Environmental Systems Research

RESEARCH

Habitat suitability analysis for hippopotamus (*H. amphibious*) using GIS and remote sensing in Lake Tana and its environs, Ethiopia

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Abstract

This research was carried out from October 2013 to May 2014. *Hippopotamus amphibious* is a mammalian species distributed in different lakes and rivers where ecological requirements are fulfilled for its survival. Lake Tana and its environs are home to Hippopotamus amphibious. The species is identified as vulnerable worldwide due to habitat loss and poaching. However, despite its vulnerability, there is no research conducted regarding the species, and its environmental requirements in Ethiopia. Therefore, the main objective of this study was to carryout habitat suitability analysis and find out suitable habitat sites of hippopotamus within the Lake Tana and its environs using the integration of GIS and remote sensing techniques. The softwares such as, Arc GIS10.2, ERDAS IMAGINE2010, and Virtual satellite image downloader were used in this research. The data used were SPOT image of 2012 of the study area, bathymetric data of Lake Tana, DEM, Google Earth data and GCP. Running a suitability model requires estimation of weights by expertise for each individual criterion on GIS software. Thus, the habitats in Lake Tana and its environs ranging from most suitable to not suitable for hippopotamus were identified. It was shown that 50.88% of the areas under study was highly disturbed and became unsuitable to hippopotamus, 42.29% of the areas were moderately disturbed, and only 1.81% of the areas were revealed to be undisturbed. As the study result showed that in and around Lake Tana, a human factor was considered to be outweighing the physical factors to minimize the habitat for the aforementioned animal. The results revealed that only 22.54% of the study areas were identified as most suitable for the animal under study of which the large portions of the areas are located at the backside of settlements which are not easily accessible by the species, while 40.5% of the areas were found to be moderately suitable, and 36.96% were unsuitable habitats for hippopotamus. Based on the findings of the present study it was concluded that there was high interference of human being in the habitats of hippopotamus especially at the shores of the lake since the land were looked-for agricultural activities. Therefore, too much proximity of human activities in identified hippopotamus habitats have to be protected and conservation buffer surrounding the Lake has to be developed.

Keywords: GIS, Habitat suitability, Hippopotamus, Lake Tana, Remote sensing, MCDM

Background

Hippopotamus (*H. amphibious*) is a mammalian species distributed in different lakes and rivers where ecological requirements are fulfilled for its survival. According to (Eltringham 1993), Lewison and Carter (2004) the species was widely distributed in sub-Saharan Africa. However, study by International Union for Conservation of Nature and Natural Resources (IUCN 2005a, b) showed that the population had declining from time to time as a result of exploitation and habitat loss. So that hippopotamus specialist group reevaluated its status to vulnerable category on the International Red List of threatened species in 2006 (Lewison 2007; Lewison and Oliver 2008). The study conducted by G/kidan and Teka

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2006 cited in Funny (2012) point out that hippopotamus are mainly restricted to pocket habitats of Lake Tana, in spite of their widespread in former times. The other study UNEP-WCMC (2010) indicated that there is no adequate countrywide information on population size of hippopotamus in Ethiopia. However, the study confirms the presence of some populations of this species in Lake Tana, and also other rivers and lakes of the country. Moreover, strategic environmental assessment report of Lake Tana and its environ (2012) elucidate the hippopotamus failed under critical conservation issues due to threats of habitats fragmentation, overgrazing, farmland, settlement, hunting and deforestation. All these problems coupled with its' ecological and economic importance requires mapping suitable habitat site in Lake Tana and its environs using GIS and remote sensing techniques.

Objectives

The objectives of this study were to carryout habitat suitability analysis and find out suitable sites of hippopotamus in Lake Tana and its environs using the integration of GIS and remote sensing techniques with MCDM.

Description of the study area

The study area is located in North Western part of Ethiopia between 11.506° to 12.394° latitudes and 36.903° to 37.717° longitudes (Amhara Design and Supervision Works Enterprise (ADSWE) 2011). The lake is a natural type which covers 309,132.12 ha area at an average elevation of 1800 m asl and with a maximum depth of 15 m (Matthew et al. 2010; Amhara Design and Supervision Works Enterprise (ADSWE) 2011). It is the largest lake in Ethiopia and the third largest in the Nile Basin. The lake is main source of the Blue Nile River which is the only surface outflow from it. The mean maximum and minimum temperature of Lake Tana are 29.20 and 10.90 °C, respectively (Amare and Rao 2011) (Fig. 1).

Methods

To determine the data type, sample size, collection tools, and analysis methods, identification of factors that can affect habitats of the spices understudy was priority. Hence based on literatures slope (Holmes (1996), cited in Dietz et al. 2000), elevation (Eltringham (2003), cited in UNEP-WCMC 2010), land use and land cover (Mackie 1976; Lock 1972 cited in Kanga et al. 2011; Pienaar et al. 1966; IUCN 1993; Eltringham 1999), forage proximity to the Lake (Tracy 1996), distance from settlement (Wengström 2009) and water depth (Tracy 1996) were identified variables. For this study mixed approaches were employed. The data used were GPS readings, SPOT image of 2012, DEM (digital elevation model), Google Earth images and pictures. In addition bathymetric data of the Lake and thorough filed observation were very helpful for the completion of the work (Table 1).

Since Lake Tana is very large; it was very difficult to cover all the area. As a result five sample areas/sites were selected by considering accessibility by road transport. The sample sites for field survey were the outlet of Nile River (at Debere Mariam), Gelda, Tana Chirkos (at the inflow of Gumara River to the Lake Tana), Korata and Robit. To classify three band SPOT images into 6 land use/land cover classes 180 GCPs were collected by following the rule of thumb which states that if each measurement vector has N features, then select N + 1points per class and the practical minimum is 10*N per class (Anji Reddy 2008). In addition by using Microsoft Virtual Earth Satellite Downloader, 544 polygons of settlement were generated. The major Software used was ERDAS IMAGIN2010 to classify land use/land cover and Arc GIS 10.2 to produce thematic maps based on their particular criteria. All the GIS and RS processes performed in this study were summarized diagrammatically in Fig. 2.

Data analysis methods

In order to map suitable habitat site for hippopotamus in Lake Tana and its environs, thematic maps were produced. The thematic layers have varied (qualitative and quantitative) values. Thus the data classes need conversion in uniform suitability measures to make the combination compatible. Each layer was reclassified into three suitability classes: highly suitable (3), moderately suitable (2), Not suitable (1) based on the literature evidences and field observation (Table 2).

Multi criteria decision making

Model factors used were: slope, grazing proximity to resting water, and proximity to settlement/human disturbance, elevation and land use/land cover. Before the layers were merged into the weighted overlay analysis, the inputs were first converted into a raster data model and segregated into common scale to make combination possible. Multi criteria decision making (MCDM) problems typically involve criteria of varying importance to decision makers. According to Eastma et al. (1995) a criterion is some basis for a decision that can be measured and evaluated. Accordingly, 1–3 class scales (most suitable-3, moderately suitable-2 and not suitable-1) were assigned for each criteria/factor. Each criterion's relative influence on suitability of habitat for selected animal was assigned or ranked by expertise decision. Then given ranks were converted in percentages on GIS software to integrate the value with its respective raster data. The criteria were ranked on the basis of their influence from

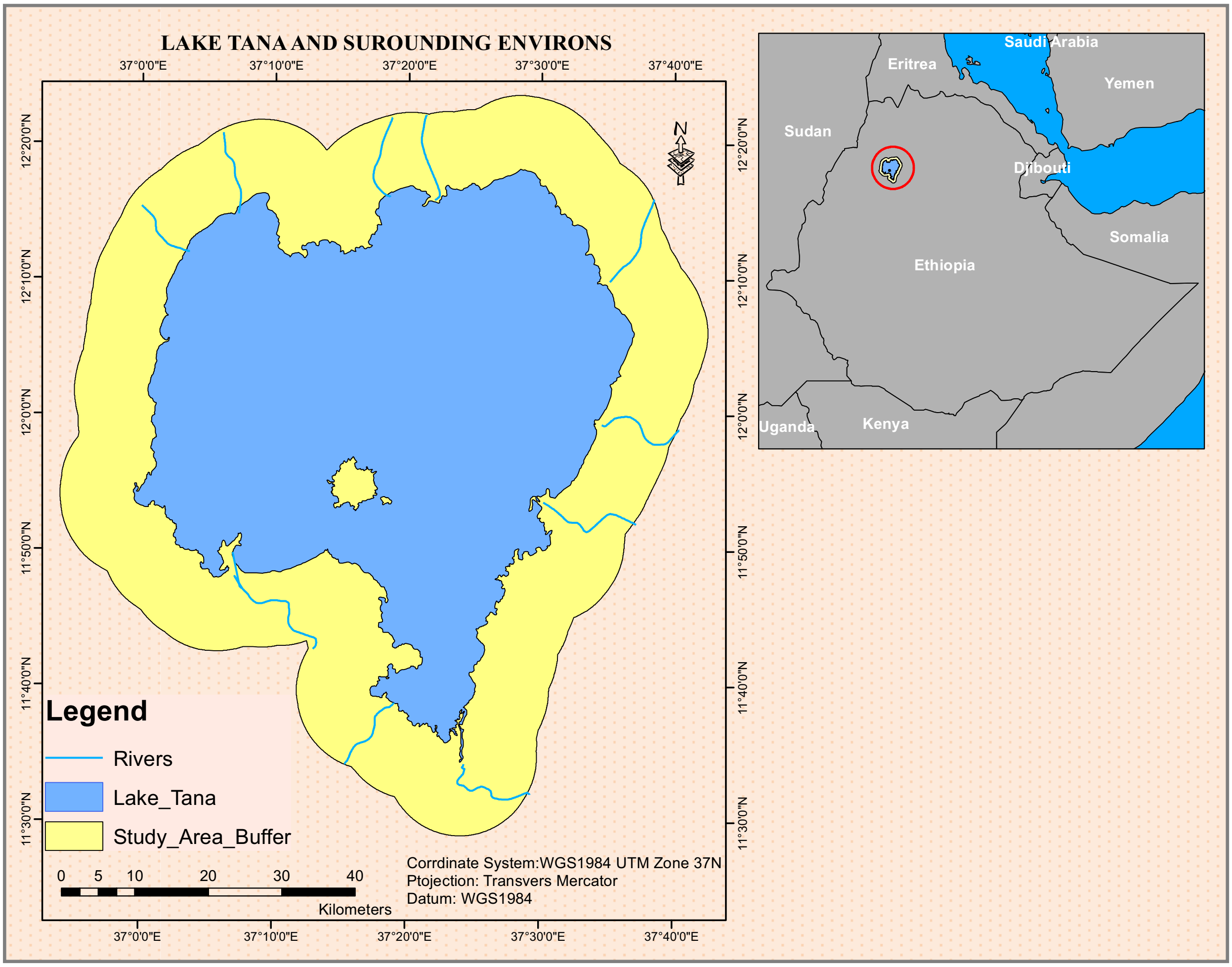

Fig. 1 Location map of the study area

Table 1 Major Data types and their sources

Data type	Data sources	Resolution	Access date
Satellite image (SPOT)	Amhara Design Supervision and Works Enterprise	5 m	February/2006E.C
Digital elevation model (DEM) of Lake Tana and its environs	Ethiopian Mapping Agency (EMA) (2012)	Resampled into 20 m	04/2006E.C
Field survey data	Ground survey with global positioning system (GPS)	±2 m error	October 15–18/2006E.C, November 30-Dec 15/2006E.C, February 1–5/2006E.C, and March 10–14/2006 E.C
Bathymetric data	Amhara National Regional State, Bureau of Industry and Urban Development (ANRS BoIUD) 2012		January, 2006E.C

most influential to least influential based on the following formula:

$$Wj = \frac{\mathrm{n} - \mathrm{rj} + 1}{\sum(\mathrm{n} - \mathrm{rk} + 1)}$$

where: *wj* is normalized weight for the jth criterion, *n* is the number of criteria under consideration (k = 1, 2, 3…….n). *rj* is the rank position of the criterion.

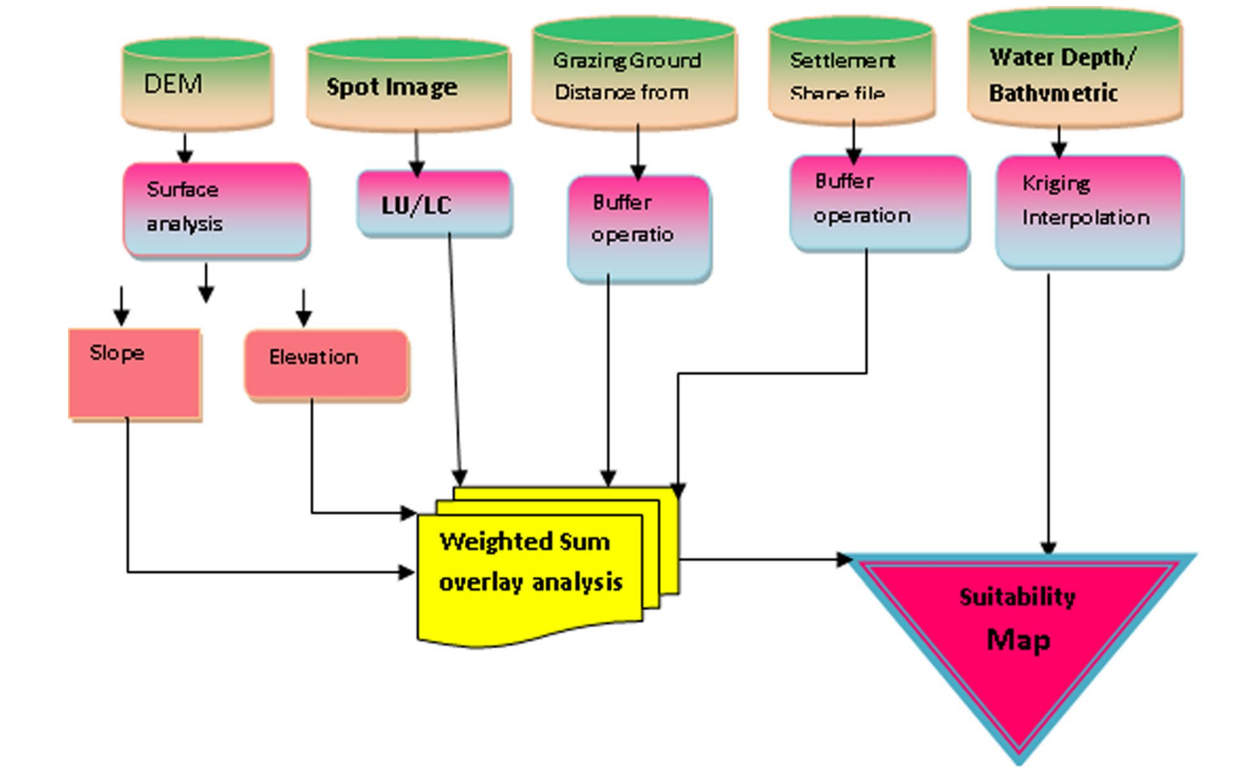

Fig. 2 Schematic frameworks for habitat suitability analysis model

Each criterion is weighted ($n - rj + 1$) and then normalized by the sum of all weights, that is Σ ($n - rk + 1$) (Malczewski 1999; Drobne and Lisec 2009).

Using this straight ranking method, each rank was converted to a weight; the higher the weight the more the important the criterion. Then the weights were summed. The sum of the criteria is 1.

Weighted linear combination

Weighted linear combination is based on the concept of a weighted average in which continuous criteria are standardized to a common numeric range, and then combined by means of a weighted average. The total score for each factor is obtained by multiplying the weight assigned to each attribute by the scaled value given for that attribute and then summing the products over all attributes (Drobne and Lisec 2009). According to Drobne and Lisec (2009) with the weighted linear combination, factors are combined by applying a weight to each followed by a summation of the results to yield a suitability map:

$$S = \sum w_i x_i$$

where, S is suitability, w_i is weight of factor i, and x_i is the criterion score of factor I (Drobne and Lisec 2009).

Results and discussion

Water depth suitability

By using GIS software, the bathymetric data was reclassified into three suitability classes based on the literature evidences. From Fig. 3 much of the lake are not suitable for hippopotamus due to its depth. The animal prefers to live in the gently sloping shallow water which is with grazing grass at the shore. This is because of the fact that Hippopotamus requires aquatic ecosystems known as their "daily living space" where they spend most of their time, and forage pasture ashore (Eltringham 1999). Most of the time, they occupy the periphery of the Lake. As a result, 71.3% of the lake areas are not suitable while only 22.34 and 6.36% of the lake area are highly suitable and moderately suitable respectively.

Elevation suitability

The digital elevation model shows an elevation ranging from very low altitude of 1646 to 2394 m above sea level. The study conducted by Eltringham (2003) cited in UNEP-WCMC (2010) showed this species is abundant between altitudes of 200 and 2000 m in Ethiopia. As the other literature evidence and the researcher's estimation from field observation, the upper altitude limit was to be approximately 2000 m (Rebecca 2008). So that based on

Table 2 Suitability classes for each criteria/factor

Criteria	Suitability classes			Sources
	Highly suitable	Moderately suitable	Not suitable	
Water depth	1.5–2 m	2–3 m	>3 m	Tracy (1996)
Elevation of lakeshore	1634–1900 m	1900.1–2000 m	>2000 m	Eltringham (2003), cited in UNEP-WCMC (2010); field survey
Slope of lakeshore	2°	2–7°	>7°	Holmes (1996), cited in Dietz et al. (2000); Field survey
Settlement and livestock disturbance of lakeshore	5.5 km = less or no disturbance	3 km = Moderately disturbed	0.5 km = Highly disturbed	Wengström (2009)
Grazing land proximity to the lake	2–5 km	5–10 km	>10	Tracy (1996)
Land use land cover of lakeshore	Short grass (*Echinochloa* species/hippo grass)+wetlands		Dense forests, bush lands, cultivated and settlements	(Mackie 1976; Lock 1972 cited in Kanga et al. 2011; Pienaar et al. 1966; IUCN 1993; Eltringham 1999)

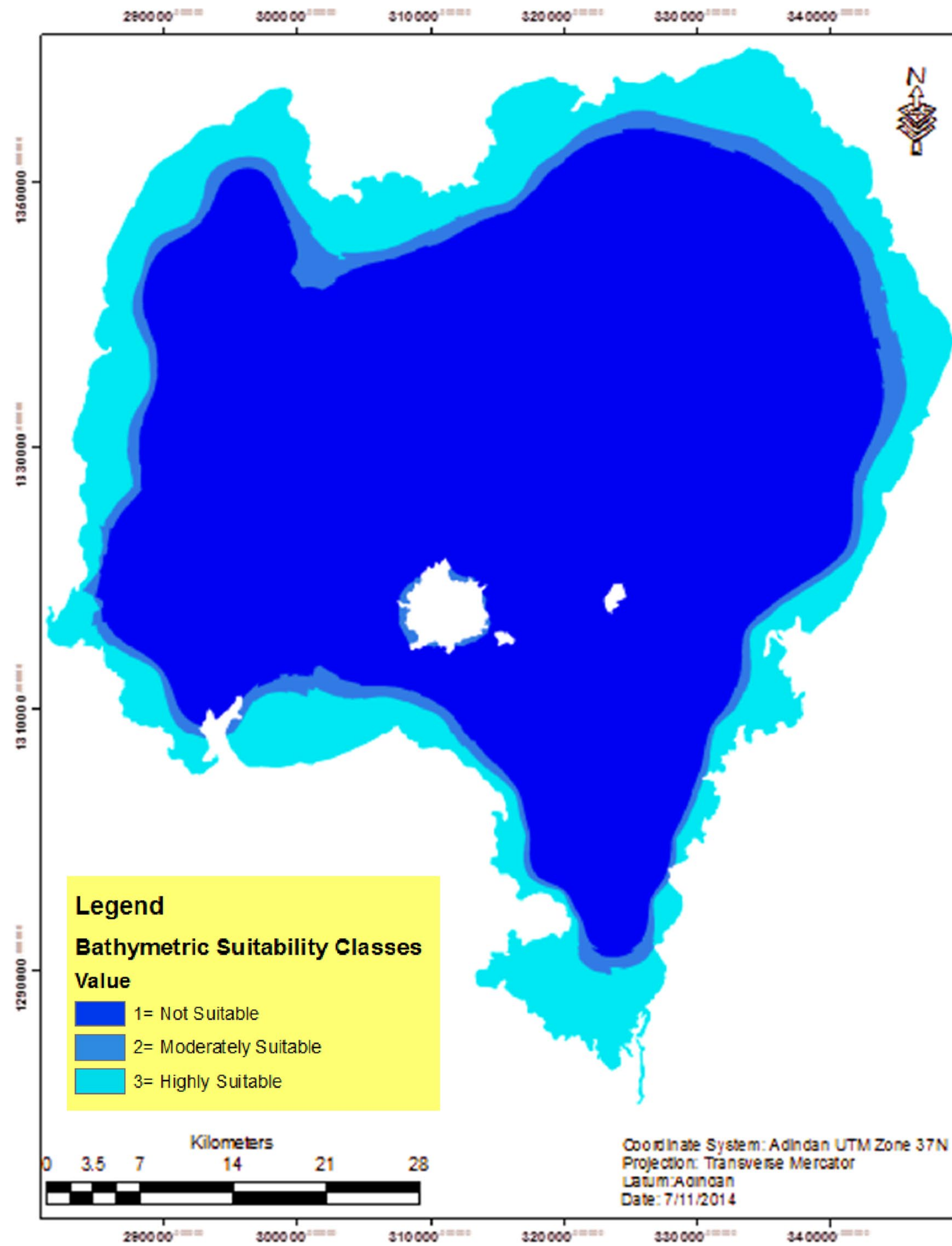

Fig. 3 Lake depth suitability classes of Lake Tana

these evidences the elevation classes between 1646 and 1900 m; 1900.1 m and 2000 m and more than 2000 m above mean sea level were identified as more suitable, moderately suitable and not suitable respectively. Thus by using raster reclass tool, the reclassification analysis was computed for elevation suitability classes. The GIS spatial analysis result shows that, most of the study area's elevation was fall under the suitable class for the species understudy. As can be seen from Fig. 4, 81.85% of the lakeshore was under suitable elevation classes for this mammal, only 11.9% of the area and the unsuitable elevation class covers the least (6.2%).

Lake shore slope suitability

The slope class which help hippopotamus movement to the land was identified based on literature and field observation. As a result the lakeshore gradient less than

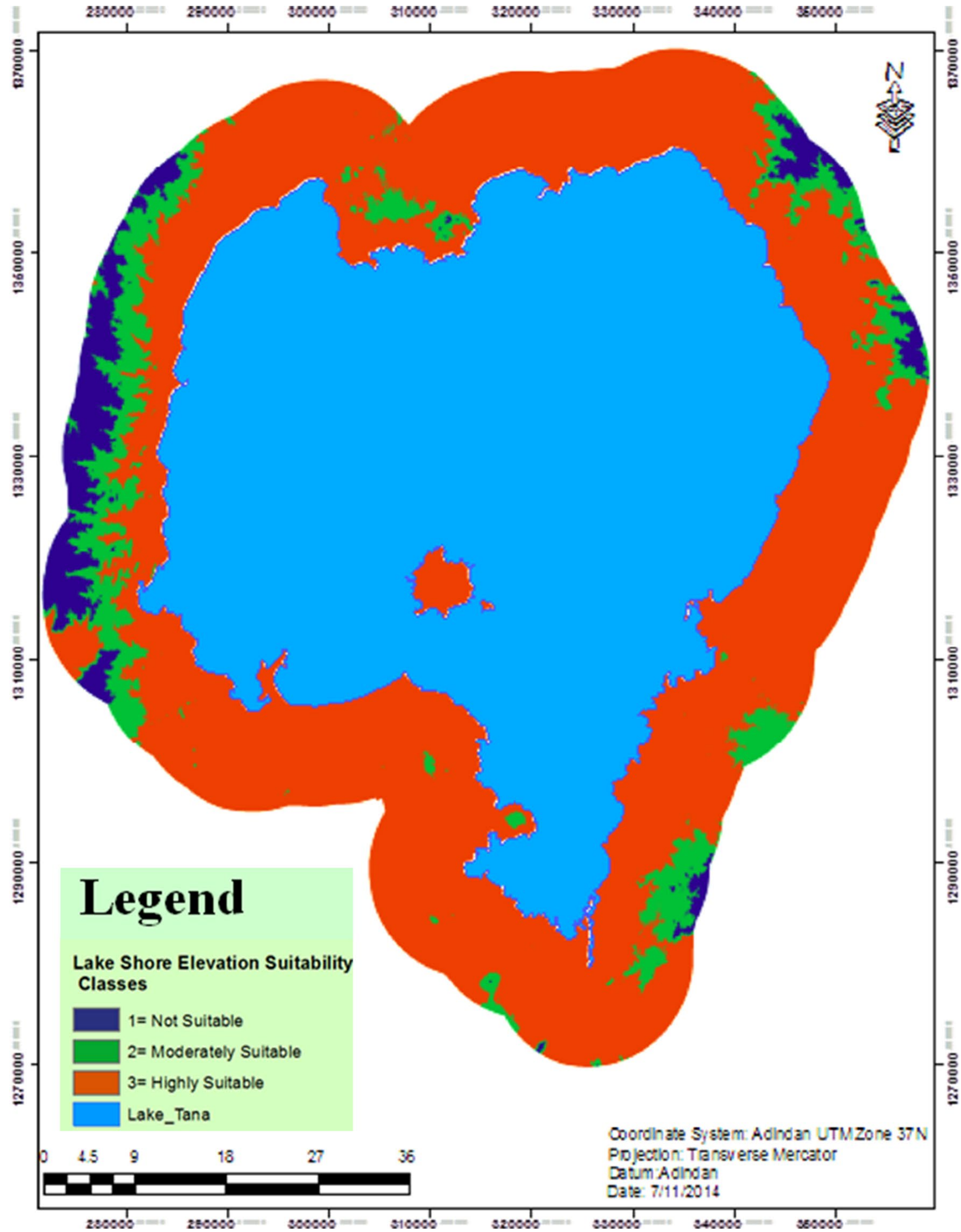

Fig. 4 Elevations suitability classes of Lake Shore

7° was identified suitable grazing ground for this animal. According to Holmes (1996), cited in Dietz et al. (2000) sites with a high slope can cause inaccessibility problems due to morphology and body size of the specious understudy. However, very shallow and gentle Lake Shore is frequently disturbed by domestic animals and human activities like irrigation and rice cultivation in the study area. The suitable slope values were those

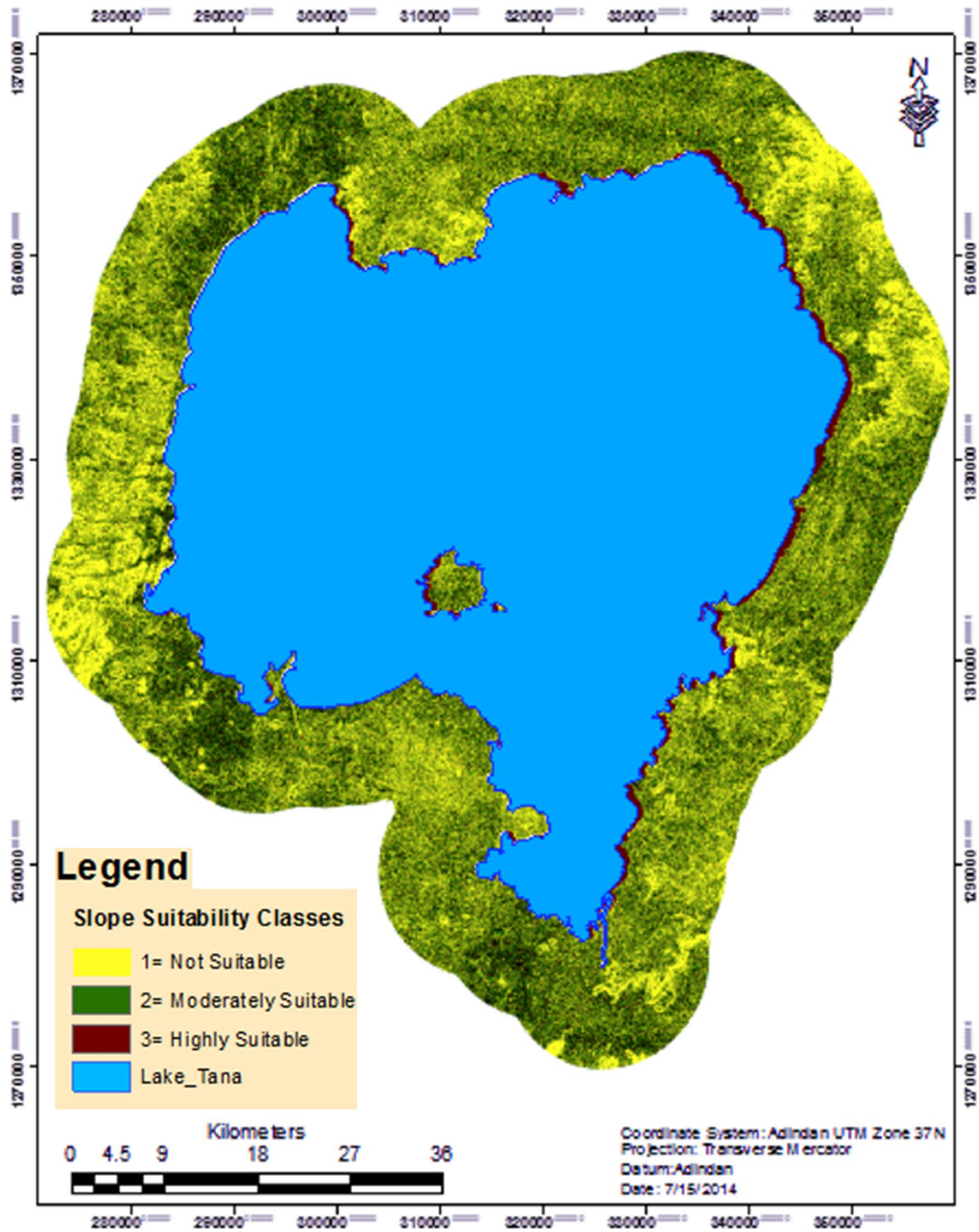

Fig. 5 Slopes suitability classes

that represent conducive travel for the species, since it could not raise high gradients due to its body size and structure.

Figure 5 depicted the slope suitability classes of the lakeshore. By slope criteria all the Lake area became suitable. However, when the terrestrial environs accessibility

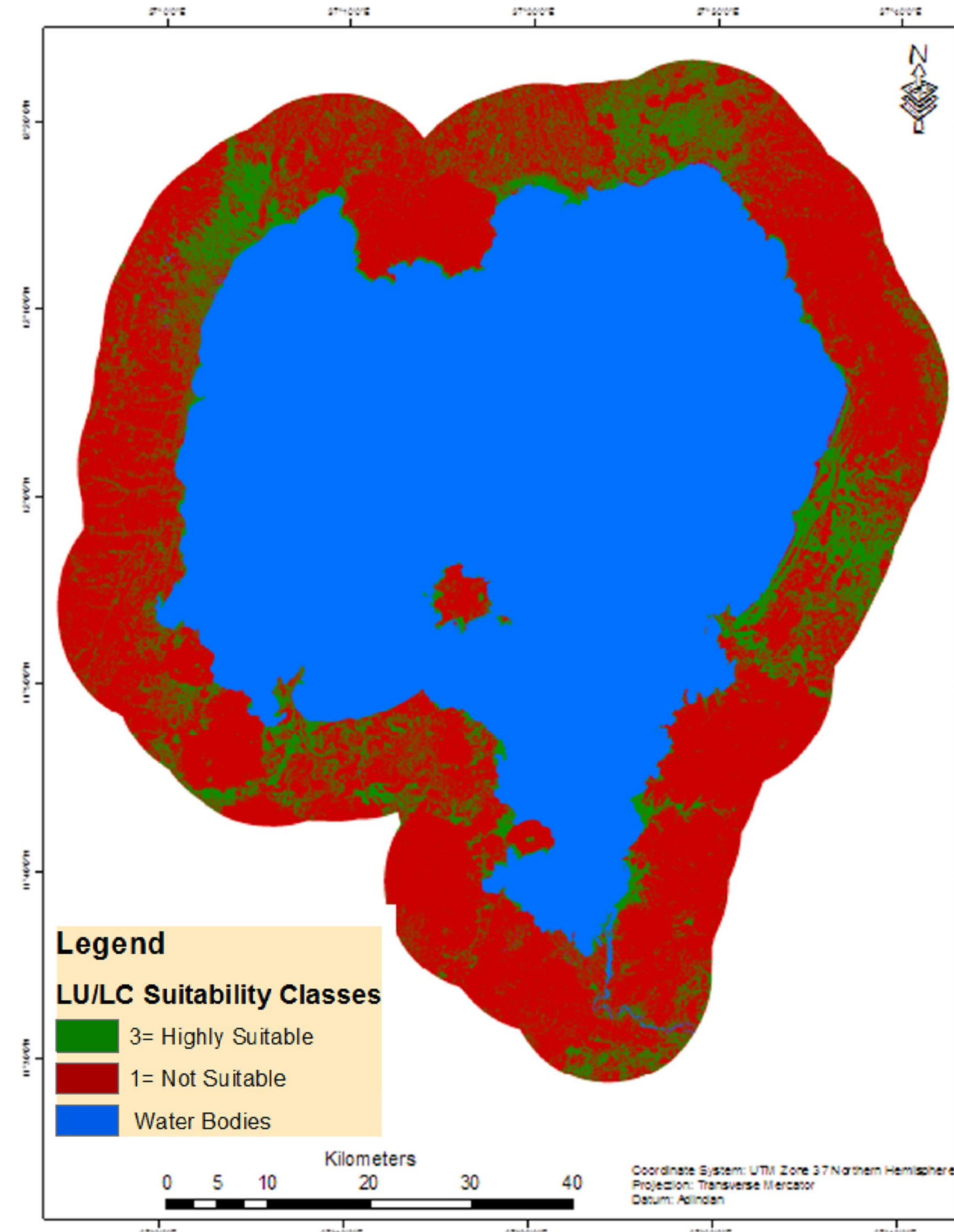

Fig. 6 Land use/land cover suitability classes

within estimated buffer zone was considered, the suitable area was very low. Thus the figure shows from the Lake shore only 6.97% as highly suitable, moderately suitable 47.2% while the remaining 45.83% is not suitable (the slope classes that could not be climbed by the hippopotamus).

Land use/land cover suitability

In order to generate the present land use/land covers status, SPOT image with spatial resolution of 5 m pixel size was processed using ERDAS Imagine version 2010 software. By using ground control points (GCP) collected by GPS in the field, land use/land covers classification

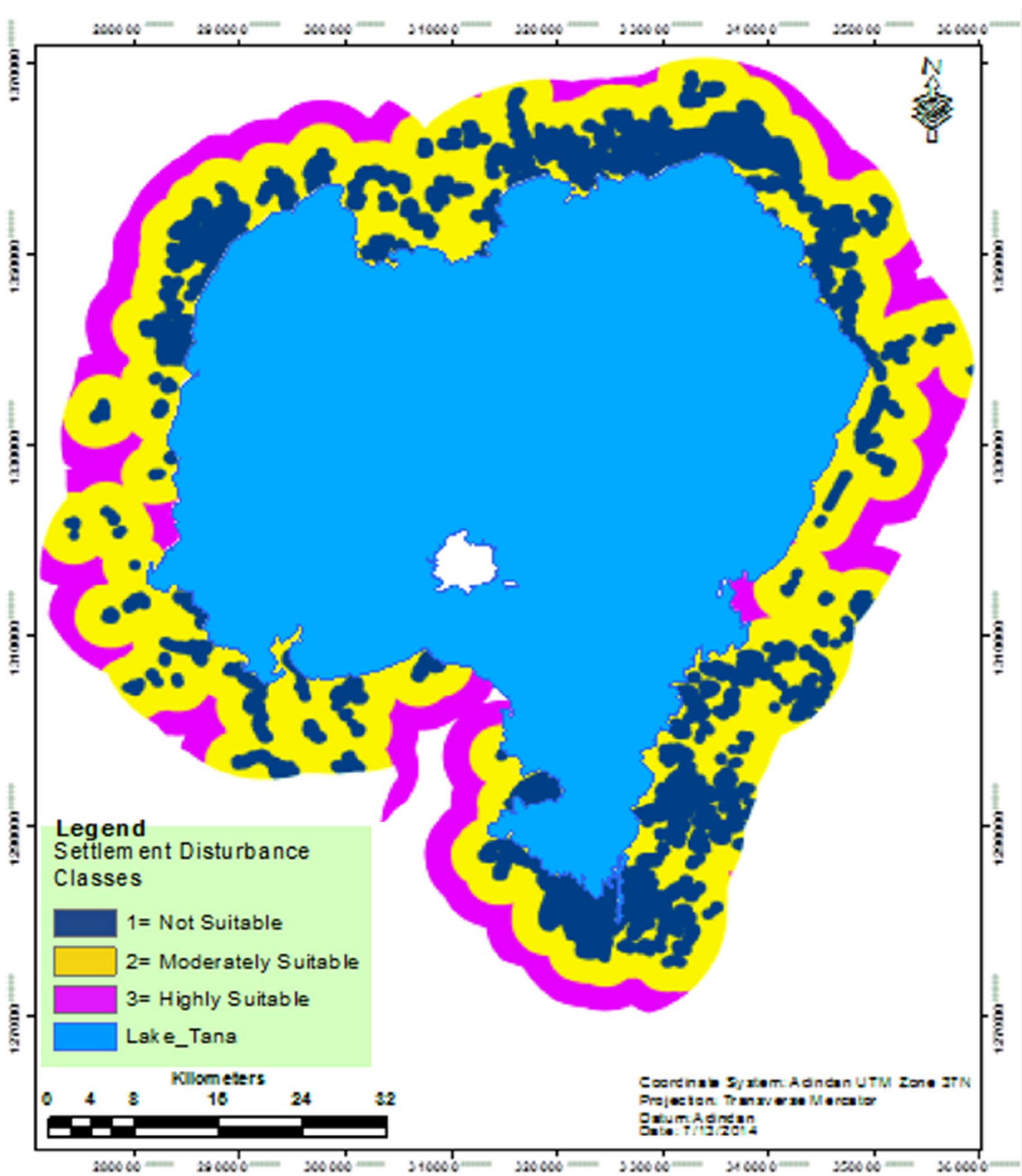

Fig. 7 Settlements and livestock disturbance on hippopotamus habita

was performed. Supervised classification was done using the maximum likelihood algorithm for 3 spectral bands corresponding to green, red and near infrared. During field visit settlements and cultivation were found highly mixed, while image classification was conducted, they were merged together. The land use/land covers map of the Lakeshore was reclassified on the basis of suitability/compatibility to hippopotamus living and feeding

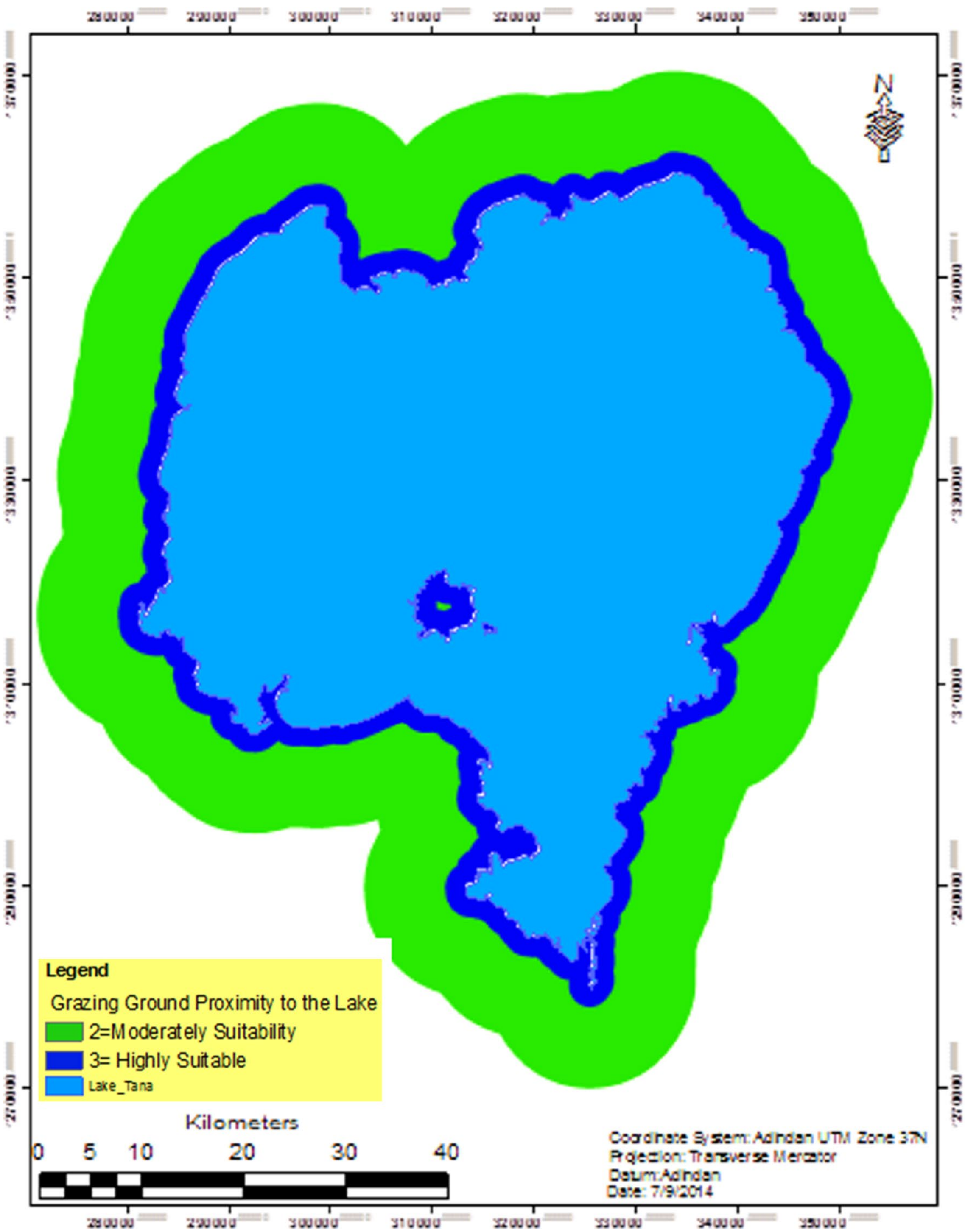

Fig. 8 Hippopotamus grazing ground proximity classes to the lake

ground. As a result, human development (cultivated and settlement) and forested banks were identified to be unsuitable (IUCN 1993), while wetlands and grasslands were classed as suitable. The classification for land use/land covers indicated that the area occupied with human action accounts about 45.26% of the total area within the study area. And is followed by bushland (27.42%) which is unsuitable for hippopotamus grazing which might be most probably converted by human over utilization of the land for long years. The remaining land use/land covers grassland, wetland and forests account about 20.77, 3.73 and 2.84% respectively. Most of grasslands near the Lake were dominantly communal (domestic animal grazing) grounds which were frequently grazed and highly disturbed due to competition over limited resources.

To evaluate habitat suitability based on land use/land covers criteria; the Lake was seen as restriction. This was because not all parts of the lake were suitable and also it was difficult to have the common criteria for aquatic and terrestrial environment. From the total estimated area of hippopotamus habitat including the Lake Tana, only 21.23% was identified as highly suitable. More over the areas depicted as suitable are not easily accessible due to their location. Most of the suitable areas from Fig. 6 were located behind settlements. On the other hand 78.77% of the lakeshore was not suitable for hippopotamus grazing due to either human interferences or natural barriers.

Settlements Proximity to hippopotamus resting and grazing area

In addition to cultivation of hippopotamus grazing land and competition with domestic animals on the same area, permanent settlements have a great disturbance on its habitat. As the field visit confirm that, people living very close to the Lake made different types of barriers to prevent the passing of these animals to their gardens. Manmade obstacles that threaten this animal's life were the holes dug for this purpose and stone hedge. People knew that due to its body size and short leg it could not pass such barriers. From settlements multiple rings buffering at specified distance around the input feature was computed as follows:

Figure 7 depicted the presence of high human and livestock disturbance on hippopotamus habitat in Lake Tana Environs. From the estimated terrestrial habitat only 1.81% of the land area was safe from human interference whereas 50.88% of the land was highly disturbed for hippopotamus survival in the study area. On the other hand 47.29% of the area was moderately disturbed.

Grazing ground proximity to the lake

In search of food individual hippopotamus is estimated to commute every night from 2 to 7 km from the river or lake in which they spent the day. However, during condition when food is not easily obtained the distance they move may increase up to 10 km (Eltringham 1999; Muller and Erasmus 1992; Tracy 1996). Hence grazing ground suitability on the basis of proximity to resting water was classified and reclassified using multiple rings buffer analysis on Arc GIS 10.2.

As the multiple rings buffer analysis depicted (Fig. 8) that the most suitable area for nocturnal grazing for hippopotamus is preferred to be close to resting water. Therefore, by keeping other factors constant and taking the capability of hippopotamus to move and forage, only 22% of estimated area was classed as highly suitable and 78% area was moderately suitable. Beyond the maximum distance that hippopotamus cannot move was not included in suitability classification.

Weight assignment for thematic maps

In multi criteria evaluation of various factors for habitat suitability, estimating weights by ranking method was taken into consideration to find optimal location for hippopotamus in the Lake Tana and its environs. The criterion was first ranked based on the influence of each factor relative to other factors (Table 3).

From the above table, weightage indicates the most influential factor that threatens the existence of the species understudy by reducing its habitat. Accordingly the higher the weightage the higher its relative influence

Table 3 Weight assignments for thematic maps

Thematic maps/criteria	Measure	Straight rank	Weight (n-rj + 1)	Normalized weight	Percentage influence %
Land use/land cove	Types of LU/LC	1	5	0.333	33.3
Slope	Degree of slope	2	4	0.266	26.7
Settlement disturbance	Proximity in km	3	3	0.20	20
Grazing distance from resting water	Proximity to the lake in km	4	2	0.133	13.3
Elevation	From mean sea level (m)	5	1	0.067	6.7

Expert's and Researcher judgment (2014)

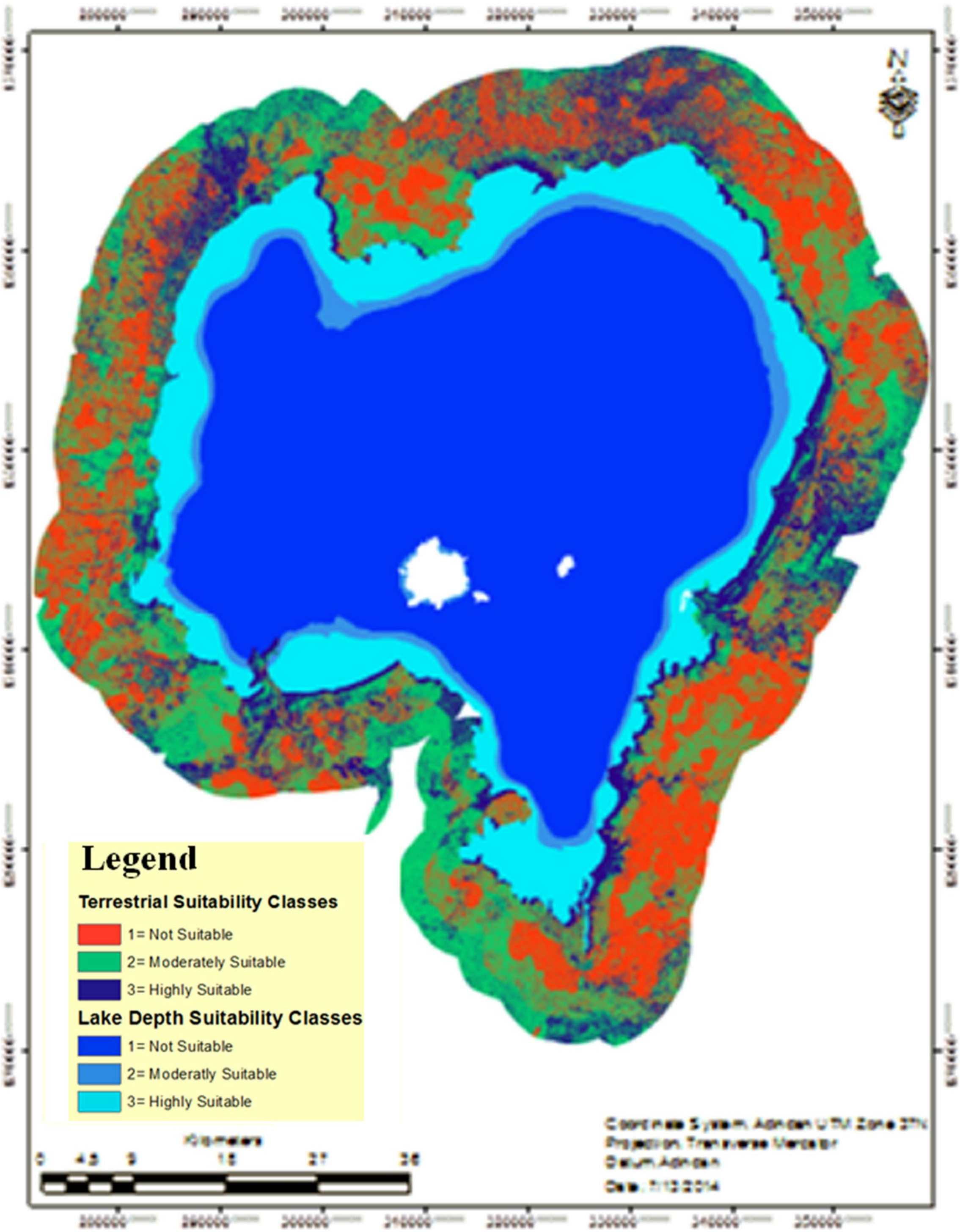

Fig. 9 Model result for hippopotamus habitat around and in Lake Tana

than others. Among the overlay method Weighted Sum tool was chosen for suitability modeling due to the fact that it provides the ability to weight and combine multiple inputs to create an integrated analysis on Arc GIS 10 soft ware. The resulting cell values were added to produce the final raster model output. To this end, higher values generally indicate that a location is more suitable whereas lower values imply least suitable location.

Weighted overlay analysis

Reclassification and weighting the factors were followed by running the overlay analysis/weighted sum for terrestrial factors. By this spatial analysis, suitable sites for hippopotamus were identified in Lake Tana environs. On the other hand the aquatic habitat was analyzed separately because of the terrestrial and aquatic environments are adjacent each other. The animal prefer the aquatic environment which has grazing ground adjacent to resting water to reduce long distance travel.

As we can see from the Fig. 9, it seems there was large area suitable for hippopotamus habitat. For instance 22.54% of the study area was suitable based on used variables analyses. However, the animals could not cross settlement areas. As a result much of the areas were inaccessible. Whereas 40.5% of the study area was moderately suitable that can made more suitable if conservation strategy is designed by the government and the community. On the other hand the analysis result showed that 36.96% of the Lake Tana environs were not suitable for hippopotamus habitat.

Conclusion

This study attempted to find out suitable sites for hippopotamus in Lake Tana and its environs by integrating MCDM with GIS and RS techniques. The analysis of each factor based on suitability class shows varied outputs and varied land size. In the study area high interferences of human activity in hippopotamus habitats takes the lion's share in making the areas unsuitable.

To this end the land use/land cover classification indicated that the area occupied with human action (settlement, cultivation) accounts about 45.26% of the total area within the study area. However, as the analysis output ilustrated the sphere of influence of settlement was beyond the area occupied by it and was followed by bushland (27.42%) which was unsuitable for hippopotamus grazing. Due to too much proximity, these animals may begin to make threats on human life and crops as its territories are disturbed continually. Therefore, too much proximity of human settlements to such mammal's habitat has to be protected by local planning and rational management of the population is desirable. The remaining area (20.77, 3.73 and 2.84%) of the Lakeshore is covered by grassland, wetland and forests respectively. Like that of bushes, forest would not be included in the diets of hippopotamus.

In general, settlement with livestock disturbance alone has made 50.88% of the areas under study highly unsuitable, 47.290% of the area fairly/moderately suitable and only 1.81% of the areas were with no disturbance/suitable. During habitat suitability modeling, physical and human factors were considered based on literature evidences and field observation. The overlay analysis/model results reveal that only 22.54.59% of the land areas under study were identified as most suitable for the species. From the model output, among the suitable areas, large portion were located at the backside of settlements which were not easily accessible by the species, while 40.5% were found to be moderately suitable for hippopotamus habitat and 36.96% were unsuitable lands.

As the study shows the habitat of hippopotamus in Lake Tana and its environs were highly reduced due to mainly human factors; much more emphasis should be placed on preserving of this vulnerable species in the study area. Moreover, there should be legal enforcements to protect hippopotamus habitats in the study area to insure its sustainable conservation.

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Competing interests

The author declares that this thesis is my original work and no anybody could claim for competing interest. In addition, all the sources of materials used for the thesis have been duly acknowledged.

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