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Land Suitability Analysis for Relocation of Settlement Based on Natural Hazard Issues: A Case Study of the Budhigandaki Hydropower Project in Nepal

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Abstract

Nepal has been exposed to different hazards due to its varied topography, including the Himalayas and Terai plains. The primary objective of this research is to use remote sensing (RS) and geographic information systems (GIS) to find suitable locations in the affected former Village Development Committees (VDCs) for the relocation of people impacted by the Budhigandaki Hydroelectric Project (BGHEP). The environmental and hazard factors were used to identify suitable land for resettlement sites. The Analytical Hierarchy Process (AHP) and GIS evaluated site suitability for settlement relocation. The weights of influence factors used for site selection are determined using AHP. Four groups were created by combining weighted scores such as environmental (slope, elevation, aspect, geological formation and land cover), landslide (Topographic Wetness Index -TWI, slope, elevation, precipitation, land cover, proximity to stream, drainage density, soil and proximity to fault line), flood (TWI, slope, elevation, precipitation, land use/cover, proximity to stream and drainage density) and hazard (landslide, flood and earthquake density). Among the overall study area, the moderate susceptibility class has the largest area (78.51%), followed by low (10.91%) and high (10.58%). The results of environmental and hazard factors were combined to create a suitability index map. Four groups have been defined on the map: most suitable, suitable, less suitable, and not suitable for relocating the settlements. This study shows how the Multi-Criteria Decision Analysis (MCDA) approach can be used to identify suitable sites for relocating settlements to reduce exposure to natural hazards. The expected total land requirements for the resettlement of the households that will be displaced physically was 405 hectares. The research shows suitable locations inside the impacted VDCs, so relocation plans should be made in the most suitable locations.

Keywords: Resettlement; GIS and Remote Sensing; MCDA; AHP; Hazard

1. Introduction

Relocation, or settlement, is a social process in which individuals leave their ancestral home and start over in a different location (Woube, 2005). It occurs due to forced migration, massive construction projects, typically because of natural or man-made calamities, and poor economic situations. Due to resettlement, people frequently lose important economic assets like homes or lands, jobs, and cultural identity. Appropriate rehabilitation is required after the relocation to protect the newly resettled people in their new surroundings. Before deciding to relocate, it is important to carefully evaluate the financial, social, and environmental consequences of doing so and any other available mitigating measures. Numerous economic, social, and governmental processes are centered on human settlements. In places with high population density and severe ecological degradation, the government of Nigeria has determined that a relocation program is the best way to address the complex socio-economic and food security issues (Babatimehin et al., 2015).

Nepal has experienced many strong earthquakes, heavy flooding and landslides caused by intense monsoon rains. These natural disasters have caused a lot of damage and loss of life and property in the past. The way people are changing the environment and the size of their activities are making society rely more on plans for cities and the environment to protect against natural disasters (Minhas, 2015). It's important to have records that give a quick overview of the types and sizes of these events to help city administrators make decisions. Nepal has many significant natural hazards like earthquakes, landslides, floods and forest fires. These processes can directly or indirectly put the environment, people, and property at risk. So, the aim of this research is to determine the geographical distribution of the major types of hazards that may occur in the study area and suggest suitable locations for resettlement.

For this research, the case of the Budhigandaki Hydroelectric Project (BGHEP) has to be studied. The Government of Nepal has proposed the Budhigandaki Hydroelectric Project (BGHEP), a hydroelectric project with national priority. The project will be developed with an installed capacity of 1200MW and is a reservoir type project located in the Bagmati and Gandaki Province. 27 former Village Development Committees (VDCs) will be affected by the reservoir of BGHEP due to the inundation of land and homes. In the Gorkha district, 14 former VDCs are within Gandaki, Shahid Lakhan, Bhimsen, and Aarughat Rural Municipalities. In the Dhading district, 13 VDCs are currently part of Nilakantha Municipality, Siddhalekh, Jwalamukhi, Tripurasundari, Gangajamuna, and Netrawati Debjong Rural Municipalities. Focusing on the main aspects of resettlement, this study has created a detailed resettlement plan for the areas in Gorkha and Dhading districts around the periphery of the proposed inundated areas by the reservoir of the BGHEP.

When people have to leave their homes and relocate to other areas, various challenges arise due to their preferences and needs. The process of resettlement has faced difficulties because of these diverse demands. The government aims to complete the resettlement at a low cost. Still, the affected people demand resettlement close to their current location, with proper infrastructure development, and in a manner that preserves their culture, religion, and community ties. The government is increasing coordination and cooperation with the affected people to prepare resettlement plans based on their needs. This study aims to find suitable sites near the inundated area so that affected people can be relocated close to their ancestral homes around the reservoir.

2. Materials and Method

2.1 Data Collection

The research uses datasets from multiple sources. Firstly, elevation, slope, aspect, TWI, and drainage density data were obtained from ALOS PALSAR with a spatial resolution of 12.5 meters. Land use and land cover data for 2019 with a spatial resolution of 30m and soil data were sourced from ICIMOD. Then, Meteorological data was provided by the Department of Hydrology and Meteorology (DHM), Nepal. Earthquake event data were collected by the USGS Earthquake Hazard Program. Historical landslides and flood data were obtained from the BIPAD portal. An orthophoto of the reservoir area was provided by BGHEP. Socio-economic data were collected through field visits.

2.2 Study Area

The study has been conducted on 14 former VDCs in Gorkha and 13 former VDCs in Dhading districts. It covers an area of 607.84 sq. km, including a reservoir area of 63 sq. km. The geographic extent of the study area is as follows: top (28.16 latitude), left (84.65 longitude), bottom (27.95 latitude) and right (85.00 longitude). The project lies in the Gorkha and Dhading districts in Nepal's Gandaki/ Bagmati province. The project site is accessible through Benighat-Dhading (125 km from Pokhara) on Prithivi Highway (Pokhara-Kathmandu). From Benighat, a motorable composite bridge can be used to cross the Trishuli River and access the Reservoir and Powerhouse site, which are about 1.5 km from the road.

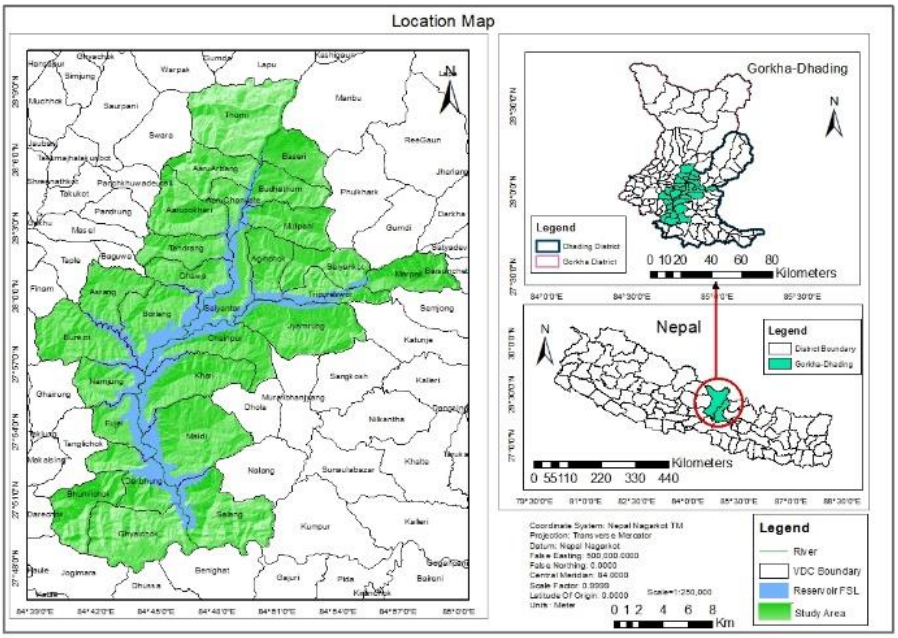


Figure 1: Study Area

2.3 Methodological Framework

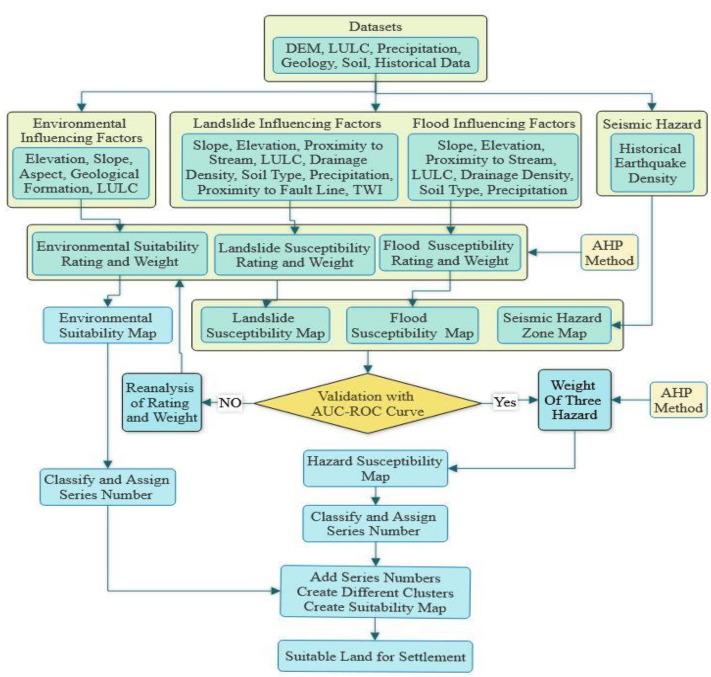


Figure 2: Procedure for Land Suitability Analysis

2.4 Criteria for Group Map Creation

Potential areas for resettlement have been recommended based on the suitability map prepared considering hazard risks.

Altogether eleven conditioning factors were selected for environmental and hazard group mapping based on the literature review and their relevance to susceptibility.

Elevation

The elevation map represents the height of any location. Settlement in high altitudes is especially vulnerable to risks resulting from climate change and extreme climate conditions including very low temperatures and snowfall (Al-shalabi et al., 2006).

Slope

The amount of inclination a physical feature or topographic landform to the horizontal surface is referred to as the slope of any terrain (Chow, 1972). The slope angle, which serves as the primary determining factor in slope stability analyses and is directly correlated with the probability of settlement, is frequently employed in creating landslide risk maps. The digital elevation model (DEM) is used to determine the slope.

Aspect

The compass direction that the slope faces is aspect. There is no slope in flat terrain. There are slopes in all directions in the regions other than flat terrain. There are north-facing, west-facing, south-facing, and east-facing slopes. If there is no slope, the cell value is -1. These are the grey cells in the aspect map above. If there is a slope, the direction is measured clockwise from 0° north. Return again as 360° north.

Land Use/Land Cover (LULC)

Land use also plays an important role in slope stability (Devkota et al., 2013). Although the terms land use and land cover are often used interchangeably, each has its own meaning. Land cover refers to surface coverage of the ground such as vegetation, urban infrastructure, water, and bare land. Land cover identification provides the basis for activities such as thematic mapping and analysis to detect change. Land use refers to the purpose that the land serves. Recreation, wildlife habitat, or agriculture are examples of land use.

Geology

Geology plays an important role in the study of landslide susceptibility as these have different geological units Various vulnerabilities to active geomorphological processes (Dahal et al., 2008)Five lithological units were identified and mapped: the Lakharpata Formation, the Naudanda Formation, the Ranimatta Formation, the Sangram Formation, and the Syangja Formation. The Ranimatta Formation, which is extremely suitable for settlements, was the maximum study area.

Topographic Wetness Index (TWI)

When mapping a region's vulnerability to risks, the Topographic Wetness Index (TWI) is a crucial factor to consider. It is the result of the DEM's secondary analysis, which considers both flow accumulation and slope. The formula was first introduced by (Beven & Kirkby, 1979) and is computed as:

$$TWI = ln\left(\frac{\alpha}{tan\beta}\right) \quad (1)$$

where β is the slope angle and α is the upslope value derived from flow accumulation, indicating the upstream contributing region.

TWI typically indicates an area's ability to hold water as well as the amount of moisture in the soil (Pawluszek & Borkowski, 2017). It may cause risks in several ways.

- Because of their higher water levels and more vigorous runoff, areas with high TWI values are usually more vulnerable to flooding.
- Because soil saturation can decrease soil stability and raise the danger of slope failure, areas

with high *TWI* values may be more vulnerable to landslides.

Rainfall

Intense rain can result in rivers and streams bursting their banks, causing sudden floods in urban areas, known as flash floods. Additionally, extended or heavy rainfall can lead to soil erosion, debris flow, and the initiation of landslides, particularly in regions characterized by steep slopes and loose soil (Tazik et al., 2014).

Drainage Density

The frequency and spacing of drainage networks in a landscape, such as rivers and streams, are called drainage density. Because there is a greater ability to convey water and runoff, areas with high drainage densities may be more vulnerable to flooding. Moreover, high drainage density locations may be more prone to erosion since runoff from them can weaken slopes and raise the possibility of landslides (Sarkar & Kanungo, 2004).

Soil

Slope stability is largely dependent on the kind of soil. In the testing with the fixed rainfall process and slope circumstances, no landslide occurred when the soil type was sandy or silty. When the soil was mixed or gravelly, landslides occurred.

Proximity to Fault Line

Another important geological component for determining the susceptibility to landslides is fault lines. These are the general lines along which the earth's surface fractures and these surfaces are more susceptible to the effects of earthquakes than other regular surfaces (Pourghasemi et al., 2012).

Proximity to Stream

Another significant aspect that raises the area's vulnerability to flooding during heavy and protracted rainfall or snowmelt periods is its proximity to a stream. This is because the stream's water can overflow and create flooding in surrounding areas (Rincon Romero et al., 2018)When there is much rainfall, the saturated soil increases in mass, which in turn causes gravity to act on the mass and pull the slope down, causing landslides that can threaten human life and damage property and infrastructure. This makes steep terrain near streams particularly vulnerable to landslides.

2.5 Analytical Hierarchy Process

Thomas L. Satty, in 1971, developed the Analytic Hierarchy Process (AHP) for decision analysis (Rincon Romero et al., 2018). The AHP method, one of the most well-known and popular multi-criteria analysis approaches, allows users to choose the relative importance of each parameter in the resolution of a multi-criteria problem (Akıncı et al., 2013). For each problem in the AHP technique, a hierarchical model made up of objectives, criteria, sub-criteria, and options is used (Saaty, 1990).

Each decision-maker input the desired amount for each participant, and using their geometric average, individual judgments (of each respondent) were transformed into group judgments (for each pair comparison) (Taherdoost, 2017). The scale ranges from 1 to 9, with 1 indicating equality or equal importance for the two components. Even so, number 9 suggests that one member is significantly more significant than the other in a pairwise matrix. The value from each pairwise comparison is used to create a pairwise comparison matrix.

A consistency index (*CI*), related to the eigenvalue technique was proposed by Saaty (1997):

$$CI = \frac{\lambda_{max} - n}{(n-1)} \quad (2)$$

where *CI* is the consistency index, λ_{max} is the maximal Eigenvalue and n is the number of factors

The consistency ratio,

$$CR = \frac{CI}{RI} \quad (3)$$

where *RI* is the random index

The matrix can be regarded as having an acceptable consistency if the *CR* is less than 10%. Saaty (1990) gave the random indices.

Table 1: Random indices from Saaty

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45

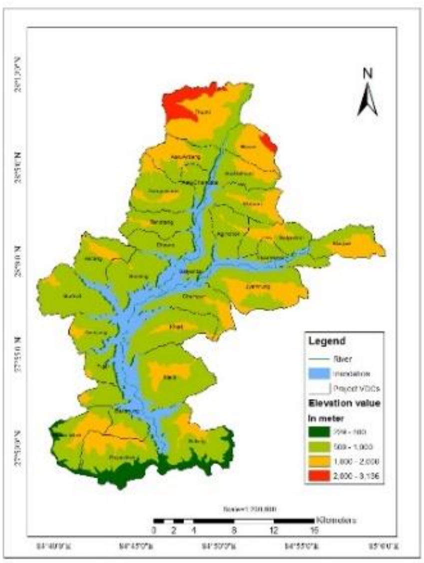


Figure 3: Elevation Map

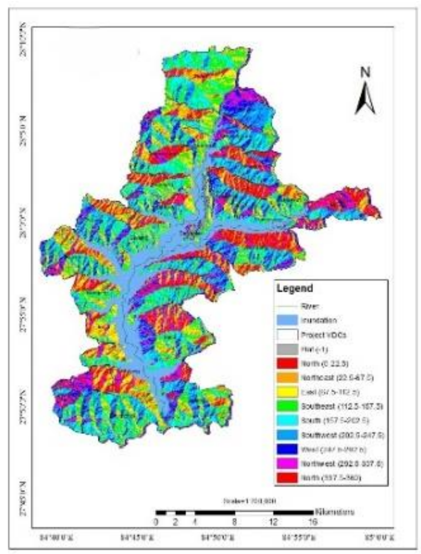


Figure 4: Aspect Map

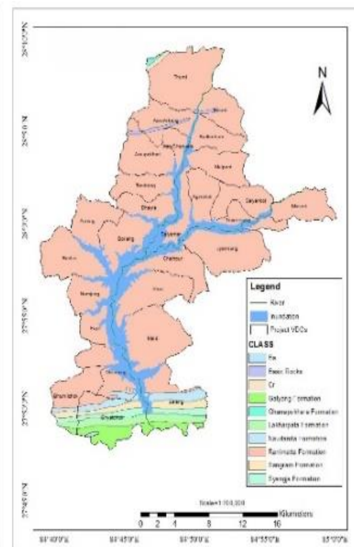


Figure 5: Geology Map

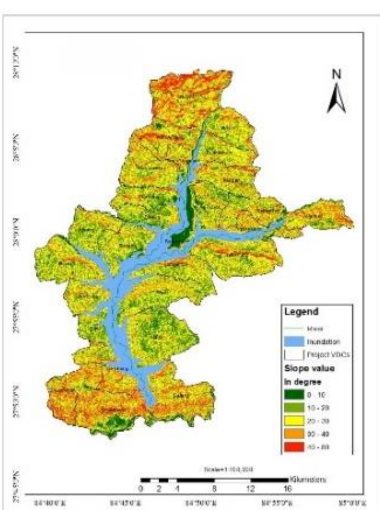


Figure 6: Slope Map

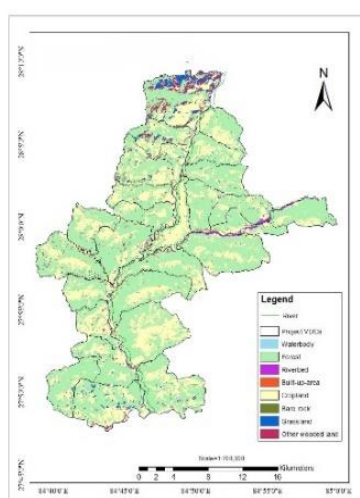


Figure 7: LULC Map

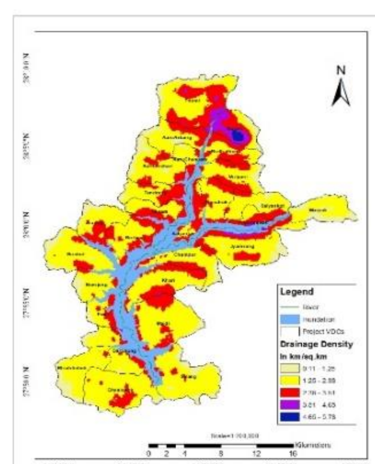
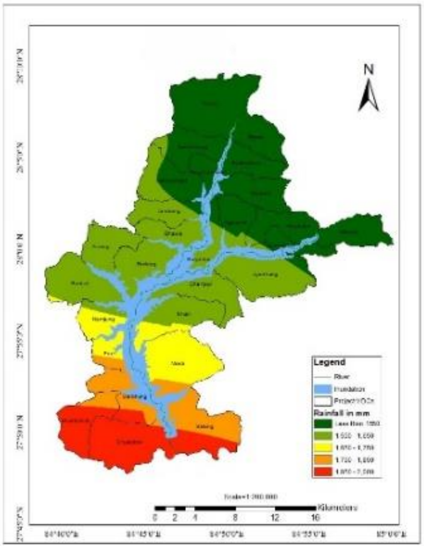
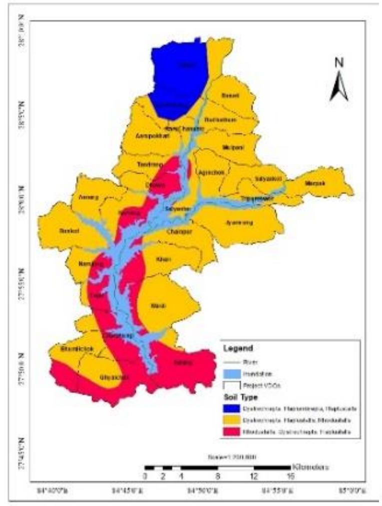


Figure 8: Drainage Density Map





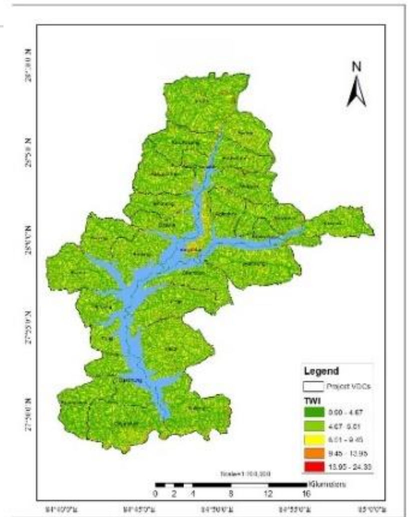


Figure 9: Rainfall Map | Figure 10: Soil Map | Figure 11: TWI Map

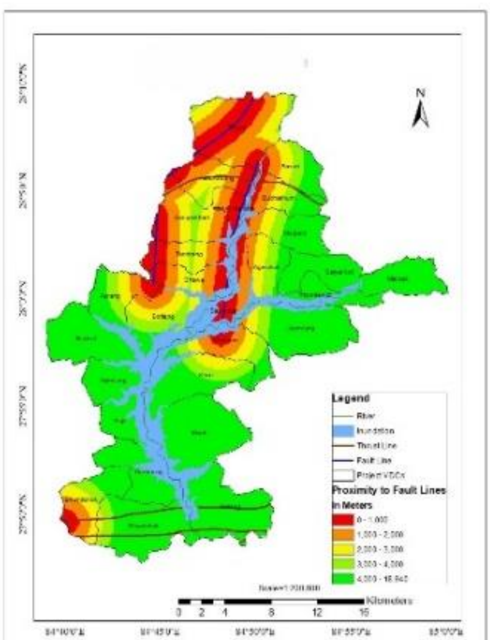


Figure 12: Proximity to Fault Line Map

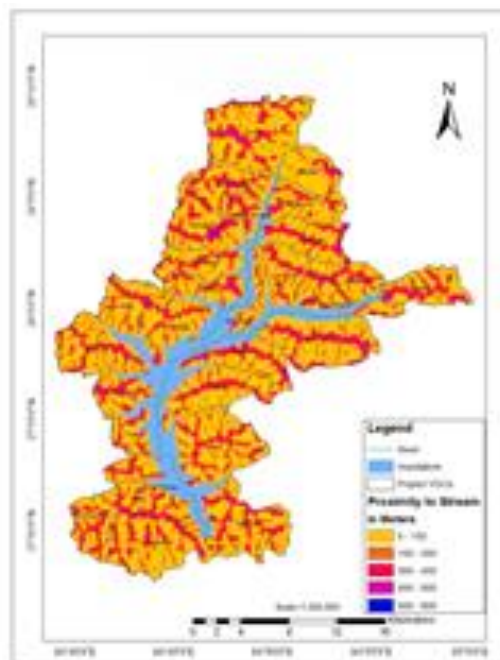


Figure 13: Proximity to Stream Map

Table 2: Pairwise comparison matrix for environmental suitability mapping

Factors	1	2	3	4	5	Wt. (%)
Slope (1)	1	3	7	3	5	46
Elevation (2)	1/3	1	3	1/3	3	15
Aspect (3)	1/7	1/3	1	1/5	1/3	5
Geology (4)	1/3	3	5	1	3	25
LULC (5)	1/5	1/3	3	1/3	1	9
					Sum	100

The consistency ratio is 0.053, indicating consistency in the pairwise comparison.

Table 3: Pairwise comparison matrix for flood Susceptibility mapping

Factors	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Wt. (%)**
Slope (1)	1	1/2	1	2	1/3	1/2	1/3	9
Elevation (2)	2	1	2	1	1	1/3	1/3	12
LULC (3)	1	1/2	1	1	1/2	1/3	1/3	8
TWI (4)	1/2	1	1	1	1/3	1/3	1/3	7
DD (5)	3/2	1	1	3	1	1	1	17
Rainfall (6)	2	3	3	3	1	1	1/2	21
Proximity to Stream (7)	3	3	3	3	1	2	1	26
							Sum	100

The consistency ratio is 0.015, indicating consistency in the pairwise comparison.

Table 4: Pairwise comparison matrix for landslide Susceptibility mapping

S.N	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1	1	7	7	5	6	3	4	7	5
2	1/7	1	2	1/3	1/3	1/5	1/4	5	1/3
3	1/7	1/2	1	1/5	1/3	1/5	1/4	1	1/3
4	1/5	3	5	1	1	1/3	1	3	2
5	1/6	3	3	1	1	1/3	1/2	4	1
6	1/3	5	5	3	3	1	2	5	3
7	1/4	4	4	1	2	1/2	1	4	1/2
8	1/7	1/5	1	1/3	1/4	1/5	1/4	1	1/3
9	1/5	3	3	1/2	1	1/3	2	3	1

The consistency ratio is 0.057, indicating consistency in the pairwise comparison.

Table 4: Influencing Factors and Weights

S.N.	**Influencing Factors**	**Weights (%)**
1	Slope	34
2	Elevation	5

3	LULC	3
4	TWI	10
5	Drainage Density	8
6	Rainfall	18
7	Proximity to Stream	10
8	Soil	3
9	Proximity to Fault Line	9
	Total	100

Table 4: Pairwise comparison matrix for hazard group

Factors	**1**	**2**	**3**	**Weights (%)**
Landslide	1	2	3	52
Flood	1/2	1	3	34
Earthquake density	1/3	1/3	1	14
			Sum	100%

3. Results and Discussion

3.1 Environmental Suitability for Resettlement

Arc GIS software was used to create the suitability map, as shown in Figure 14. The tool used was a weighted overlay in which particular normalized criteria were multiplied by the respective weight of criteria. It was found that the area above the inundation due to the reservoir, the suitable class, has the largest area (35.26%) for resettlement, followed by most (28.67%), less (28.25%), and not suitable (7.83%).

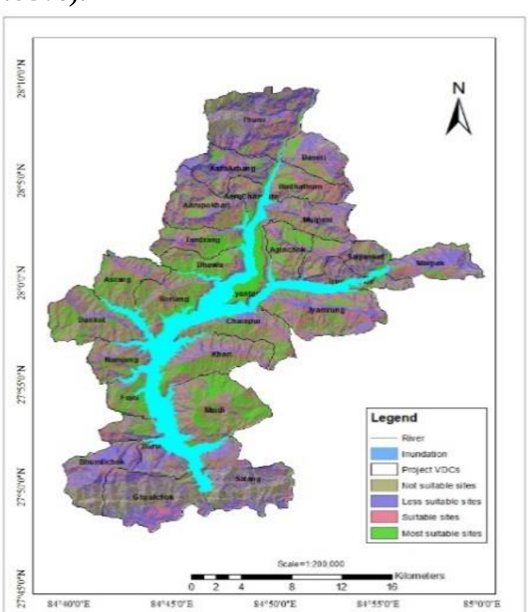


Figure 14: Environmental suitable sites for Resettlement

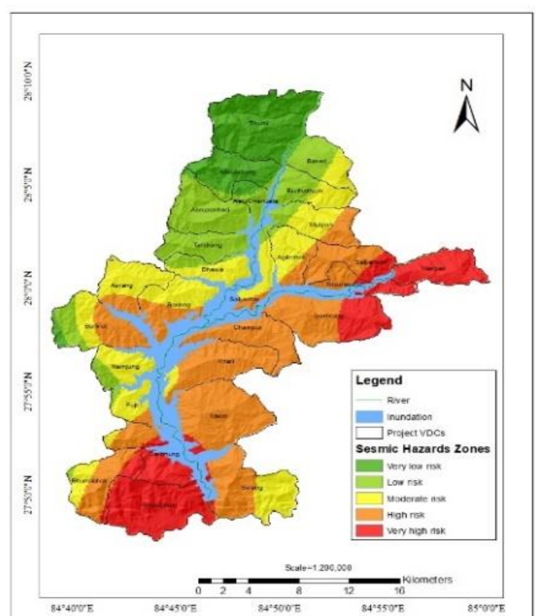


Figure 15: Seismic hazard zone map

3.2 Seismic Hazard Zone Map

A seismic hazard zone map was generated based on earthquake density. The earthquake density was reclassified into five categories employing the natural breaks method. It was found that the area above the inundation due to the reservoir, the high-risk class has the largest area (34.87%), followed by moderate (21.43%), very high (16.60%), low (15.25%) and very low (11.85%).

3.4 Landslide Susceptibility Map

Arc GIS software was used to create the landslide susceptibility map; the tool used was a weighted overlay in which particular normalized criteria were multiplied by the respective weight of criteria. It was found that the area above the inundation due to the reservoir, the moderate susceptibility category has the largest area (84.65%), succeeded by high (11.15%) and low (4.19%).

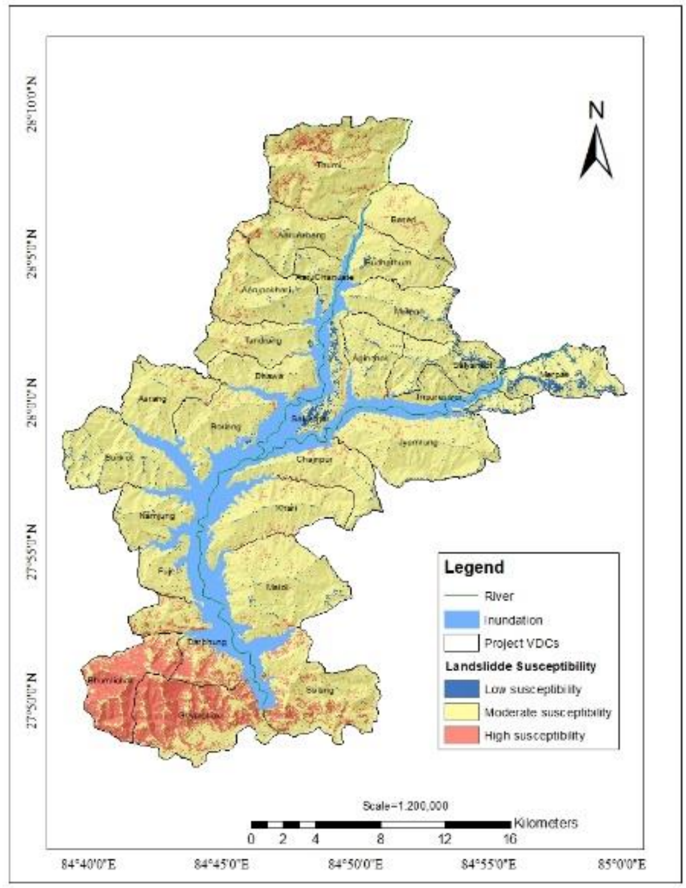


Figure 16: Landslide susceptibility map

3.5 Model validation

Field verification is one of the best ways to validate the results from susceptibility analysis, but it takes a lot of time and effort. Despite this, enough samples were collected. Historical data from the BIPAD Portal was digitized using Google Earth Pro, and a Receiver Operating Characteristic (ROC) curve was created for verification. This method quantitatively evaluates the hazard susceptibility model based on prediction accuracy. It shows how effective a diagnostic test is.

The success rate of the ROC curve indicates how well the hazard susceptibility maps classify landslides, floods, and earthquakes, both current and historical.

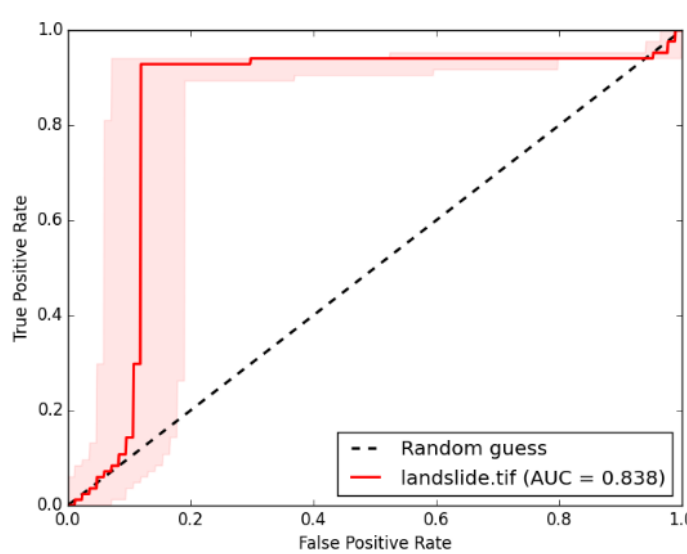


Figure 17: ROC Curve of landslide susceptibility with AUC value

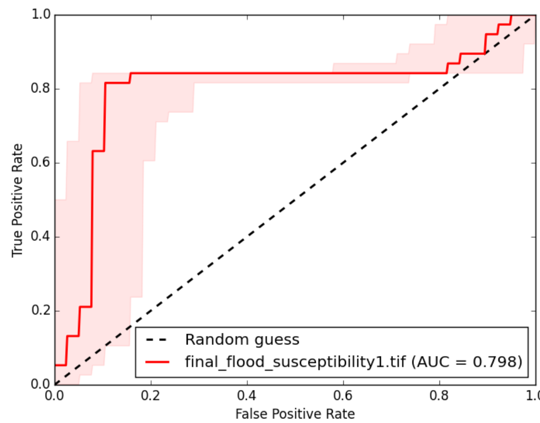


Figure 18: ROC Curve of flood susceptibility with A UC value

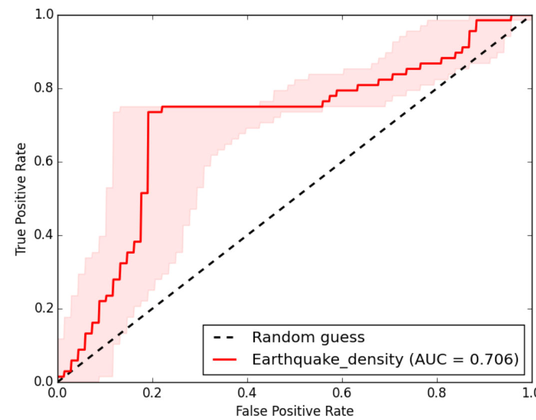


Figure 19: ROC Curve of the earthquake with AUC v alue

3.6 Hazard Group Map

A hazard group map using AHP was generated using the weighted overlay tool in GIS software. It was found that the area above the inundation due to the reservoir, moderate susceptibility category has the largest area (78.51%), succeeded by low (10.91%) and high (10.58%).

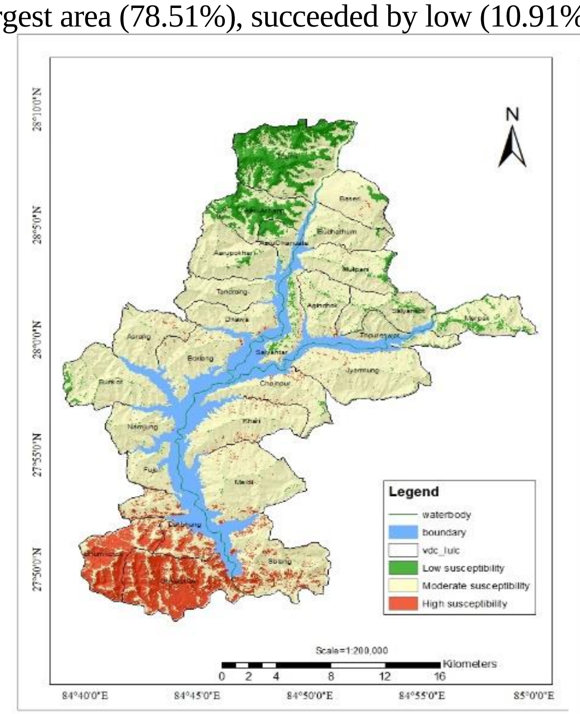


Figure 20: Hazard group map

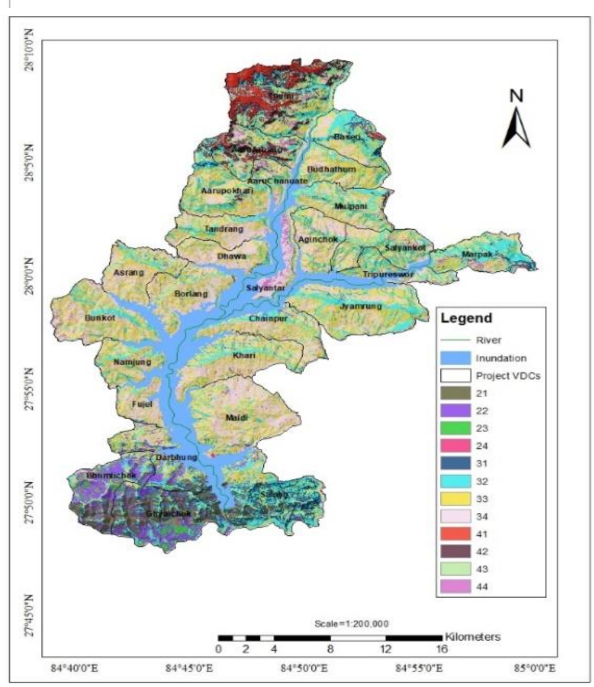


Figure 21: Final Land Suitability Index Map for Resettlement

3.7 Suitability Map for Resettlement

Arc GIS software was used to create the suitability map as shown in Figure 22. In order to preserve each group's sovereignty while combining the two group layers, the first environmental group map was grouped into four classes and assigned series number 1, 2, 3 and 4, and for the hazard group map, it was found that three classes as shown in figure 21 above and allocated series number 20, 30 and 40 for high susceptibility, moderate susceptibility and low susceptibility respectively. A low series number was assigned for high susceptibility because a low susceptibility zone is more suitable for settlement and vice versa. Simply combining two groups resulted in a final score map that displayed suitability scores of 21, 22, 23, 24, 31, 32, 33, 34, 41, 42, 43, and 44, as shown in Figure 22. Higher score values generally indicated greater suitability, while lower scores indicated lower suitability. However, upon closer examination, it was found that the combination of higher score values from both contributing maps indicated the highest level of suitability (Minhas, 2015). Then the suitability index map can be categorized into four clusters. The first cluster was made from values 21, 22 and 31, which is unsuitable for settlement. The second cluster was made from values 23, 24 and 32, which are less suitable for settlement. The third cluster was made from values 33, 41 and 42, which is suitable for settlement. The fourth cluster was made from values 34, 43 and 44 most ideal for settlement.

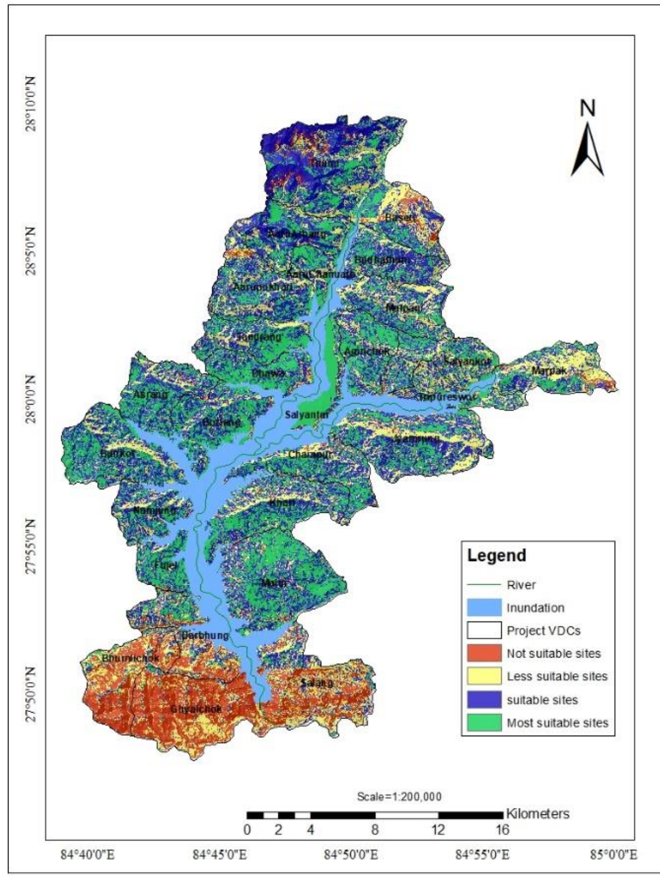


Figure 22: Final Suitable Land for Resettlement

The final suitability map for resettlement was generated using Arc GIS software. It was found that the area above the inundation due to the reservoir, the suitable class, has the largest area (37.60%) followed by most (29.89%), less (21.77%) and not suitable (10.74%).

3.8 Discussion

The study was conducted to find the best settlement area for relocating people by looking at well-known environmental conditions. Three main natural hazards, such as earthquakes, floods, and landslides, were mapped and combined to reduce future losses. The data processing produced three types of maps: environmental suitability map, hazard susceptibility map, and final land suitability map for relocation. To generate the final land suitability map, the first environmental group map was categorized into four classes and assigned series numbers 1, 2, 3, and 4; the hazard group map was classified and allocated series numbers 20, 30, and 40 for high susceptibility, moderate susceptibility, and low susceptibility respectively. A low series number was allocated for high susceptibility because a low susceptibility zone is more suitable for settlement and vice versa. The scores in the two contributing group maps must

be considered when processing the final suitability map scores. A combination of higher score values indicates higher suitability, while a combination of lower score values indicates lower suitability.
In order to preserve each group's sovereignty while combining the two group layers, the first environmental group map was divided into four classes and assigned series numbers 1, 2, 3, and 4; then hazard group map was classified and allocated series number 20, 30 and 40 for high susceptibility, moderate susceptibility and low susceptibility respectively. A low series number was allocated for high susceptibility because a low susceptibility zone is more suitable for settlement and vice versa. Simply combining two groups resulted in a final score map that displayed suitability scores of 21, 22, 23, 24, 31, 32, 33, 34, 41, 42, 43, and 44, as shown in Figure 22 above. Higher score values generally indicated greater suitability, while lower scores indicated lower suitability. However, upon closer examination, it was found that the combination of higher score values from both contributing maps indicated the highest level of suitability (Minhas, 2015).

3.8 Limitations of the study

For a successful resettlement plan, various variables, including social and environmental issues, geological stability, terrain, the extent of a suitable location, the availability of public facilities (such as schools, hospitals, transportation and electricity etc.), natural resources (such as firewood, water sources etc.), public willingness, socio-cultural issues, and environmental impacts are the major parameters to be considered. However, the study area is rural. Therefore, the study does not cover public facilities like schools, hospitals, transportation and electricity. It is assumed that these infrastructures can be developed once suitable locations have been found, and they will also be included in the rehabilitation plan. The thesis only includes the suitability analysis for relocation sites based on natural hazard issues near the reservoir.

3.9 Potential areas for future research

- Collect and incorporate socio-economic information into LSA, such as social infrastructure, economic activity, and population density.
- Create frameworks for multi-criteria decision analysis (MCDA) that take into account cultural, socioeconomic, and physical elements in equal measure

4. Conclusion

The process of choosing an appropriate location for resettlement is complex and has a great impact on the time and cost needed to establish and maintain urban infrastructure. The study aimed to achieve the objective by integrating the multi-criteria decision analysis (MCDA) framework with GIS and the Analytical Hierarchy Process (AHP). Four steps were involved in this process: choosing criteria, preparing and standardizing criteria maps, using AHP to compare criteria and calculate their weights, and combining the results.
This study was done using environmental and hazard factors. The analysis was carried out using the AHP, considering five criteria, such as elevation, slope, aspect, LULC and geological formation, for the environmental suitability map and three criteria, such as landslide, flood and earthquake density, for the hazard group map. It was determined that slope was the main factor for the environmental suitability map. The analysis considered nine and seven factors for landslide and flood, respectively, following the AHP. The process identifies slope as the main factor influencing landslide susceptibility mapping. On the other hand, for flood susceptibility mapping proximity to stream has a greater influence. And for the hazard group mapping landslide has a greater influence. The accuracy of landslide susceptibility mapping, flood susceptibility mapping, and earthquake density was verified using historical records of hazards documented by the BIPAD Portal. The AUC value was obtained as 0.838, 0.798, and 0.706 for landslides, flood, and earthquake density, respectively. From the result, it is concluded that there is enough land around the reservoir to relocate the settlements, which will be displaced by

inundation after the dam construction.

4.1 Recommendations

Environmental factors such as slope, elevation, aspect, geological formation, and land cover, and other hazard factors such as landslide, flood, and earthquake density must be considered in identifying suitable sites for resettlement. Therefore, before planning and implementing resettlement, the area's suitability must be analyzed thoroughly.

- To reduce the project's geographic and economic scope, relocation sites should be looked at as much as feasible within the geographic borders of project VDCs'.
- Effective resettlement planning requires a complete approach integrating environmental considerations, hazard mitigation strategies, community engagement, and long-term infrastructure and capacity-building investment.

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References

[1] Akıncı, H., Özalp, A. Y., & Turgut, B. (2013). Agricultural land use suitability analysis using GIS and AHP technique. Computers and Electronics in Agriculture, 97, 71–82.

[2] Al-shalabi, M. a., Mansor, S. Bin, Ahmed, N. Bin, & Shiriff, R. (2006). GIS-Based Multicriteria Approaches to Housing Site Suitability Assessment. XXIII FIG Congress. Shaping the Change. Munich, Germany, October 8-13, 1–17.

[3] Babatimehin, O., Ibrahim, I., Muibi, K. H., Alaga, A. T., Babatimehin, O., Ige-Olumide, O., Mustapha, O. O., & Hafeez, S. A. (2015). Suitability Analysis of Resettlement Sites for Flood Disaster Victims in Lokoja and Environs Validating the place of Onchocerciasis in migration: the case of endemic communities in Kwara State, Nigeria.

[4] Beven, K. J., & Kirkby, M. J. (1979). A physically based, variable contributing area model of basin hydrology / Un modèle à base physique de zone d'appel variable de l'hydrologie du bassin versant. Hydrological Sciences Bulletin, 24(1), 43–69.

[5] Chow, V. Te. (1972). Hydrologic Modeling. In J Boston Soc Civ Eng (Vol. 59, Issue 1). https://doi.org/10.1016/b978-0-08-057164-5.50017-7

[6] Dahal, R. K., Hasegawa, S., Nonomura, A., Yamanaka, M., Masuda, T., & Nishino, K. (2008). GIS-based weights-of-evidence modelling of rainfall-induced landslides in small catchments for landslide susceptibility mapping. Environmental Geology, 54(2), 311–324.

[7] Devkota, K. C., Regmi, A. D., Pourghasemi, H. R., Yoshida, K., Pradhan, B., Ryu, I. C., Dhital, M. R., & Althuwaynee, O. F. (2013). Landslide susceptibility mapping using certainty factor, index of entropy and logistic regression models in GIS and their comparison at Mugling-Narayanghat road section in Nepal Himalaya. Natural Hazards, 65(1), 135–165.

[8] Minhas, A. I. (2015). GIS-based GEO HAZARD ASSESSMENT OF PAKISTAN FOR Pakistan has been subject to frequent earthquakes, which are often severe. 7(3), 405–426.

[9] Pawluszek, K., & Borkowski, A. (2017). Impact of DEM-derived factors and analytical hierarchy

process on landslide susceptibility mapping in the region of Rożnów Lake, Poland. *Natural Hazards*, *86*(2), 919–952.

[10] Pourghasemi, H. R., Pradhan, B., & Gokceoglu, C. (2012). Application of fuzzy logic and analytical hierarchy process (AHP) to landslide susceptibility mapping at Haraz watershed, Iran. Natural Hazards, 63(2), 965–996.

[11] Rincon Romero, D., Khan, U., & Armenakis, C. (2018). Flood Risk Mapping Using GIS and Multi-Criteria Analysis: A Greater Toronto Area Case Study. *Geosciences*, *8*, 275.

[12] Sarkar, S., & Kanungo, D. P. (2004). An integrated approach for landslide susceptibility mapping using remote sensing and GIS. Photogrammetric Engineering & Remote Sensing, 70(5), 617–625.

[13] Shiau, Y., Tsai, T., Wang, W., & Huang, M. (2017). Use Questionnaire and AHP Techniques to Develop Subcontractor Selection System. *Proceedings of the 19th International Symposium on Automation and Robotics in Construction (ISARC)*.

[14] Taherdoost, H. (2017). Decision Making Using the Analytic Hierarchy Process (AHP); A Step by Step Approach Hamed Taherdoost To cite this version : HAL Id : hal-02557320 Decision Making Using the Analytic Hierarchy Process (AHP); A Step by Step Approach. *Journal of Economics and Management Systems*, *2*(International), 244–246.

[15] Tazik, E., Jahantab, Z., Bakhtiari, M., Rezaei, A., & Alavipanah, S. K. (2014). Landslide susceptibility mapping by combining the three methods Fuzzy Logic, Frequency Ratio and Analytical Hierarchy Process in Dozain basin. *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *XL-2/W3*, 267–272.

[16] Woube, M. (2005). Effects of resettlement schemes on the biophysical and human environments: The case of the Gambela Region, Ethiopia. Universal-Publishers.