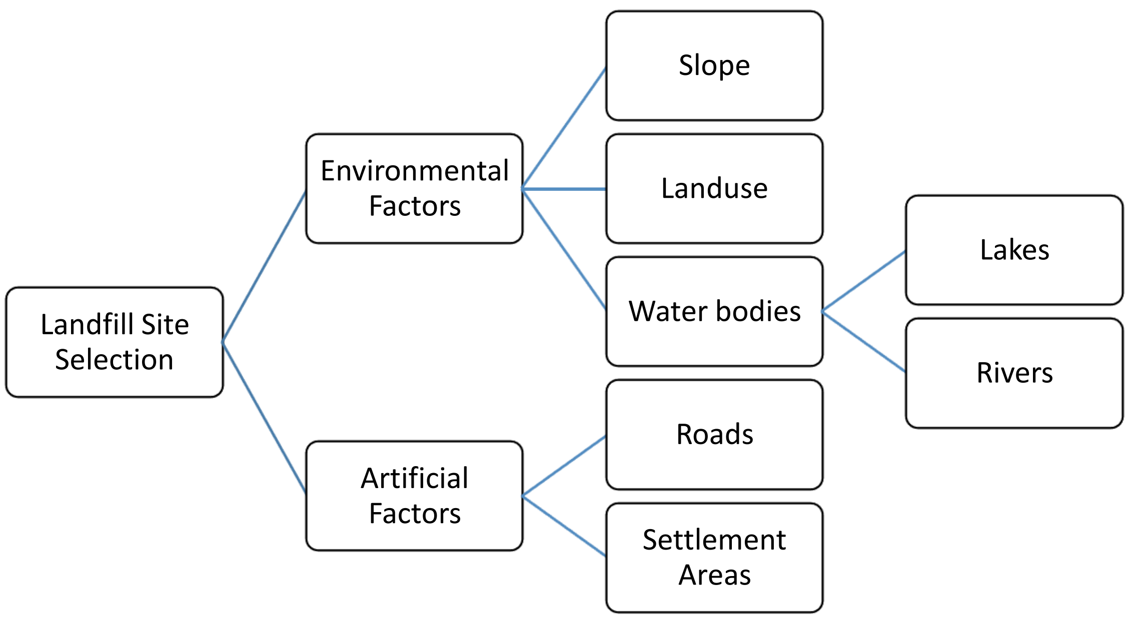

Figure 2. Decision tree developed for waste disposal site selection in Pokhara Lekhnath

3.3.2 Criteria Weights and Analysis

Among different techniques of assigning the weights of criteria as aforementioned in the Literature Review, a pairwise comparison technique was implemented in this case.

The comparison matrix indicating the relative importance of the criterion in the columns compared to the criterion in the rows as shown in the table below. For each comparison it was decided which of the two criteria was most important, and then assigned score was given to show how much more important it is. A scale with values 1 to 9 where 1 refers that the column and row factors are equally important. On the other hand, the rating 1/9 demonstrates that the column factor is very important relative to the row factor, whereas rating 9 shows that the row factor is more important than column factor.

Table 1. Comparision Matrix

	Roads	Rivers	Lakes	Settlement	Landuse	Slope
Roads	1	¼	1/4	1/5	5	7
Rivers	4	1	1	1/3	6	8
Lakes	4	1	1	1/3	6	8
Settlement	5	3	3	1	7	9
Landuse	1/5	1/6	1/6	1/7	1	2
Slope	1/7	1/8	1/8	1/9	1/2	1

The weights were then developed from the above pair wise comparisons matrix by following the logic induced by Dr. Thomas L. Saaty (Saaty, 1977) in which these pairwise comparison were analyzed to produce weights that sum to 1 (*Normalization*).

Table 2. Weights derived by calculating the principal eigenvector of pairwise comparison matrix

Factors	Eigenvector Weight	Influence %
Roads	0.099	9.9
Rivers	0.213	21.3
Lakes	0.213	21.3
Settlement	0.415	41.5
Landuse	0.036	3.6
Slope	0.024	2.4
$\sum$	1	100

Also, during this procedure, a test for the consistency of comparisons was carried out by determining consistency ratio (CR).

$$\text{Consistency Ratio} = \frac{\text{Consistency Index (CI)}}{\text{Random Index (RI)}}$$

	A - wrt AHP priorities - or B?		Equal	How much more?
1	○ Road	◉ River	○ 1	4
2	○ Road	◉ Lake	○ 1	4
3	○ Road	◉ Settlement	○ 1	5
4	◉ Road	○ Landuse	○ 1	5
5	◉ Road	○ Slope	○ 1	7
6	◉ River	○ Lake	◉ 1	
7	○ River	◉ Settlement	○ 1	3
8	◉ River	○ Landuse	○ 1	6
9	◉ River	○ Slope	○ 1	8
10	○ Lake	◉ Settlement	○ 1	3
11	◉ Lake	○ Landuse	○ 1	6
12	◉ Lake	○ Slope	○ 1	8
13	◉ Settlement	○ Landuse	○ 1	7
14	◉ Settlement	○ Slope	○ 1	9
15	◉ Landuse	○ Slope	○ 1	2

CR = 7.1% OK

Here,

$$CI = \frac{\lambda_{max} - n}{n - 1},$$

where, λ_{max} is the principle Eigen Value and n is the number of factors and RI depends upon the number of elements being compared.

In our problem, λ_{max} was found to be 6.4427

$$\text{So, } CI = \frac{6.4427 - 6}{6 - 1} = 0.0885$$

$$\therefore\ CR = \frac{0.0885}{1.24} = 0.0714 < 0.10 \text{ (Acceptable)}$$

The factors and their resulting weights were used as input for the Multi Criteria Evaluation (MCE) module for weighted linear combination of overlay analysis.

3.3.3 Digital Environment Maps and GIS Analysis

GIS has become a marvelous tool and is able to place itself in the top of the board because of its efficiently storing, retrieving, analyzing and displaying large volume of spatial data from a variety of sources, which is also the fundamental necessity for proper waste disposal site selection.

The following models were developed in the ArcGIS environment for waste disposal site selection.

i) Rating Maps Model

Rating Model were created for standardizing each of the criteria to a common scale. At first, Euclidean distance tool was used for distance calculation of road, river lake and settlement criteria up to the extent of the boundary of the study area, i.e. boundary of Pokhara Lekhnath Metropolitan City. The next step was the use of Reclassify tool under Spatial Analysis for developing rating models. Altogether 6 classes were generated for each factor; 0 representing restricted zones and 5 representing most suitable zones for waste disposal (*Standardizing into a common scale of 0-5*).

Note: All the distances referred to each criterion for waste disposal in this project are assumed in reference to different articles published in the international journals and is not based on community standards and guidelines of local municipality.

- Road rating Model

A road rating model was generated using the following distances. It was based on the concept that, the nearer the distance to the roads, the more suitable the disposal area because it minimizes the impedance of relative transportation cost just for the disposal of waste (HUNDU, n.d.). However, the distance 0-700 m was ranked 4 (suitable) rather than 5 because of health and sanitary purpose.

Table 3. Classification in distance from Road for Suitability

Criteria	Distance (m per class)	Suitability	Ranking
Road	<700	Suitable	4
	700 – 3000	Most Suitable	5
	3000 – 4000	Moderately Suitable	3
	4000 – 6000	Less Suitable	2
	6000 – 8000	Least Suitable	1
	>8000	Restricted	0

➢ <u>River rating Model | Lake Rating Model</u>

The contaminated runoff from a disposal site would have an adverse effect on water bodies and its ecosystem (Asif et al., 2019). River and lake rating models were generated based on the consideration that the waste disposal site must be away from these water resources. Classification was done using same class intervals (distances) for both of the factors. Following distances were taken into account for defining suitability.

Table 4. Classification in distance from River and Lake for Suitability

Criteria	Distance (m per class)	Suitability	Ranking
River and Lake	<700	Restricted	0
	700 – 2500	Least Suitable	1
	2500 – 3500	Less Suitable	2
	3500 – 4500	Moderately Suitable	3
	4500 – 5500	Suitable	4
	>5500	Most Suitable	5

➢ <u>Settlement Rating Model</u>

Settlement is the most important factor determining location of waste disposal sites. As a hub of human population, high preferences were given to settlement for the public health, safety and sanitation. Settlement rating model was generated with the assumption that waste disposal site must be far away from settlement areas for the sanitary and hygienic purpose.

Table 5. Classification in distance from Settlement for Suitability

Criteria	Distance (m per class)	Suitability	Ranking
Settlement	<700	Restricted	0
	700 – 2500	Least Suitable	1
	2500 – 3500	Less Suitable	2
	3500 – 4500	Moderately Suitable	3
	4500 – 5500	Suitable	4
	>5500	Most Suitable	5

➢ Slope Rating Model

Slope raster was generated from the DEM file and the degrees of the slope were classified. It was assumed that a little slope (5°-15°) was considered best suited that the plain land because a little slope would aid in excavation for burying the waste. However, more sloppy terrain may be prone to landslide and sewage flow thus affecting the vicinity of the area.

Table 6. Classification of degree rise of Slope for Suitability

Criteria	Degree (°) per class	Suitability	Ranking
Slope	< 5	Suitable	4
	5 – 15	Most Suitable	5
	15 – 25	Moderately Suitable	3
	25 – 35	Less Suitable	2
	35 – 45	Least Suitable	1
	>45	Restricted	0

➢ Landuse Rating Model

Based on occupancy of the land in the metropolitan city, classification was done for the suitability. Agricultural areas were counted as restricted site for waste disposal whereas grassland and barren land were given more preferences.

Table 7. Classification in Land use type for Suitability

Criteria	Type	Suitability	Ranking
Landuse	Agriculture	Restricted	0
	Water body	Restricted	0
	Built-up	Least Suitable	1
	Forest	Less Suitable	2
	Shrub Land	Moderately Suitable	3
	Grassland	Suitable	4
	Barren Land	Most Suitable	5

ii) Suitability Map Model

A suitability map model was generated by overlaying all the rating maps together to obtain the level of suitability (unsuitable to most suitable) in the study area for waste disposal. The weighted overlay tool was used in ArcGIS environment. For each of the factors, the weight (% influence) was used in the entry.

iii) Restriction Map Model

A restriction map model was generated based on the suitability map model. The restricted zones (ranked as 0) of the suitability map was classified as one class and other zones (ranked from 1 - 5) of the suitability map were classified as another class, hence defining two zones; one restricted area for waste disposal and another non-restricted area.

iv) Suitable Area Model

Finally, a suitable area model was generated. The most suitable zones for the waste disposal were extracted seperately using *Conditional* tool is ArcGIS.

v) Removing Logical Fallacies and Field Verification

Some of the obtained suitable zones were not in proper shape. Meaning, some of them had more length and less breadth such that the breadth can be considered negligible. Such zones were identified and removed. Furthermore, it is a best practice to witness the present context of those analyzed suitable sites by field verification. However, it was difficult during the current pandemic time to reach at such destinations. Thus, the situation of the sites were observed from the Sentinal-2 satellite imageries.

3.4 Workflow

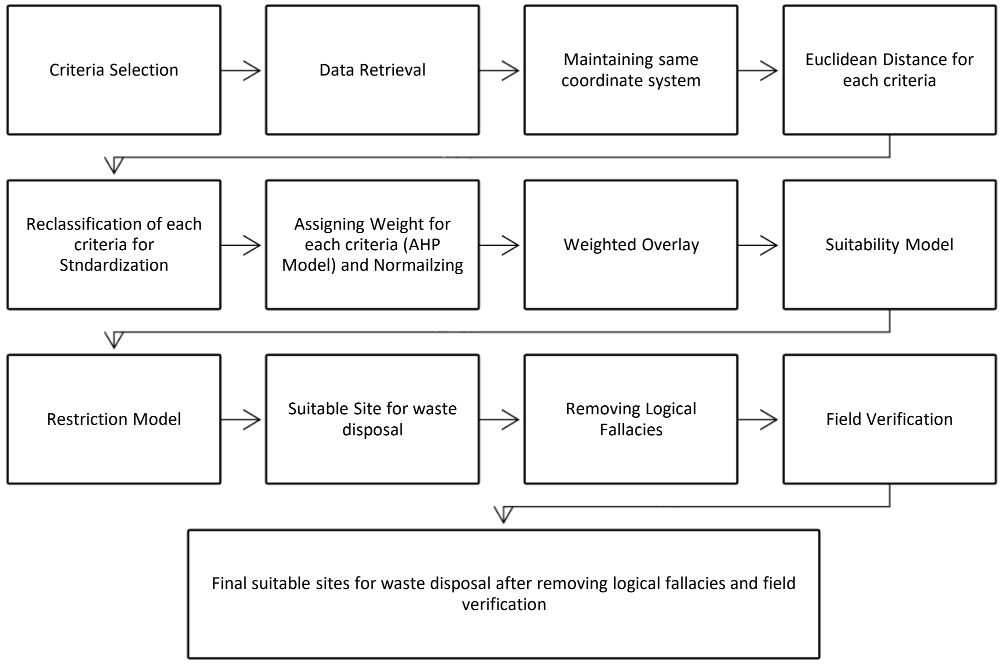

Figure 3. Methodological flow diagram

4. RESULTS

The suitable waste disposal site selection was done by embracing GIS based Multi-Criteria Analysis procedure. The reclassified rating maps of each selected factors were overlaid to achieve a single suitability map, which later is used to locate suitable sites for waste disposal in this study area.

Following were the key outcomes:

4.1 Rating Maps

The following rating maps represent the level of suitability of sites for waste disposal from proximity of each factors. The rating values were assigned ranging from highly suitable to restricted, the former one ranked as 5 and the latter one ranked as 0.

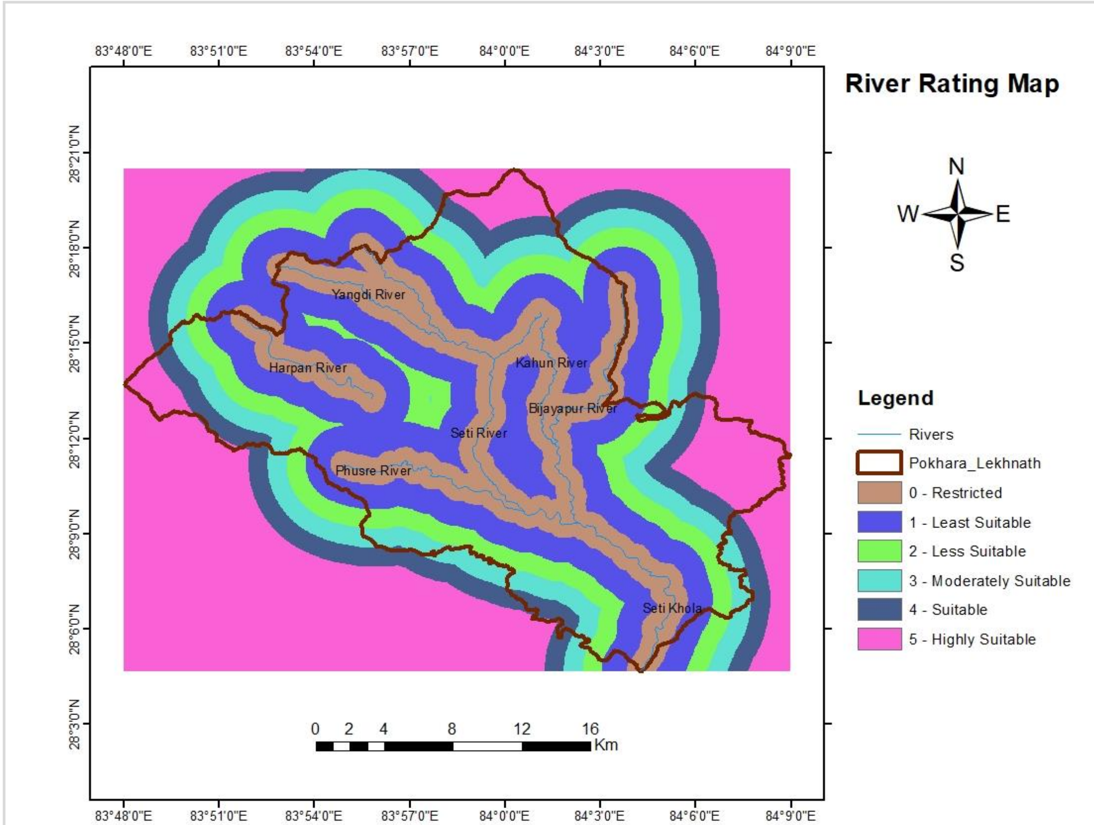

Figure 4. River Rating Map

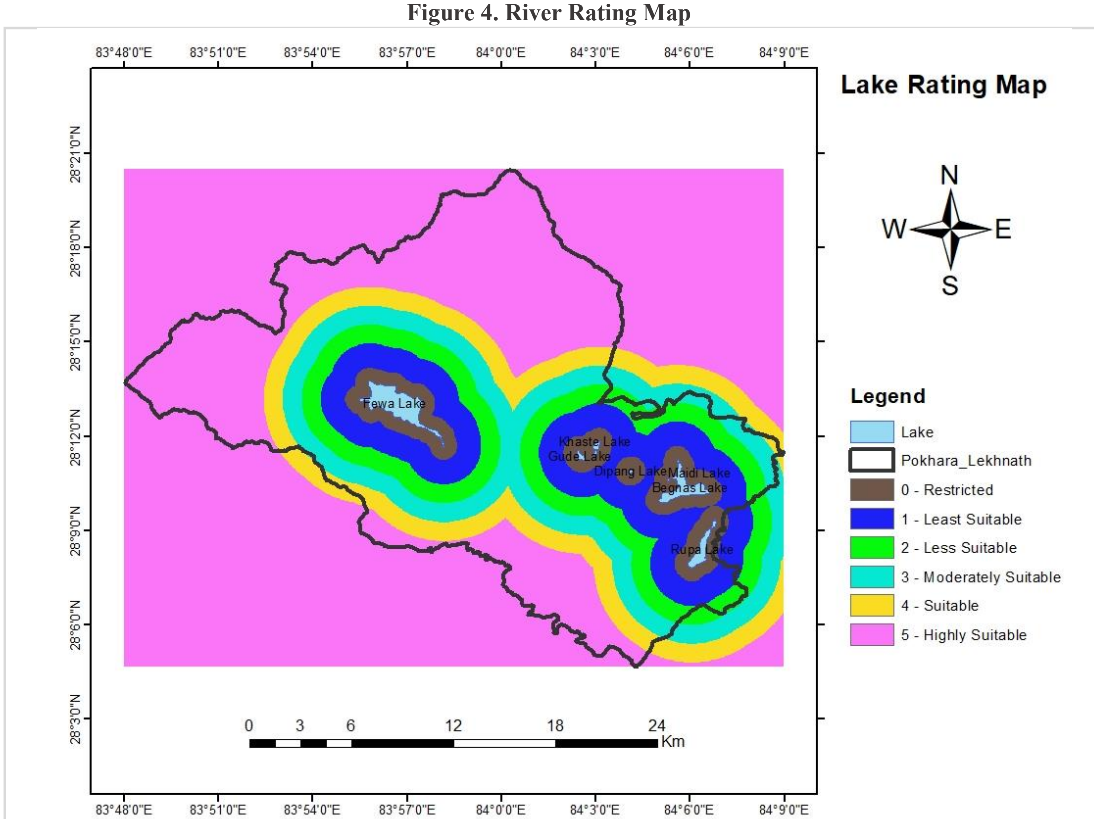

Figure 5. Lake Rating Map

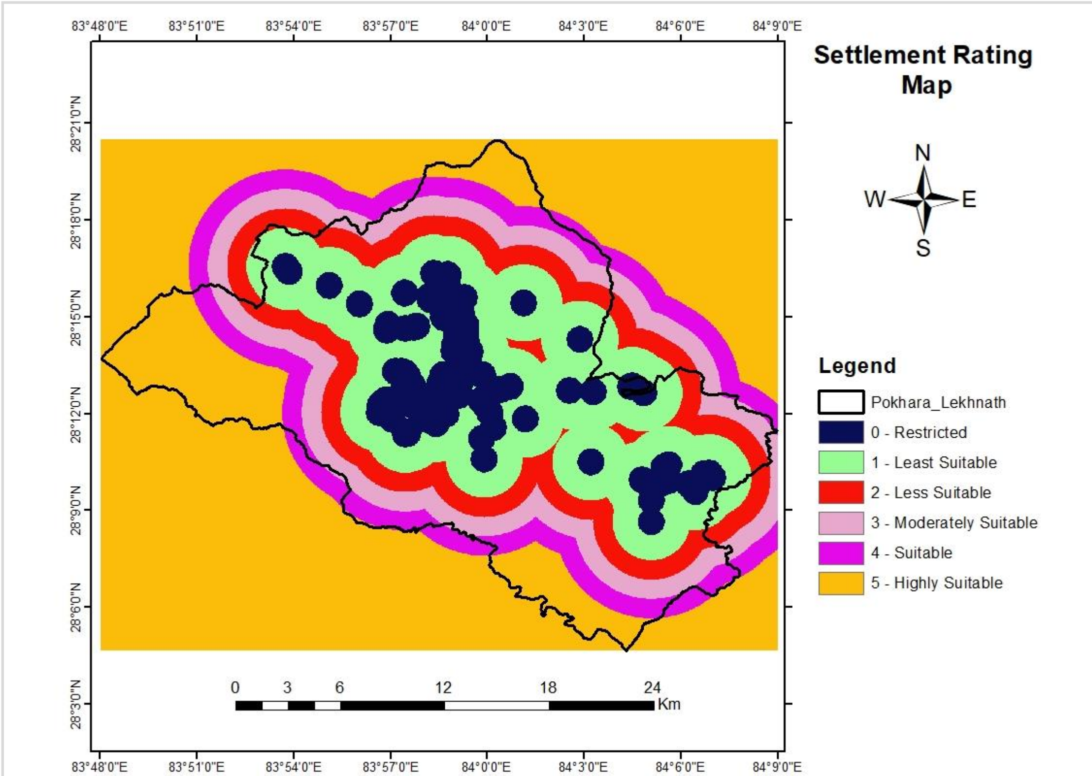

Figure 6. Settlement Rating Map

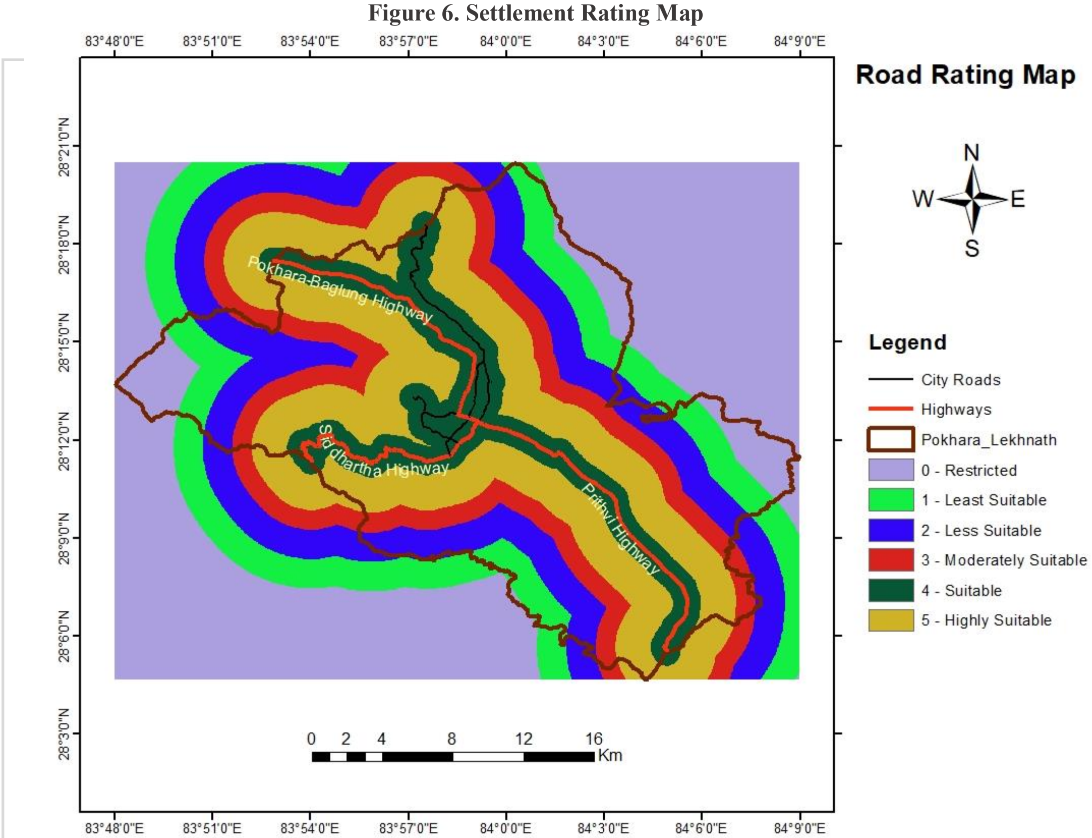

Figure 7. Road Rating Map

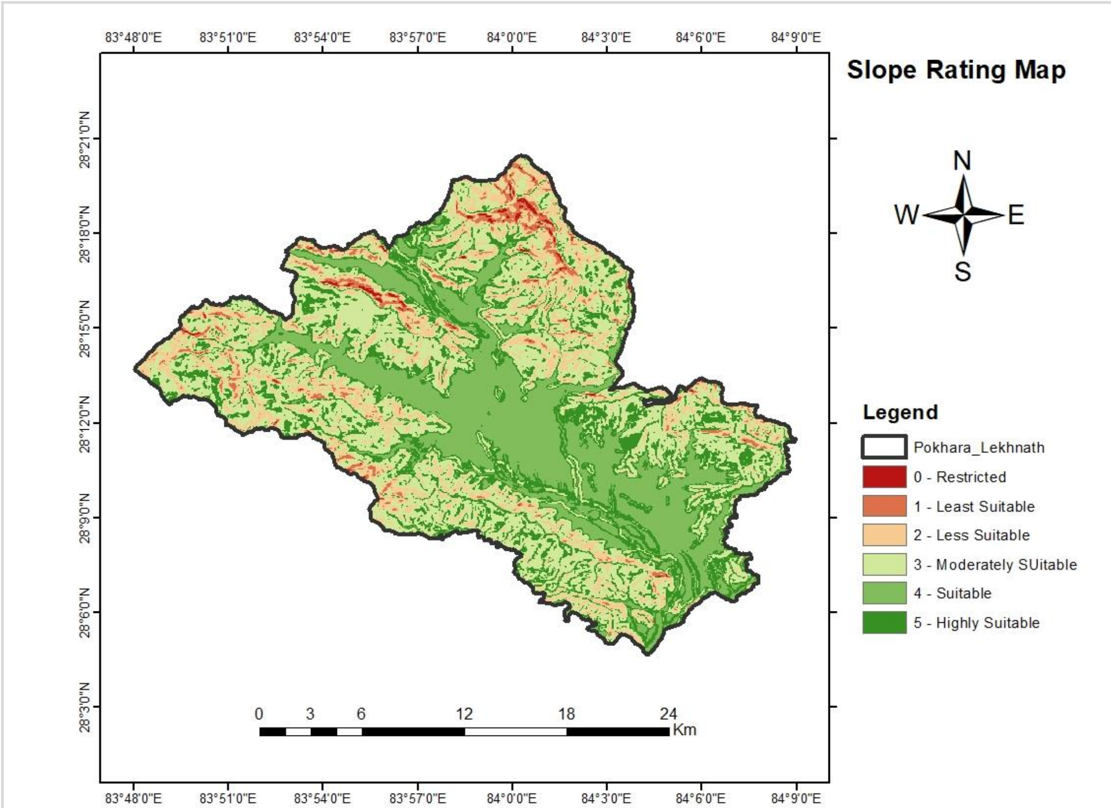

Figure 9. Slope Rating Map

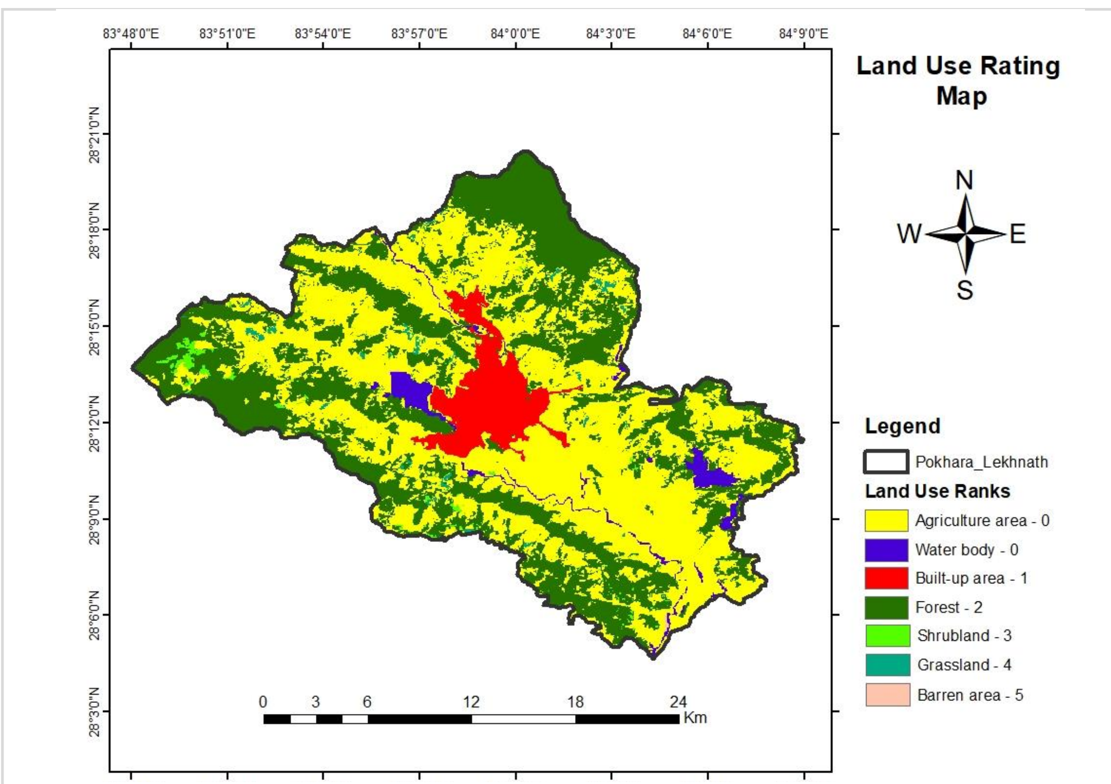

Figure 8. Land Use Rating Map

4.2 Suitability Map

The following suitability map that was synthesized from the weighted overlay of each rating maps represents the grade of suitability of sites for waste disposal ranging from highly suitable (5) to restricted (0) symbolized with the ramps of green color.

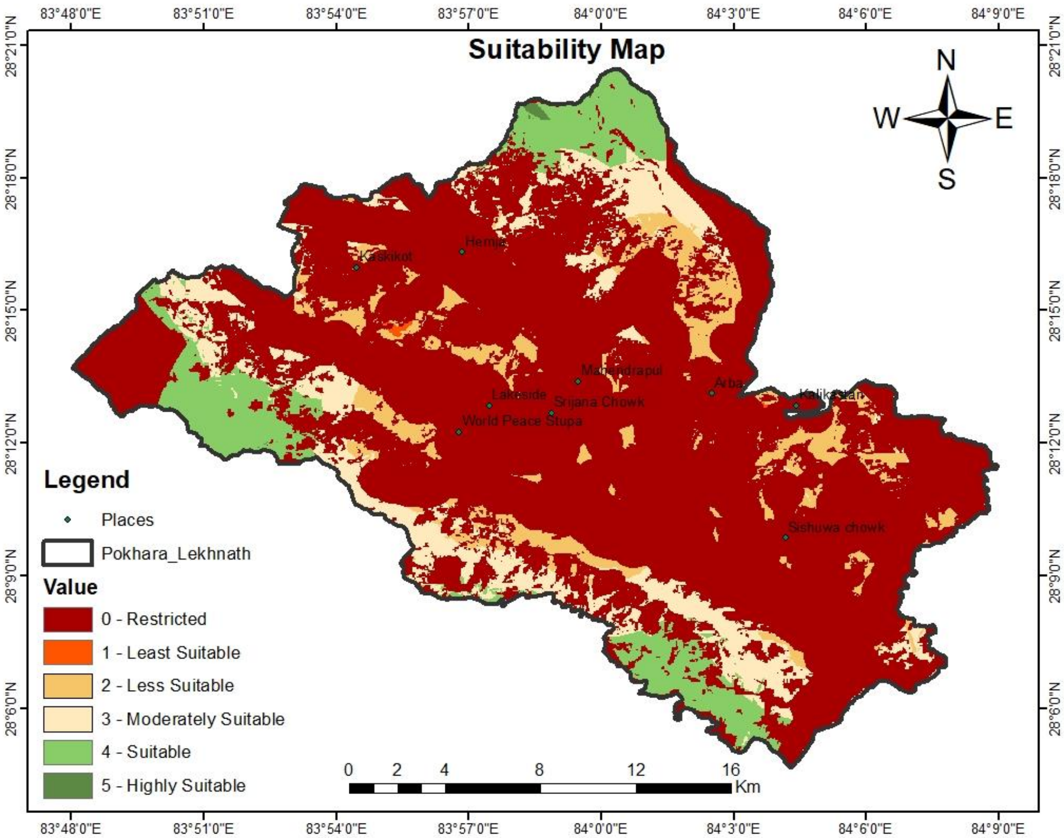

Figure 10. Suitability Map

4.3 Restriction Map

The following restriction map shows the areas that is classified into restricted and unrestricted zones for waste disposal. The dark red color represents the sites restricted for wasted disposal whereas the sites represented by lotus green were not restricted.

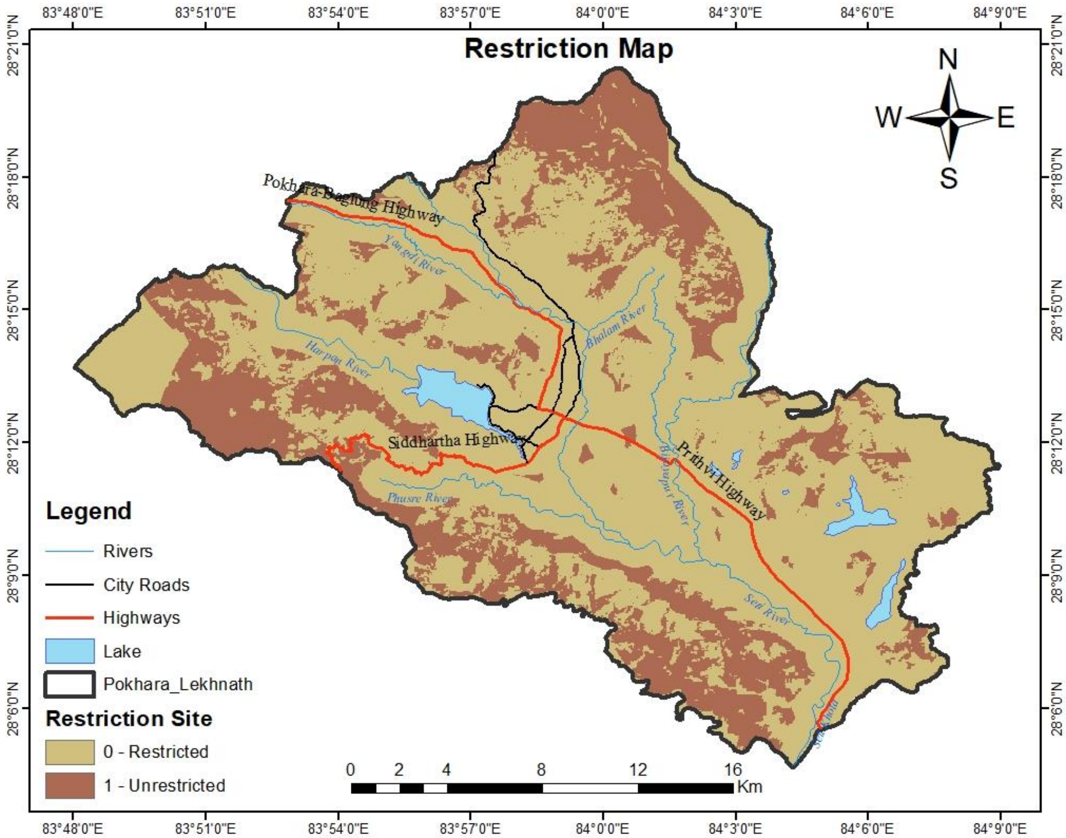

Figure 11. Restriction Map

4.4 Final Map Depicting Suitable Sites for Waste Disposal

Altogether, 11 sites were obtained as the suitable sites for waste disposal. Nevertheless, only those sites that has an area more than 2000 m^2 were selected, thus narrowing the count to 7 sites.

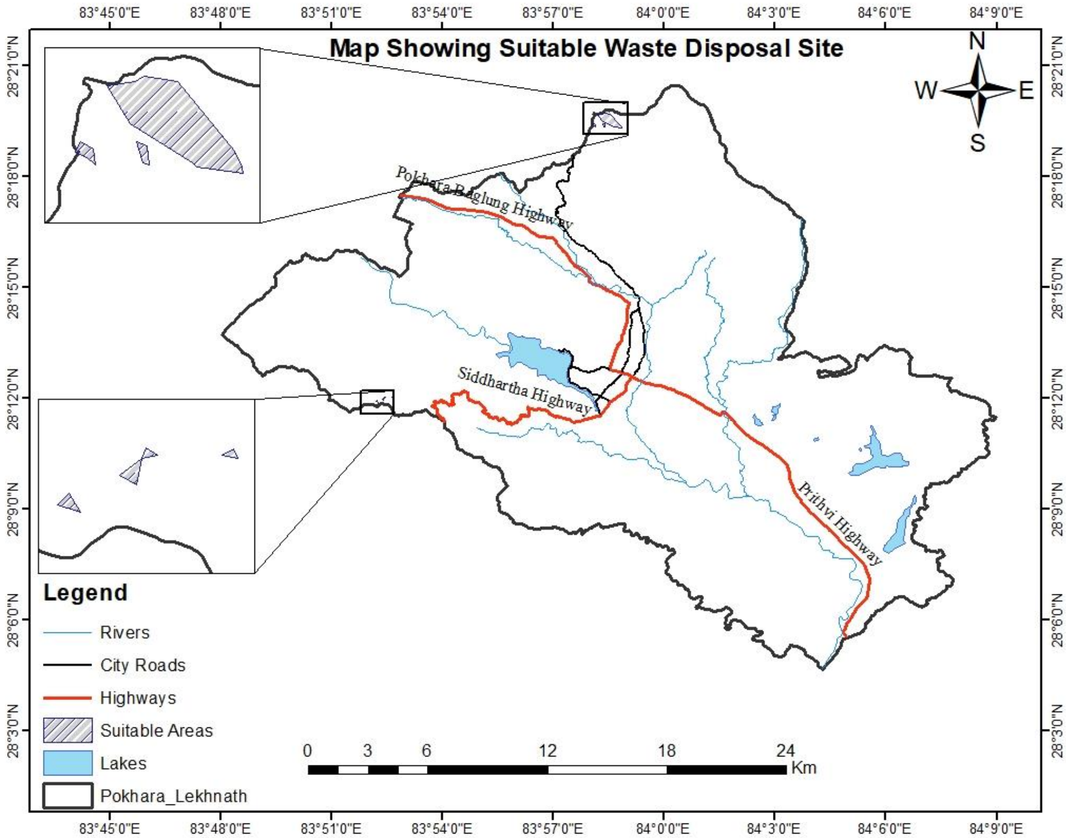

Figure 12. Map Showing Suitable Areas for Waste Disposal

It is a best practice to witness the present context of those analyzed suitable sites by field verification. However, it was difficult during the current pandemic time to reach at such destinations. Thus, the recent situation of the sites was observed from the Sentinal-2 satellite imagery. It was found that the 3 of the sites were located in the lap of the mountain and many national and international tourists reach there to perceive the scenic beauty of the Himalayas. Also, a community project for construction of homestays around these sites are being carried out. So, three of the sites were discarded and the remaining four sites were manifested as suitable sites for waste disposal as screened in the map below:

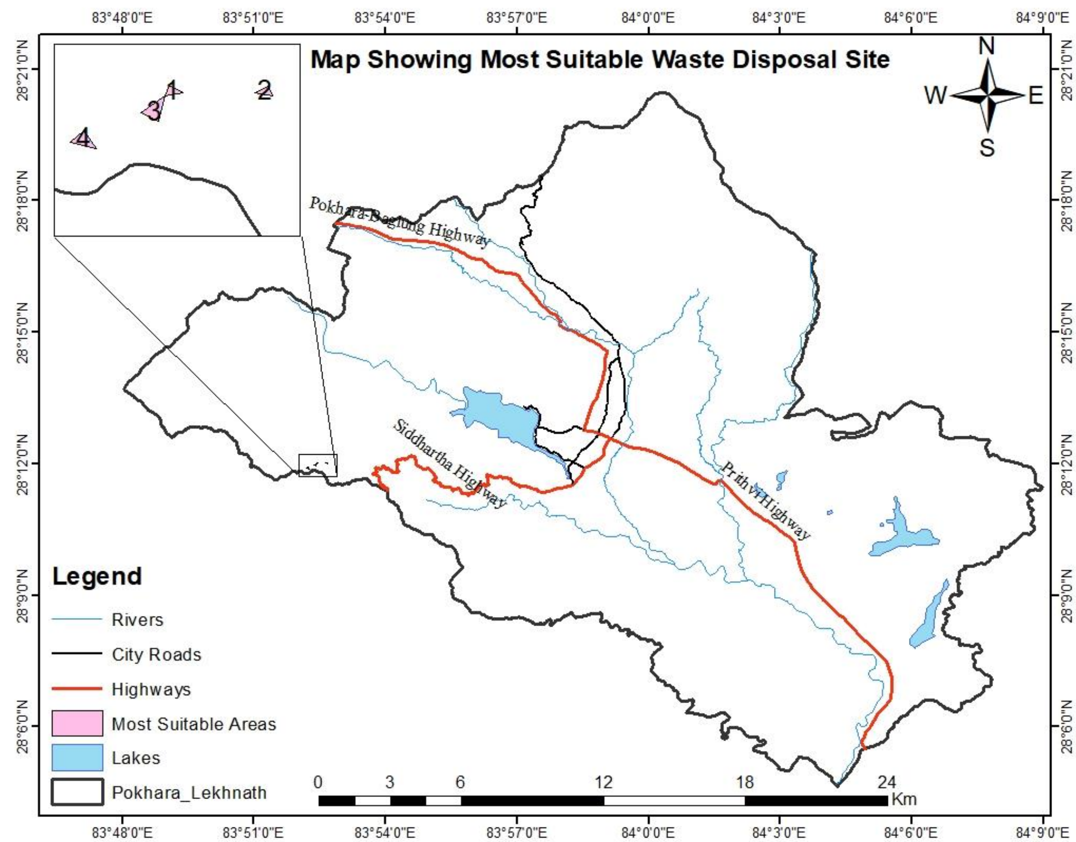

Figure 13. Map Demonstrating Most Suitable Waste Disposal Sites

5. LIMITATIONS

Besides of all the procedures, factors and considerations that is adopted in this study, there are some limitations of this project that are pinpointed below:

i) Only few of the factors that affects the waste disposal site are considered.

ii) The distances assumed for the suitability are not based on community standards and guidelines or as provoked in the law and constitution.

iii) The openly access data sets used for this project retrieved from the internet source may not be cent percent authentic and reliable.

iv) This is just a study project and the suitable site resulted from this study may not depict the suitable site for the waste disposal in reality.

6. CONCLUSION

Pokhara Lekhnath Metropolitan City has been facing garbage woes in the recent years. The increasing population and urbanization have become a triggering factor for waste disposal. The present existing dumping sites are overwhelmed with the garbage of the city thus demanding a systematic and logically developed waste disposal sites.

This study has provided a systematic framework of choosing suitable site for waste disposal using GIS based MCDA procedures using six major parameters. Incorporating MCDA with GIS for a spatial decision-making process is complicated as it deals with the huge and conflicting criteria in waste disposal site selection. However, this procedure also helps in making right choice with logical reasoning. Waste disposal suitability maps were prepared in GIS. The result shows that 11574285 m^2 (2.24%) is extremely unsuitable whereas 632115 m^2 (0.26%) of the total study area is highly suitable for waste disposal. Also, on contrasting the suitable sites with each other and observing the present context of those sites, only 4 sites were decoded as most suitable for waste disposal, located in the southern side of metropolitan city.

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