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Suitable Dam Site Selection with Gis-Based Sensitivity Analysis of Factors Weight Determination (In Birr River, Upper Blue Nile, Ethiopia)

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Abstract:- Now day GIS based suitable dam site identification has been adaptable in order to minimize the requirement of high cost, time, and many specialists. GIS-based sensitivity analysis of factors weights reduces the uncertainty of the final dam site suitability map and increases confidence by avoiding the errors coming due to an expert's opinion suggestion. According to the GIS-based sensitivity analysis, the cumulative geological fault suitability class difference was the highest value and elevation was the lowest value from different weighting. As the suitability area difference of the geological fault at different weighting is highest; it is the highest sensitive factor for dam site selection in the Birr watershed and elevation was the lowest sensitive factor as the difference of suitability area is relatively lowest. The geological fault is given the highest rank or preference and finally, the highest weight and elevation are given the lowest rank and weight. It indicates that more of the dam site suitability of the watershed is depend on the suitability of the geological fault. The geological fault is the highest weight (31%), foundation geology (21%), soil texture (11%), slope (8%), erosion rate (5%), road proximity (4%), river proximity (3%) and the lowest weight is elevation range (2%). Dominantly the watershed area is suitable (47.57%) and moderately suitable (41.81%) for the dam site. GIS is software that is able to input, manipulate, analyze, and displays the output of spatial data. Therefore when the factor's weight is certainly determined the final map of the watershed dam site suitable map is also certain.

Keywords:- *GIS, Sensitivity, Weight, Suitable Dam Site.*

I. INTRODUCTION

Site selection is a common practice and is one of the vital decisions in the startup process of land planning (Weldu et al., 2016; Qureshi, 2015; Rikalovic et al., 2014). The important thing to be considered is to utilize technology and methods for site selection, as the previous traditional methods are costly and more time consumable (Baban & Wan-yusof, 2003; Umrikar, 2017). Nowadays due to the advancement of GIS and remote sensing of space technology, it is possible to utilize maximum resources at optimum cost (Kahsay et al., 2018; Bosompem et al., 2016). Locating a suitable dam site is a decision-making process that involves the consideration of diverse criteria and a need for multi-criteria decision analysis techniques (MCDA) (Al-ruzouq et al., 2019; Tanveer et al., 2019). During this stage, large volumes of datasets have to be handled and analyzed. In order to consider these factors and the fact that the information about the environment is inherently geospatial, it is pressured to use Geographic Information System (GIS) tools, concepts, and technology in managing the data (Ayele, 2018; Mohebzadeh et al., 2018; Tsiko & Haile, 2011). In the last decade, the rapid advances in computer technology and the widespread use of Geographical Information Systems (GIS) become essential tools for analyzing suitable dam site locations (Taşkin, 2014; Ahmad & Verma, 2017). GIS-based MCDM is a multi-disciplinary and multi-step process that can result in many sources of uncertainty including criteria selection, input data accuracy, standardization method, weight calculation, and aggregation method (Ghorbanzadeh et al., 2018; Xu & Zhang, 2013).

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GIS based sensitivity analysis is the evaluation of the impact or effect of changes in input values on the final out put(Elsheikh, A and Shariff, 2015). Sensitivity analysis is used to determine how sensitive an output is to the changes in the value of the parameter while keeping the other parameters unchanged (Feizizadeh et al., 2014;Crosetto et al., 2000). It also helps to build confidence in the output by studying the uncertainties that are often associated with parameters in models(Elsheikh, A. Shariff, 2015). Criteria weights are often recognized to represent the major source of controversy and uncertainty in the multi-criteria decision-making process (Feizizadeh et al., 2014; Frey, 2004). Most of the main shortcomings of the Analytical hierarchy process method of land suitability identification is its giving priority between criteria and it is a mostly subjective judgment of the expert (Njiru & Siriba, 2018). Moreover, in cases especially when multiple decision makers are involved, it is often not possible to derive only one set of weights, however, ranges of weights, and thus a variety of results. The usefulness of the sensitivity analysis procedures is that they can help to reduce the uncertainty in the way how an AHP of the MCDM method operates and the stability of its outputs by illustrating the effect of making slight changes to specific input parameters on evaluation outcomes done with Arc map GIS(Crosetto et al., 2000). It is indicated that the most frequently used sensitivity analysis for land suitability is based on the determination of dam site suitability with the variation of the weights of the factors which are implied in the process to test whether it significantly modifies the output obtained that processed with GIS weight overlay process. One –at- time method investigates the sensitivity of one-dimensional weight by changing the relative influence of each factor separately in the Arc map GIS(Xu & Zhang, 2013). It estimates the effect on the evaluation result of variation in a single input parameter while holding all other parameters fixed at a constant value. It leads to a logical approach as any change observed in the output will unambiguously be due to the single factor changed**.** The criteria which changing the weight leads to a dramatic change in the land suitability is the more sensitive criteria. From the sensitive analysis; the factor is the higher the sensitivity the higher to be the weight given for dam site suitability evaluation (Al-mashreki et al., 2011). Now a time there are different land suitability evaluation studies conducted with GIS and multi criteria decision analysis (MCDA) methods for different land planning including school site, industry site, hospital site, residential site, irrigation land, solid waste disposal site, dam site etc. However, this method of suitable site identification has its limitation in factors weight determination due to its subjective comparing of factors to rank the factor based on level of impact or significance. Birr River is one of the perennial streams of the upper Blue Nile River. However, the people had not used the river for their economic purposes.

II. MATERIALS AND METHODS

The study area was done in Birr watershed located in the west Gojjam zone of Amhara national regional state. Geographically it is located between 37 E - 37 E and between 10 N - 11 N latitudes and longitudes respectively are shown in Figure 1. The watershed covers a drainage area of about 3178.74 square kilometers and a perimeter of 392 km extending from Adama Mountain to the junction of Birr River and Temcha River near the Blue Nile River.

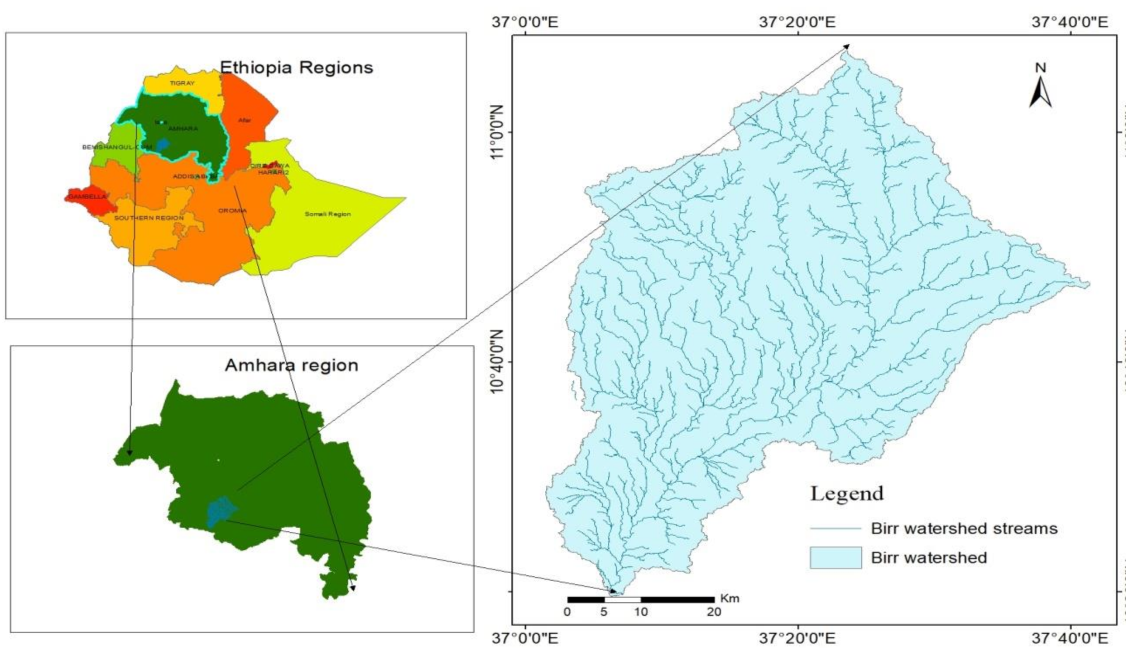

Fig. 1 Location of study area

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- *Data type used and its source*

In this study nine geospatial data has been used from different sources as shown in Table1.

Table 1 Data type used

Main data type	Sub data type	Source of data
Geo spatial data	30m*30m SRTM-DEM	USGS earth explorer (https://earthexplorer.usgs.gov/)
	20m*20m and 10m*10m DEM	By IDW interpolation of 30m*30m DEM
	Soil texture	Ethiopian Geospatial Information Agency
	Land use land cover(2019)	Landsat 8 satellite images, USGS earth explorer (https://earthexplorer.usgs.gov/).
Geo spatial	Geological map	Amhara Design Supervision Work Enterprise
Data	River map	DEM
	Road map	Ethiopian Geospatial Information Agency
	Fault map	Ethiopian Geospatial Information Agency
	Slope	DEM
	Elevation	DEM
	Erosion rate map	Determined by using RUSLE

- *Soft wares used*

All the geospatial data input analysis and result mapping was done with Arc map GIS. Table 2 indicated the software used and its application in the study

Table 2 Software used

Software's used	Main activities done in the study
Arc GIS 10.5	All the necessary geospatial data analysis from data entering up to dam site suitability map determination,
Google earth	As the watershed is large and it is unable to access all the watershed area, Google earth was used to identify the land use land cover as a guide with the sample point collected from the watershed.

- *General conceptual frame of the overall work flow path of the study*

The first step of the study was the collection of all the necessary input data from the relevant sources and it is processed with GIS spatial analysis tool is summarized in Figure 2.

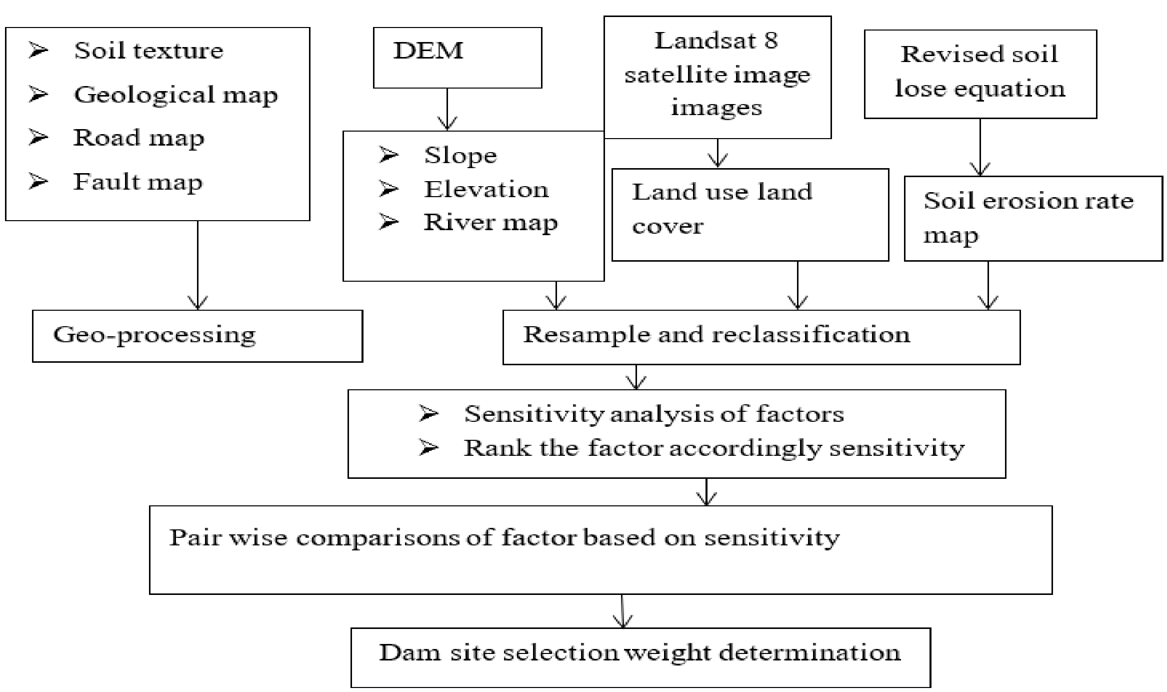

Fig. 2 conceptual frame work

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- *Dam site factors suitability classification*

The classification of dam site factors for dam site was done based with previous literature. The summarized classification of factors for both dam site and reservoirs are shown in Table 3. Igneous rock which is high age are mostly weathering rocks has fracture and joints and quaternary igneous rock formation is highly suitable than the Paleozoic and Mesozoic age rocks (Baban & Wan-yusof, 2003). The fault distance less than 1000m from dam site is unsuitable and beyond 5000m is highly suitable (Rafiee, 2011). A flat terrain is the easiest and least expensive to build on. On the contrary, a rolling or sloping terrain is more difficult and more expensive for construction(Njiru & Siriba, 2018). The infiltration rate of the soil texture according to Rates (2010) has given as clay (1 up to 5mm/hr), clay loam (5 up to 10mm/hr), loam (10 up to 20mm/hr), sandy loam (20 up to 30mm/hr) and sand is greater than 30mm/hr. The lower the infiltration rate is the highest suitability for dam site in order to reduce the loose of stored water due to deep percolation and foundation seepage (Prasad et al., 2014). The main criteria for land use land cover suitability classification for dam site is its importance for local agriculture and livelihood, so the barren land or grass land is more preferable for dam construction than constructing the dam on land under agricultural use (Raza et al., 2018). As forest is one of the natural resource to be reserved and it is not recommended for dam site selection (Stemn and Kumi-boateng, 2016). Water body and built up area should be restricted or not to be considered for suitability analysis (Dai, 2016).

Table 3 Dam site factors suitability classification

Factors	**Criteria**	**Ranking**	**Suitability**
	Granite and Mafic- ultramafic	5	
	quaternary basalts		Highly suitable
	High grade metamorphism	4	
Geological make up	Oligocene- Miocene flood basalt		Suitable
	Miocene choke shield volcano	3	Moderately suitable
	Mesozoic sedimentary rocks	2	Less suitable
	quaternary sediments		
	0-1000	1	Not suitable
	1000-2500	2	Less suitable
Fault proximity	2500-3500	3	moderately suitable
	3500-5000	4	Suitable
	>5000	5	Highly suitable
	0-9%	5	Highly suitable
	9-16%	4	Suitable
Slope (%)	16-25%	3	Moderately suitable
	25-40%	2	Less suitable
	>40%	1	Not suitable
	Clay, clay to clay loam	5	Highly suitable
	Clay loam and clay to silt loam	4	Suitable
Soil texture	Clay to loam	3	Moderately suitable
	Clay loam to sandy clay	2	Less suitable
	Sandy loam	1	Not suitable
	Shrubs and bushes	5	Highly suitable
	Grass land	4	Suitable
Land use land cover	Cultivated land	2	Less suitable
	Forest	1	Not suitable
	Water body and built up area	0	Restricted
	0-1000	5	Highly Suitable
Road Proximity(m	1000-2000	4	Suitable
	2000-3000	3	Moderately Suitable
	3000-400	2	Less Suitable
	>4000	1	Not Suitable

	0-500	5	Highly suitable
	500-1000	4	Suitable
River proximity(m)	1000-1500	3	Moderately suitable
	1500-2000	2	Less suitable
	>2000	1	Not suitable
	989-1669	5	highly suitable
	1669-1974	4	suitable
Elevation	1974-2263	3	moderately suitable
	2263-2636	2	less suitable
	2636-3518	1	not suitable
	None to slight	5	Highly suitable
	Slight	4	Suitable
Soil erosion rate	Moderate	3	Moderately suitable
	High	2	Less suitable
	Very high	1	Note suitable

➢ *GIS based sensitivity analysis for factors suitability*

The percent of influence or weight used for a sensitivity analysis was done by considering from lowest percent up to higher percent, the number of criteria and sum of the weight is one or one hundred in percent (R. Elsheikh, A. Shariff, 2015, Al-mashreki et al., 2011). Al-mashreki *et al* (2011) used 10%, 30%, 50%, and maximum 70% weights for their sensitivity analysis for sorghum crop suitability by using five factors; R. Elsheikh, A. Shariff, (2015) used 5%, 20%, 35%, 50, 65% and 80% for Mango suitability evaluation and sensitivity analysis by considering five factors. Accordingly, this study used the lowest percent (4%), medium percent (28%, 52%) and 68 % higher percent to visualize the effect of changing weight significantly and its weighting schemes for each factor based on the principles of one – at –a time method is shown in Table 4.

Table 4 one at a time method of factors weight given

Model run	Slope (%)	Soil texture (%)	Geology (%)	LULC (%)	Road proximity (%)	River proximity (%)	Erosion rate (%)	Fault (%)	Elevation (%)	Total (%)
1	4	12	12	12	12	12	12	12	12	100
2	28	9	9	9	9	9	9	9	9	100
3	52	6	6	6	6	6	6	6	6	100
4	68	4	4	4	4	4	4	4	4	100
5	12	4	12	12	12	12	12	12	12	100
6	9	28	9	9	9	9	9	9	9	100
7	6	52	6	6	6	6	6	6	6	100
8	4	68	4	4	4	4	4	4	4	100
9	12	12	4	12	12	12	12	12	12	100
10	9	9	28	9	9	9	9	9	9	100
11	6	6	52	6	6	6	6	6	6	100
12	4	4	68	4	4	4	4	4	4	100
13	12	12	12	4	12	12	12	12	12	100
14	9	9	9	28	9	9	9	9	9	100
15	6	6	6	52	6	6	6	6	6	100
16	4	4	4	68	4	4	4	4	4	100
17	12	12	12	12	4	12	12	12	12	100
18	9	9	9	9	28	9	9	9	9	100
19	6	6	6	6	52	6	6	6	6	100

20	4	4	4	4	68	4	4	4	4	100
21	12	12	12	12	12	4	12	12	12	100
22	9	9	9	9	9	28	9	9	9	100
23	6	6	6	6	6	52	6	6	6	100
24	4	4	4	4	4	68	4	4	4	100
25	12	12	12	12	12	12	4	12	12	100
26	9	9	9	9	9	9	28	9	9	100
27	6	6	6	6	6	6	52	6	6	100
28	4	4	4	4	4	4	68	4	4	100
29	12	12	12	12	12	12	12	4	12	100
30	9	9	9	9	9	9	9	28	9	100
31	6	6	6	6	6	6	6	52	6	100
32	4	4	4	4	4	4	4	68	4	100
33	12	12	12	12	12	12	12	12	4	100
34	9	9	9	9	9	9	9	9	28	100
35	6	6	6	6	6	6	6	6	52	100
36	4	4	4	4	4	4	4	4	68	100

For the purpose of sensitivity analysis, suitability maps for every weighting scheme were created in the Arc map GIS. The outputs of suitability maps were compared to each other to investigate the influence of each criterion on the overall suitability for dam site suitability. The cumulative variation of the suitability class percentage area was conducted to interpret the output of the sensitivity analysis. By comparing the cumulative variation of suitability class percentage area for the different weighting schemes, the sensitivity of the suitability criteria was estimated

➢ *Cumulative suitability class difference*

According to Xu and Zhang (2013) and (R. Elsheikh, A. Shariff, 2015) the suitability class area difference between weightings is calculated by using absolute value of the difference value, in order to show the extent of variation magnitude.

$$CR_i = abs\ (SA_{i+1} - SA_i) \quad (1)$$

Where, CRi is the change rate of suitability class at different weighting, abs is absolute value, SA_i and SA_{i+1} is the suitability class area coverage in percent at different weighting.

$$CACR_i = \frac{CR_i}{N} \quad (2)$$

Where CACRi is the cumulative average change rate of factor suitability, N is the total number of suitability change rates considered. In this study, the total number of suitability change rates considered was 6; between 4% and 28%, between 4% and 52%, between 4% and 68%, between 28% and 52%, between 28% and 68% and between 52% and 68%.

➢ *Weighting of dam selection factors using GIS based sensitivity analysis and AHP*

Among the different methods of Multi-criteria decision analysis method, a pairwise comparison method of AHP of Saaty (2008) is the most widely used one. First of all, a matrix was constructed using each criterion preference scale value. Then each criterion is compared with the other criteria relative to its importance done with sensitivity analysis. The pair-wise comparison methods were applied using a scale with values from 1/9 to 9. These point scale includes:[1/9, 1/8, 1/7, 1/6,1/5, 1/4,1/3, 1/2,1,2,3,4,5,6,7,8,9]. 9 means extreme preference,7 means very strong preference,5 means strong preference, and so on down to 1 which means no preference. Scale numbers 2, 4, 6, and 8 are intermediate scales between two adjacent judgments. Depending on these relative scale values, construction 9×9 matrix of rating was done, where 9 is the number of factors considered for this study. Finally the estimated factors weight accuracy is checked with consistency ratio of factors.

➢ *Weight calculation from AHP matrixes*

Finally, this study used GIS-based sensitivity analysis to identify the rank of factors that impact the dam's suitability and done group discussion after the pair-wise comparison matrix was made, factors values of the pairwise comparison matrix were determined. Priority matrix normalized vectors of the number of criteria were calculated from the pairwise matrix table by dividing each column entry by the sum of a column. The normalized matrix was determined by assuming the matrix as matrix B, such that:-

$$b_{ij} = a_{ij} / \sum_{i=1}^{i=9} aij \quad (3)$$

Each value in the matrix represents the weighting value of each criterion and the relative weight for each factor is determined within the range from 0 to 1 which means a higher weight indicates a greater contribution of the factor to best site selection criteria suitability. The summation of column-wise of the normalized matrix is one.

$$W=\sum_{j=1}^{9} bij \Big/ \sum_{i=1}^{i=9}\sum_{j=1}^{9} bij \quad (4)$$

Where bij is relative importance in pair-wise comparisons of factor i compared with criteria j, n is a number of factors considered in the study, for this study case n is nine, i and j are the factors listed in the first left column, and the upper top raw respectively.

➢ *Evaluation of matrix consistency*

The value of pair wise comparison and the calculated weight certainty is checked with determination of consistency ratio (Jaiswal et al., 2015; Yasser et al., 2013). A numerical index called consistency ratio (CR) is used for evaluating the consistency of pairwise comparison matrix. This index indicates the ratio of the consistency index (CI) to average consistency index which also called random index(RI),

$$CR = \frac{CI}{RI} \quad (5)$$

Where CI is consistency index, RI is random index values to determine the consistency index value based on number of factor as shown in Table 5.

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (6)$$

Where λ_{max} is the principal Eigen value, n is the number of criteria considered 9 in this study cause.

Table 5 Values of random index based on number of factor ((Jaiswal et al., 2015)

N	2	3	4	5	6	7	8	9	10
RI	0	0.52	0.90	1.12	1.24	1.32	1.41	1.45	1.49

The random index (RI) values of 1.45 from the corresponding number of 9 factors considered from above table.

➢ *Finding the biggest Eigen value (λ_{max})*

Its value is determined from the summation of multiplying the pairwise comparison matrix weight with the sum total of column wise of criteria.

III. RESULT AND DISCUSSION

➢ *Dam site suitability area at one –at-a time method of factors weight*

The suitability area of dam site with one at a time method of factors weighting indicated that geological fault and foundation geology has varied greatly the suitability area at different weighting than the other factors as shown in Table 6.

Table 6 Dam site suitability area suitability at different weighting of factors

	Area of suitability at different weight				
	Suitability category	4%	28%	52%	68%
Geology	Lakes/ built up area	1.73	1.73	1.73	1.73
	Not suitable	0.00	0.01	0.26	1.66
	Less suitable	4.75	5.51	23.24	27.19
	Moderately suitable	47.14	49.69	21.41	7.03
	Suitable	45.92	42.43	48.10	43.77
	Highly suitable	0.46	0.63	5.26	18.63
Erosion rate	Lakes/ built up area	1.73	1.73	1.73	1.73
	Not suitable	0.00	0.00	0.02	0.08
	Less suitable	4.80	3.22	4.56	7.02
	Moderately suitable	52.89	42.18	31.06	23.58
	Suitable	40.21	52.20	56.55	45.43
	Highly suitable	0.37	0.67	6.09	22.16
	Highly suitable	0.38	0.66	5.76	24.48
Elevation	Lakes/ built up area	1.73	1.73	1.73	1.72
	Not suitable	0.00	0.00	0.00	0.07
	Less suitable	4.08	3.82	5.90	9.69
	Moderately suitable	49.94	51.31	49.97	46.66
	Suitable	43.82	42.77	41.03	37.92
	Highly suitable	0.43	0.37	1.37	3.93
Road	Lakes/ built up area	1.73	1.73	1.73	1.73
	Not suitable	0.00	0.01	0.15	0.85

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	Less suitable	4.77	5.00	14.86	19.92
	Moderately suitable	48.05	49.89	35.85	27.75
	Suitable	45.07	42.86	43.05	33.90
	Highly suitable	0.38	0.52	4.36	15.85
River	Lakes/ built up area	1.73	1.73	1.73	1.73
	Not suitable	0.00	0.01	0.12	0.75
	Less suitable	4.25	5.60	13.78	22.80
	Moderately suitable	50.11	48.23	37.36	26.22
	Suitable	43.52	43.78	43.13	33.60
	Highly suitable	0.38	0.65	3.88	14.91
Slope	Lakes/ built up area	1.73	1.73	1.73	1.73
	Not suitable	0.00	0.01	0.26	1.77
	Less suitable	3.23	8.11	17.75	22.75
	Moderately suitable	50.83	44.31	31.38	23.72
	Suitable	43.84	45.24	43.73	33.92
	Highly suitable	0.36	0.60	5.14	16.09
LULC	Lakes/ built up area	1.73	1.73	1.73	1.73
	Not suitable	0.00	0.00	0.05	0.40
	Less suitable	4.07	6.79	20.26	40.20
	Moderately suitable	44.24	62.55	57.37	35.94
	Suitable	48.94	28.68	19.51	17.13
	Highly suitable	1.02	0.24	1.09	4.60
Soil texture	Lakes/ built up area	1.73	1.73	1.73	1.73
	Not suitable	0.00	0.00	0.00	0.02
	Less suitable	4.45	6.07	21.16	32.93
	Moderately suitable	48.17	46.96	22.93	7.34
	Suitable	45.26	44.79	51.74	48.08
	Highly suitable	0.39	0.45	2.45	9.90

- *Foundation geology sensitivity*

When the importance of the geology weight was represented by 28%, the moderately suitable class was 49.69%, whereas as the weight of geology increased up to 68%, the moderately suitable class decreased to 7.03% with the maximum suitability class difference of 42.66%. Thus, the percentage of 0.46 % represents the highly suitable class and such a percentage is possible to exist when the geology weighting is 4%, whereas it reached 0.63%, 5.26%, and 18.63% when the geology weightings were represented by 28%, 52%, and 68% respectively. The suitable class has found at 45.92%, 42.43%, 48.10%, and 43.77% when the geology weighting was 4%, 28%, 52%, and 68% respectively, and has not shown significant change. The suitability class of the restricted area was the same as the geology weighting change from 4% up to 68% because the restricted area was not considered for dam construction. As summarized the sensitivity of geology, the average suitability difference was 1.17%, 8.58%, 14.09%, 9.43%, 14.22% and 6.24% for geology weighting between 4% and 28%, 4% and 52%, 4% and 68%, 28% and 52%, 28% and 68%, 52% and 68% respectively with the cumulative difference of 8.95%. The suitability area difference at different weighting, the cumulative average suitability area difference, the chart representation and the map of suitability of geological foundation is shown in Table 7 and Fig 3 respectively

Table 7 Suitability area difference of geological foundation between different weighting

	Absolute value of percent area difference (%) between					
Suitability category	**4% and 28%**	**4% and 52%**	**4% and 68%**	**28% and 52%**	**28% and 68%**	**52% and 68%**
Lakes/ built up area	0.00	0.00	0.00	0.00	0.00	0.00
Not suitable	0.01	0.26	1.66	0.26	1.65	1.40
Less suitable	0.76	18.48	22.43	17.73	21.68	3.95
Moderately suitable	2.55	25.73	40.11	28.28	42.66	14.38
Suitable	3.49	2.17	2.16	5.67	1.34	4.33
Highly suitable	0.18	4.81	18.17	4.63	17.99	13.37
Average difference	1.17	8.58	14.09	9.43	14.22	6.24
Cumulative	8.95					

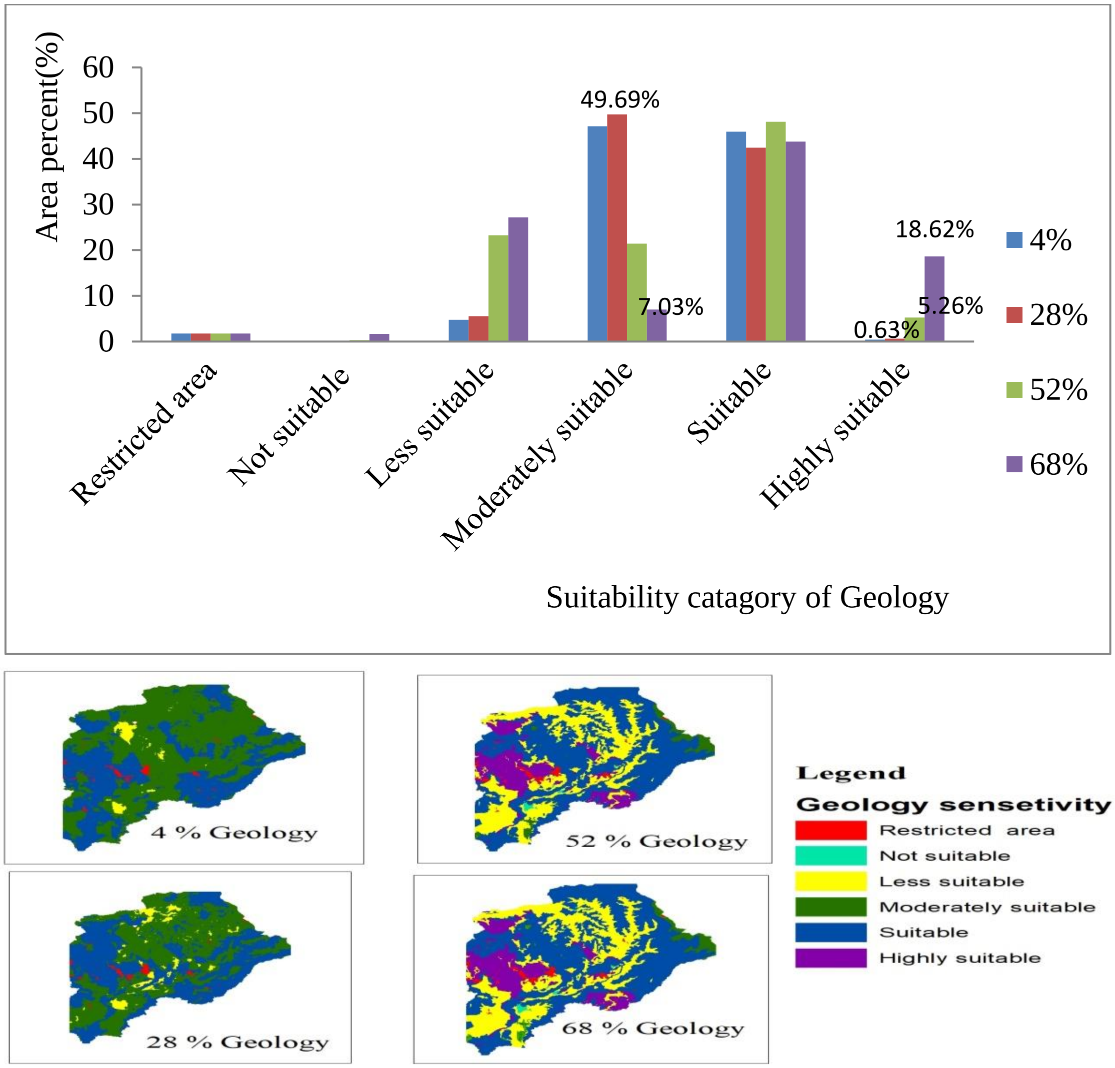


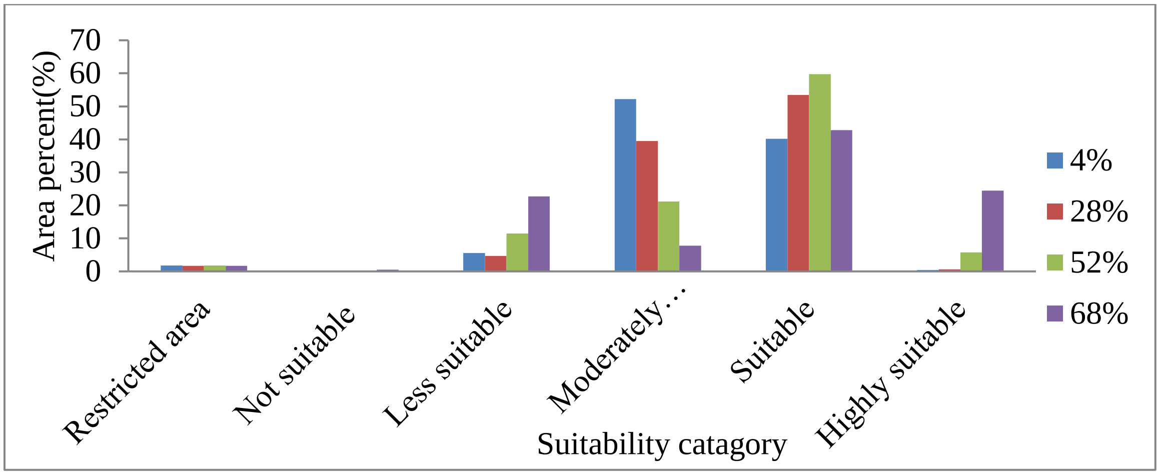
Fig. 3 Sensitivity analysis map for geological foundation

With the same pattern of geology the remaining eight factors suitability area difference and average cumulative suitability area difference at different weighting, the chart and map of suitability area is shown from Table 8 up to Table 15 and from Fig 4 up to Fig 11 respectively.

➢ *Geological fault*

Table 8 Suitability area difference of geological fault between different weighting

	Absolute value of percent area difference between					
Suitability category	**4% and 28%**	**4% and 52%**	**4% and 68%**	**28% and 52%**	**28% and 68%**	**52% and 68%**
Lakes/ built up area	0.00	0.00	0.00	0.00	0.00	0.00
Not suitable	0.00	0.11	0.51	0.10	0.51	0.41
Less suitable	0.84	5.98	20.54	6.83	21.39	14.56
Moderately suitable	12.71	31.03	37.81	18.32	25.10	6.78
Suitable	13.28	19.56	2.66	6.29	10.62	16.90
Highly suitable	0.28	5.38	24.10	5.10	23.82	18.72
Average difference	4.52	10.34	14.27	6.11	13.57	9.56
Cumulative	9.73					



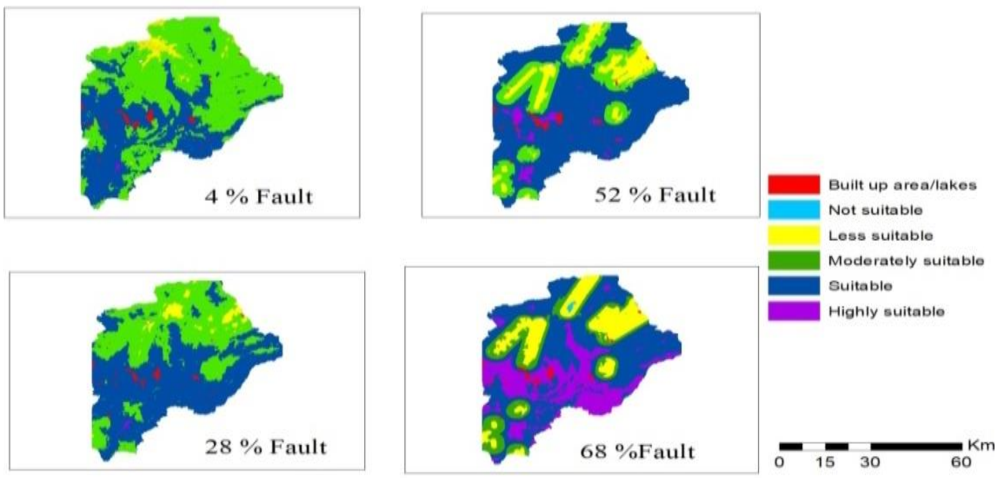
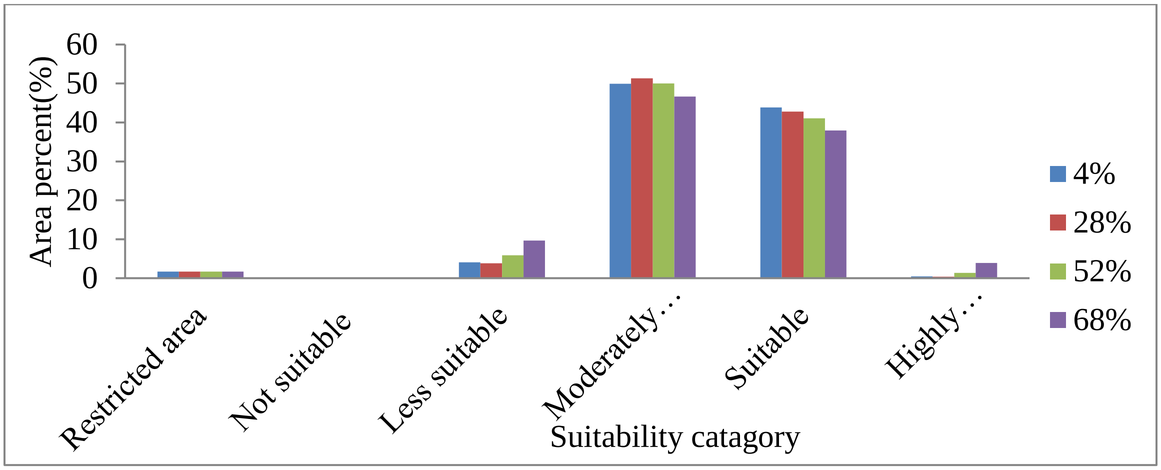


Fig. 4 Sensitivity analysis map for geological fault

➢ *Elevation sensitivity*

Table 9 Suitability area difference of geological fault between different weighting

	Absolute value of percent area difference between					
Suitability category	**4% and 28%**	**4% and 52%**	**4% and 68%**	**28% and 52%**	**28% and 68%**	**52% and 68%**
Lakes/ built up area	0.00	0.00	0.00	0.00	0.00	0.00
Not suitable	0.00	0.00	0.07	0.00	0.07	0.07
Less suitable	0.27	1.82	5.60	2.08	5.87	3.78
Moderately suitable	1.37	0.03	3.28	1.34	4.65	3.32
Suitable	1.05	2.79	5.89	1.74	4.84	3.10
Highly suitable	0.05	0.94	3.51	0.99	3.56	2.57
Average difference	0.46	0.93	3.06	1.03	3.17	2.14
Cumulative	1.80					



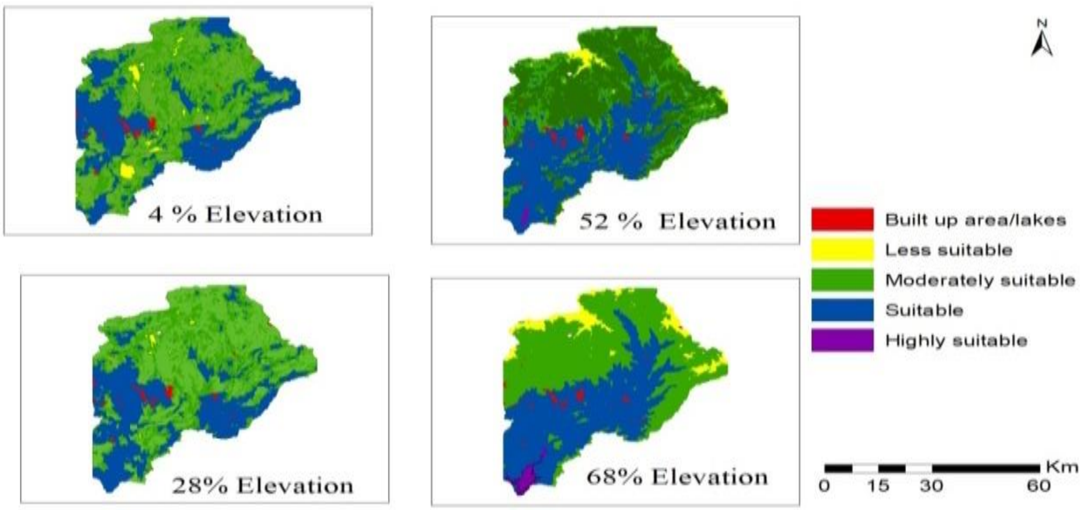
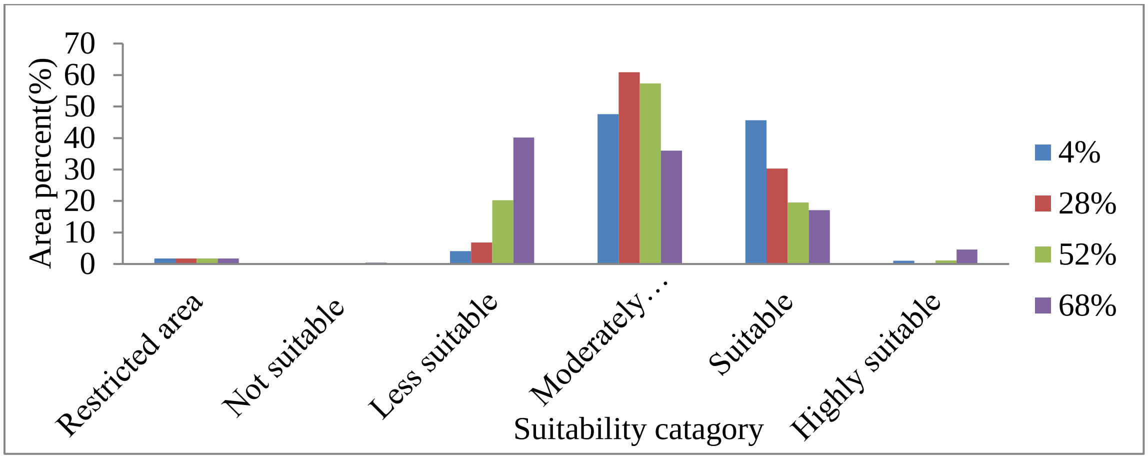


Fig 5 Sensitivity analysis map for elevation

- *Land use land cover sensitivity*

Table 10 Suitability area difference of land use land cover between different weighting

	Absolute value of percent area difference between					
Suitability category	**4% and 28%**	**4% and 52%**	**4% and 68%**	**28% and 52%**	**28% and 68%**	**52% and 68%**
Lakes/ built up area	0.00	0.00	0.00	0.00	0.00	0.00
Not suitable	0.00	0.05	0.40	0.05	0.40	0.36
Less suitable	2.72	16.18	36.12	13.46	33.40	19.94
Moderately suitable	18.31	13.13	8.30	3.53	24.96	21.43
Suitable	20.26	29.43	31.81	10.83	13.21	2.38
Highly suitable	0.78	0.07	3.58	0.85	4.36	3.51
Average difference	7.01	9.81	13.37	4.79	12.72	7.94
Cumulative	8.81					



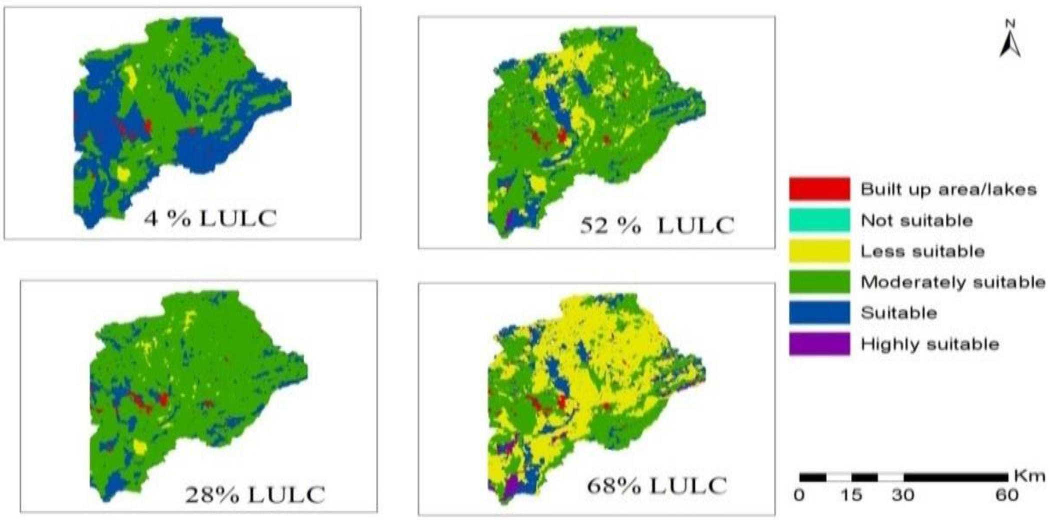


Fig 6 Sensitivity analysis map for land use land cover

➢ *River center proximity sensitivity*

Table 11 Suitability area difference of river center proximity between different weighting

	Absolute value of percent area difference between					
Suitability category	**4% and 28%**	**4% and 52%**	**4% and 68%**	**28% and 52%**	**28% and 68%**	**52% and 68%**
Lakes/ built up area	0.00	0.00	0.00	0.00	0.00	0.00
Not suitable	0.01	0.12	0.75	0.11	0.75	0.63
Less suitable	1.35	9.53	18.55	8.18	17.20	9.02
Moderately suitable	1.88	12.75	23.90	10.86	22.01	11.15
Suitable	0.26	0.39	9.93	0.65	10.19	9.53
Highly suitable	0.27	3.49	14.52	3.22	14.26	11.03
Average difference	0.63	4.38	11.27	3.84	10.73	6.89
Cumulative	6.29					

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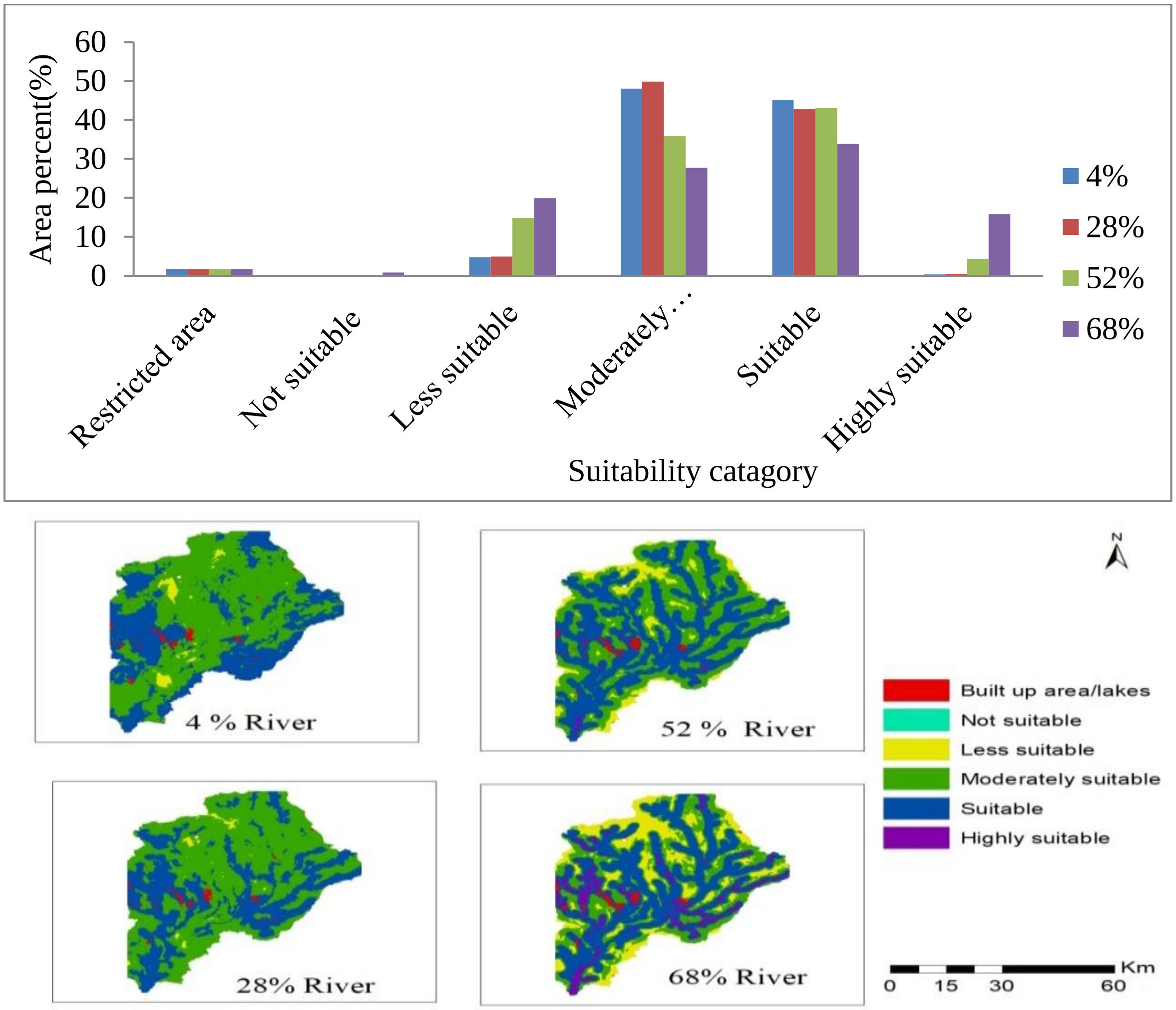
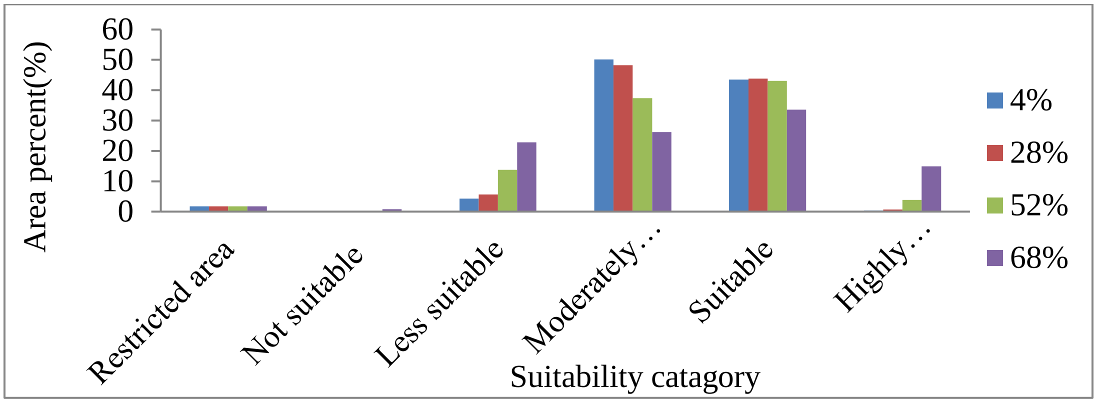


Fig 7 Sensitivity analysis map for river proximity

➢ *Road proximity sensitivity*

Table 12 Suitability area difference of road center proximity between different weighting

	Absolute value of percent area (%) difference between					
Suitability category	**4% and 28%**	**4% and 52%**	**4% and 68%**	**28% and 52%**	**28% and 68%**	**52% and 68%**
Lakes/ built up area	0.00	0.00	0.00	0.00	0.00	0.00
Not suitable	0.01	0.15	0.85	0.15	0.85	0.70
Less suitable	0.22	10.09	15.15	9.87	14.93	5.06
Moderately suitable	1.84	12.20	20.30	14.04	22.14	8.10
Suitable	2.21	2.02	11.17	0.19	8.96	9.15
Highly suitable	0.15	3.98	15.47	3.83	15.32	11.49
Average difference	0.74	4.74	10.49	4.68	10.37	5.75
cumulative	6.13					



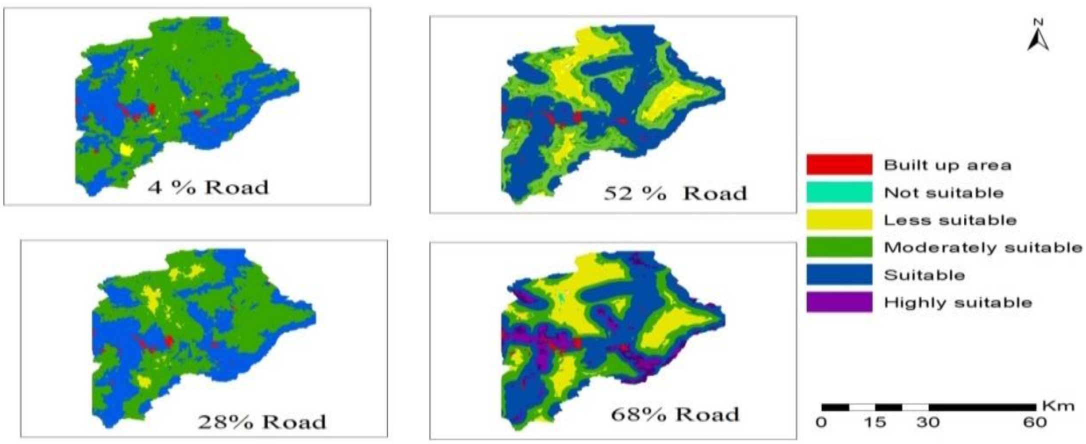
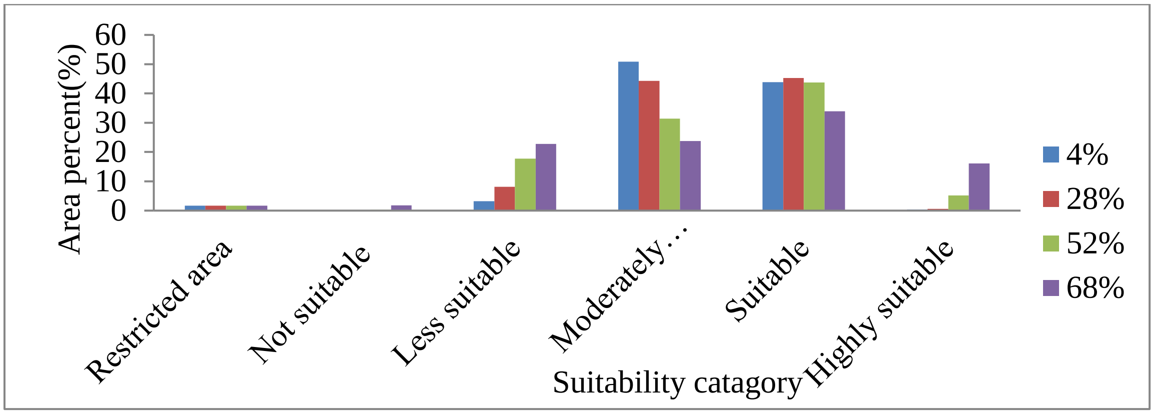


Fig 8 Sensitivity analysis map for road proximity

➢ *Watershed slope sensitivity*

Table 13 Suitability area difference of watershed slope between different weighting

	Absolute value of percent area difference between					
Suitability category	**4% and 28%**	**4% and 52%**	**4% and 68%**	**28% and 52%**	**28% and 68%**	**52% and 68%**
Lakes/ built up area	0.00	0.01	0.01	0.00	0.00	0.00
Not suitable	0.01	0.26	1.77	0.26	1.76	1.51
Less suitable	4.87	14.52	19.52	9.64	14.64	5.00
Moderately suitable	6.52	19.45	27.11	12.93	20.58	7.65
Suitable	1.40	0.11	9.92	1.52	11.32	9.81
Highly suitable	0.24	4.78	15.73	4.54	15.49	10.95
Average difference	2.17	6.52	12.34	4.81	10.63	5.82
Cumulative	7.05					



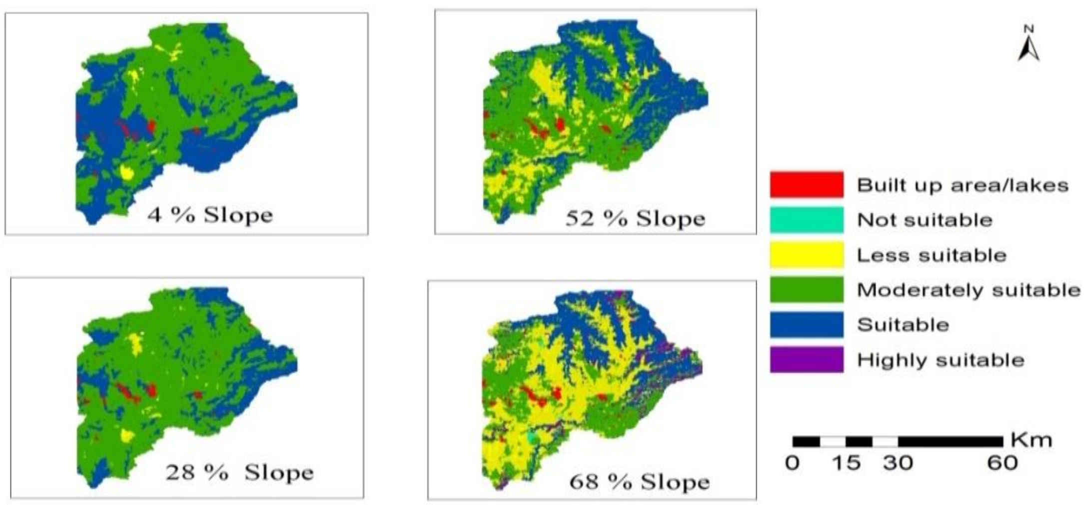
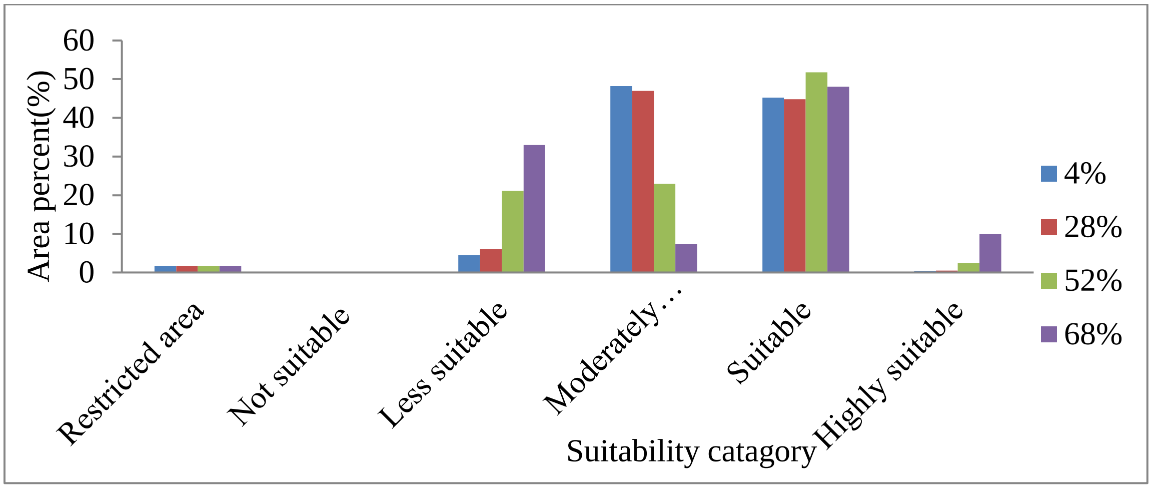


Fig 9 Sensitivity analysis map for watershed

➢ *Soil texture sensetivity*

Table 14 Suitability area difference of soil texture between different weighting

	Absolute value of percent area difference between					
Suitability category	**4% and 28%**	**4% and 52%**	**4% and 68%**	**28% and 52%**	**28% and 68%**	**52% and 68%**
Lakes/ built up area	0.00	0.00	0.00	0.00	0.00	0.00
Not suitable	0.00	0.00	0.02	0.00	0.02	0.02
Less suitable	1.62	16.71	28.49	15.08	26.86	11.78
Moderately suitable	1.21	25.24	40.83	24.03	39.61	15.59
Suitable	0.47	6.48	2.82	6.95	3.29	3.66
Highly suitable	0.06	2.05	9.50	1.99	9.44	7.45
Average difference	0.56	8.41	13.61	8.01	13.21	6.42
Cumulative	8.37					



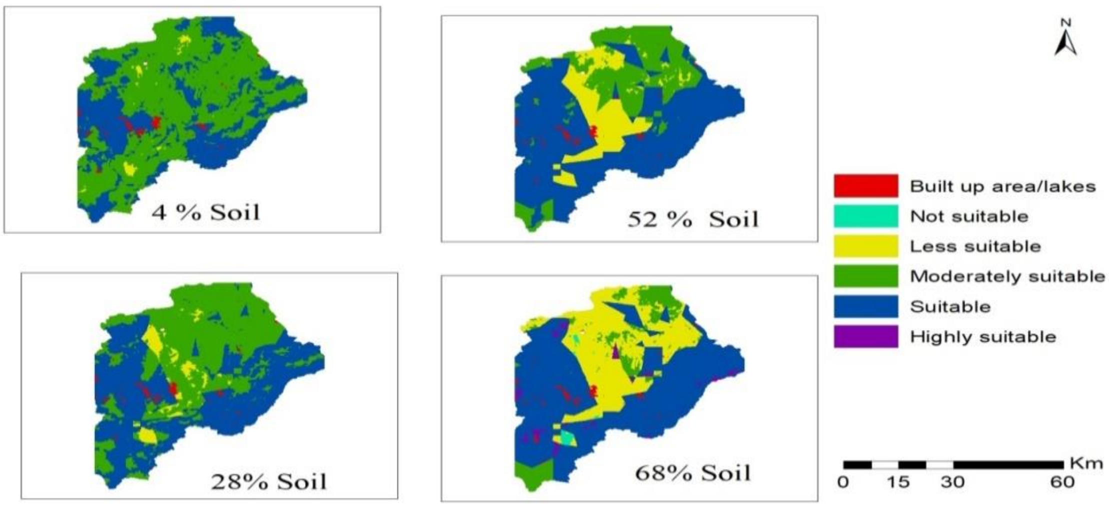
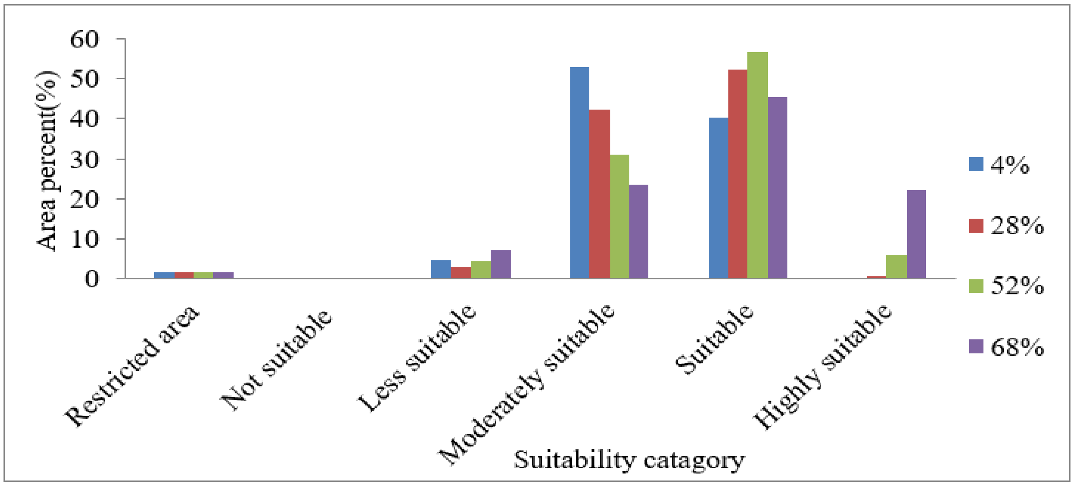


Fig 10 Sensitivity analysis map for soil texture

- *Erosion rate sensitivity*

Table 15 Suitability area difference of soil erosion rate between different weighting

	Absolute value of percent area difference between					
Suitability category	**4% and 28%**	**4% and 52%**	**4% and 68%**	**28% and 52%**	**28% and 68%**	**52% and 68%**
Lakes/ built up area	0.00	0.00	0.00	0.00	0.00	0.00
Not suitable	0.00	0.01	0.08	0.01	0.08	0.06
Less suitable	1.58	0.24	2.22	1.34	3.81	2.47
Moderately suitable	10.71	21.83	29.31	11.12	18.60	7.48
Suitable	11.99	16.34	5.22	4.35	6.77	11.12
Highly suitable	0.30	5.71	21.79	5.41	21.48	16.07
Average difference	4.10	7.36	9.77	3.71	8.46	6.20
Cumulative	6.60					



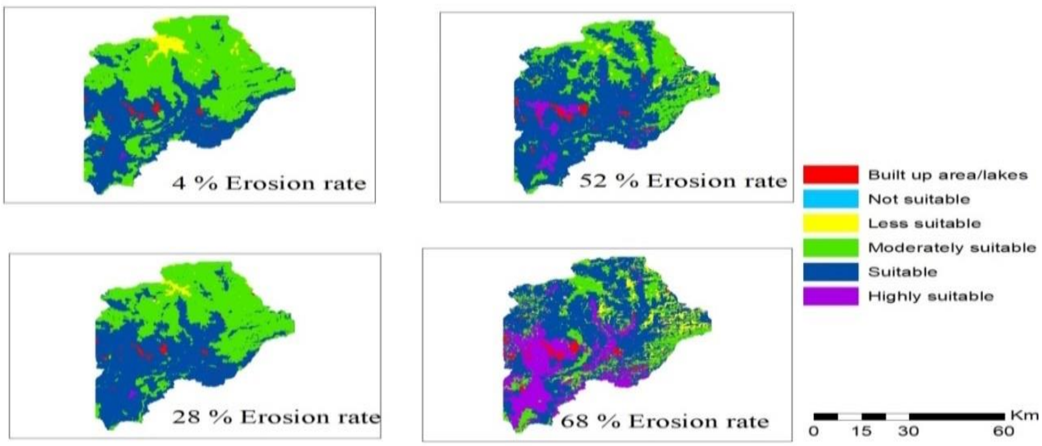


Fig 11 Sensitivity analysis map for erosion rate

The geological fault suitability class difference was the highest value and elevation was the lowest value. Then according to Al-mashreki et al (2011) geological fault was the highest sensitive factor for dam site selection in the Birr watershed and elevation was the lowest sensitive factor. Satty's (2008) scale value has given according to its sensitivity result. The first rank has been given geological fault, the second for foundation geology, the third for land use land cover, the fourth for soil texture, the fifth for watershed slope, and the sixth for soil erosion rate, the seventh for road proximity, the eighth for river proximity and the last ninth rank for elevation.

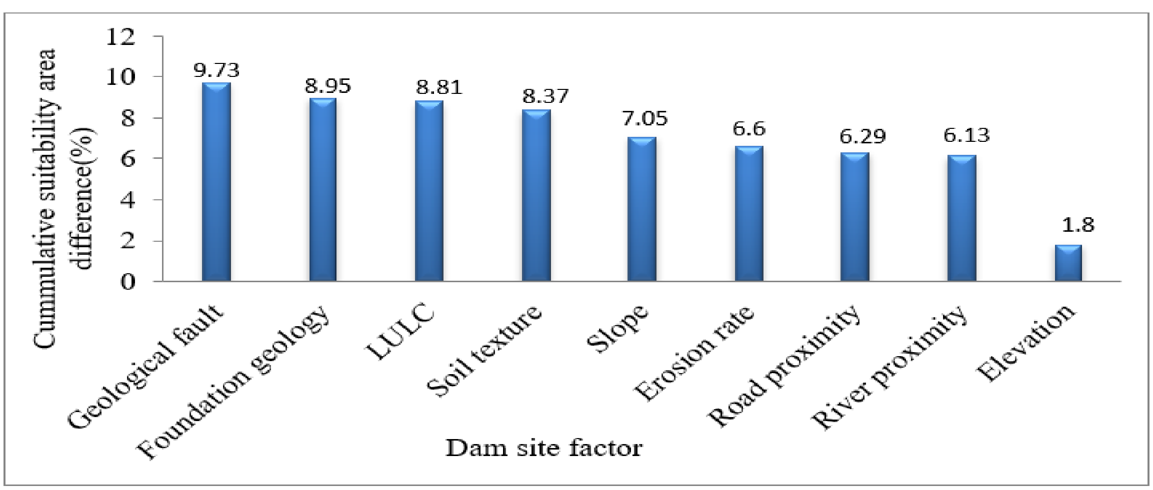


Fig 12 Cumulative suitability area difference of factors at different weighting

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➢ *Dam site selection factor weights using pairwise comparison*

The matrix was completed with the principles of Weldu et al., (2016), Saaty (2008) by making 9 by 9 matrix A. The value of the diagonal matrix (aij), is 1 because the pairwise comparisons of the same criteria to the dam site suitability are equal, then for the equal contribution, the values of Saaty's (2008) scale is one. The upper matrix value (aij) was assigned based on the pair-wise comparisons of the sensitivity result of the criteria as obtained from the above Fig 12. The lower matrix value (aji) is assigned with the corresponding upper matrix reciprocal value which is aji=1/ aij.

Table 16 Pair wise matrix of dam site selection factor

Factors	Fault	Geology	LULC	Soil	Erosion	Slope	Road	River	Elevation
Fault	1	2	3	4	5	6	7	8	9
Geology	0.50	1	2	3	4	5	6	7	8
LULC	0.33	0.50	1.0	2	3	4	5	6	7
Soil	0.25	0.33	0.50	1	2	3	4	5	6
Slope	0.20	0.25	0.33	0.50	1	2	3	4	5
Erosion	0.17	0.20	0.25	0.33	0.50	1	2	3	4
Road	0.14	0.17	0.20	0.25	0.33	0.50	1	2	3
River	0.13	0.14	0.17	0.20	0.25	0.33	0.50	1	2
Elevation	0.11	0.13	0.14	0.17	0.20	0.25	0.33	0.50	1
Total	2.83	4.72	7.59	11.45	16.28	22.08	28.83	36.50	45

Table 17 Normalization of matrixes for factors weight determination

Factors	Fault	Geology	LULC	Soil	Slope	Erosion	Road	River	Elevation
Fault	0.35	0.42	0.40	0.35	0.31	0.27	0.24	0.22	0.20
Geology	0.18	0.21	0.26	0.26	0.25	0.23	0.21	0.19	0.18
LULC	0.12	0.11	0.13	0.17	0.18	0.18	0.17	0.16	0.16
Soil	0.09	0.07	0.07	0.09	0.12	0.14	0.14	0.14	0.13
Slope	0.07	0.05	0.04	0.04	0.06	0.09	0.10	0.11	0.11
Erosion	0.06	0.04	0.03	0.03	0.03	0.05	0.07	0.08	0.09
Road	0.05	0.04	0.03	0.02	0.02	0.02	0.03	0.05	0.07
River	0.04	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.04
Elevation	0.04	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.02
Total	1	1	1	1	1	1	1	1	1

Table 18 Weight of dam site selection Factors

Factor	Fault	Geology	LULC	Soil	Slope	Erosion	Road	River	Elevation
Weight (%)	31	21	15	11	8	5	4	3	2

The geological fault has the maximum weight, whereas elevation has the minimum weight for dam site selection with the value of 31% and 2% respectively. The selected dam sites highly depend on the geological fault more than the other factor.

➢ *Assessment of consistency*

$CR = \frac{CI}{RI}$; RI for 9 number of factor is 1.45.

CI = $\frac{\lambda max-n}{n-1}$

λ_{max}= 0.31*2.83+0.218*4.72+0.154*7.593+0.1088*11.45+0.0764*16.283+0.05*22.083+0.037*28.8333+0.0259*36.5+0.0189*45 = 9.25

CI = $\frac{\lambda max-n}{n-1} = \frac{9.25-9}{9-1}$ = 0.03125

CR=0.03125/1.45=0.02

Then the CR value was less than the maximum acceptable CR value of 0.1. It indicates that the value used in pair-wise comparison and the final dam site factor weight is acceptable. As the consistency ratio is acceptable, then the calculated dam site factors weight is used in the final dam site selection by using weighted overlay analysis of Arc map GIS.

- *Dam site suitability map*

The overall Birr watershed suitability for dam site from weighted overlay of nine factors by Arc map GIS indicated that nearly half of the watershed was suitable for dam site which covers 47.57%. Both highly suitable and less suitable of the watershed area was less area percent coverage with the magnitude of 0.42% and 0.01% respectively and it is almost nearly null. The dominant dam site suitability of the watershed was suitable area and moderately suitable area which account 89.38% is shown in Fig 13 and Fig 14.

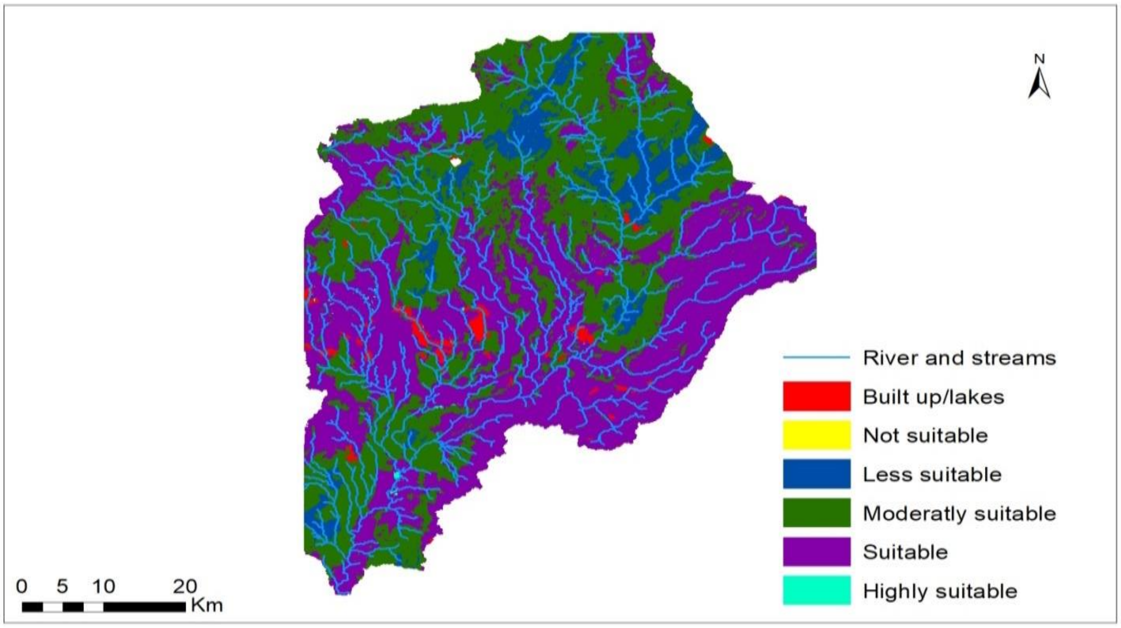

Fig 13 Dam site suitability map of the study area

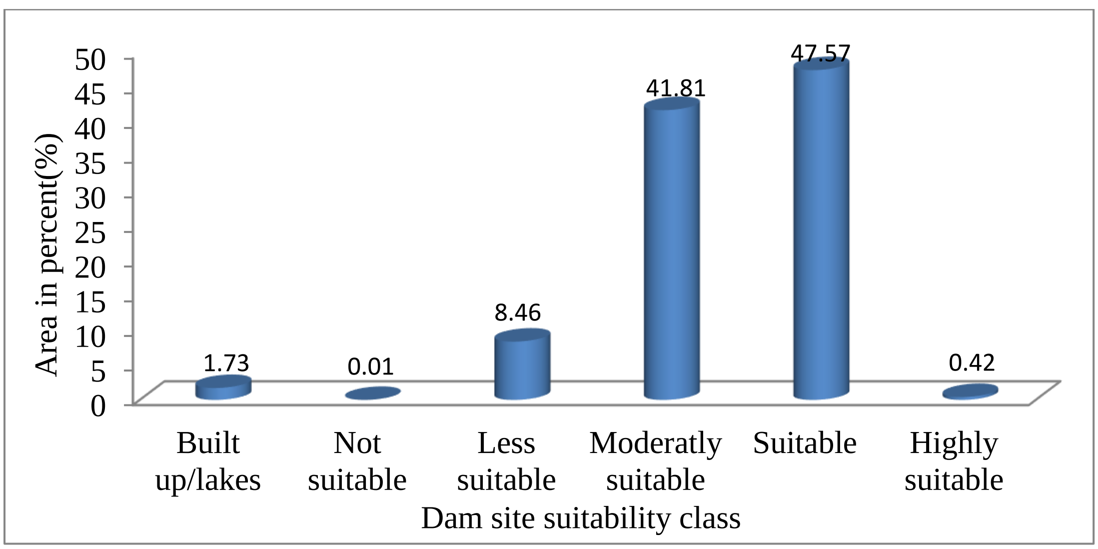

Fig 14 Dam site suitability area coverage charts

- *Validating GIS based sensitivity analysis for suitable dam site selection criteria weight determination*

To validate the result, this study has two options of validation. The first option was by holding the sensitivity analysis result and rank of the factor for dam site selection, there was a group discussion with 5 Amhara design supervision work enterprise professionals that working under dam site selection and design. According to the discussion 4 of them agreed with the result and one of them explained that foundation geology should be at the first rank and soil texture be given high preference to LULC. As four of them were agree with the sensitivity analysis result, this result was in line with the previous adapted experts-based method of dam site selection factors weight determination.

The second option compares the dam site selection factor rank of preference with the previous study. Tanveer et al., (2019) conducted a study on identifying dam sites by using GIS and remote sensing on Diamer Basha and it was said that tectonically active fault regions are considered worst for construction sites such as for dam construction for any scenario and it must be avoided for dam construction. Choo et al., (2017) have used land cover (LC), hydrological geology (GE), slope (SL), river (RI), and topography rugged index (TRI) as dam site selection factors. Accordingly his result, hydrological geological was given the highest weight than the other reaming factors. (Al-ruzouq *et al.,* 2019) has used elevation as one of a factor for dam site selection and has given the lowest weight. The overall GIS-based sensitivity analysis of dam site factors for dam site selection factor weight determination was in line with the previous study. This way of suitable dam site selection factors weight determination highly reduces the time, cost, and the expert's requirement and is relatively consistent with the expert's opinion-based factors weight determination. For expert, opinion-based factors weight determination the weight of the factors vary with different experts, and maybe the result will change after ten years from now, as the experts are changed. However, for GIS-based sensitivity analysis of suitable dam site factors weight determination, the weight should be consistent through time, unless the data type and the number of data changed.

IV. CONCLUSION

The GIS-based multi-criteria decision analysis method is the preferable method of dam site selection as it is less costly, and less time required. The main constraint or limitation of this method is the way of giving weights for a factor. As the weight of the factors is certain or accurate, the remaining activity is done with GIS. GIS is software that can input, manipulate or analyze and finally display the map or result. Then the quality data is inputted to GIS, it is possible to get good and certain maps. The cause of the GIS-based multi-criteria decision analysis method of suitable dam site selection uncertainty is the experts-based factors weight determination. This study has tried to minimize the expert-based factor's weight uncertainty with a GIS-based sensitivity analysis of the dam site selection factor's weight. According to the GIS-based sensitivity analysis, the cumulative geological fault suitability class difference was the highest value and elevation was the lowest value. As the suitability area difference of the geological fault at different weighting is highest; it is the highest sensitive factor for dam site selection in the Birr watershed and elevation was the lowest sensitive factor as the difference of suitability area is relatively lowest. The geological fault is given the highest rank or preference and finally, the highest weight and elevation are given the lowest rank and weight. It indicates that more of the dam site suitability of the watershed is depend on the suitability of the geological fault. The high area of the watershed is unsuitable for the dam site concerning geological fault, and the overall watershed suitability is also not suitable for the dam site. The geological fault is the highest weight (31%), foundation geology (21%), soil texture (11%), slope (8%), erosion rate (5%), road proximity (4%), river proximity (3%) and the lowest weight is elevation range (2%). There for, this study tried to open the door for further investigation to avoid subjective based comparing of factors and factors weight determination for land suitably evaluation and maintain the land suitability map certain.

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Author’s contribution: We all authors contribute equally

Conflict of interest: We declared no conflict of interest for publishing this manuscript in international journal of innovation in science and technology.

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