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Larus relictus HABITAT HIERARCHICAL EVALUATION BASED ON A DATA DRIVEN APPROACH

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Abstract

The application of Species Distribution Models (SDM) in the management of species habitat and environmental impact changes has been widely used by scientists and ecologists globally, however this study proposes a novel analytical technique involving the combination of a statistical ranking algorithm and Remote sensing GIS data (habitat and threat) to analyze the suitability hierarchy of the habitat of a signature water-bird (*Larus relictus*). The results indicate that about 47.63% of the study region was suitable to accommodate *L. Relictus* during their breeding/resting season, while 27.08% proved to be highly unsuitable for this species. Based on the spatial distribution of the statistical data already incorporated into the GIS environment, it was observed that regions surrounding the Bojiang Lake (especially polygons 38 and 42) dominated by low vegetation and increased amount of moisture proved to be the best region for this species. On the contrary, polygon 23, located in the southern part of the study region proved to be the worst region for this species being dominated by significantly high amount of threat factors having the highest mean normalized hierarchical value and ranking 60th out of 61 in terms of standard deviation. To distinctively capture different suitability level of the study region, we could say that the application of this technique is quite effective and beneficial. This is because, compared to other decision making tools, this technique which solely relies on remote sensing and vector data gives decision makers an option of weight application if so desired.

Key words: GIS, habitat suitability, RNK algorithm, remote sensing, vector; water-birds

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1. Introduction

In recent decades, the ecological function of species habitat has been facing increasing problems such as habitat alternation, loss and fragmentation induced by pollutions, land use alteration from increased anthropogenic activities and so on (Dong et al., 2013; Lee et al., 2010; Jacquin et al., 2005; Rönkä et al., 2008). This loss in habitat is a major contributing factor for the decrement in water-bird population experienced globally, hence putting the health and integrity of this species in severe jeopardy (Debeljak et al., 2001). This is what makes having a good knowledge of water-bird's habitat quite significant to support an effective protection of this species. Several methods have been applied to assess the suitability of species habitat, the popular approach is the Habitat Suitability Model (HSM) (Dong et al., 2013; Gillenwater et al., 2006; Hirzel and Guisan, 2002; Hirzel et al., 2001; Na et al., 2018; Ouyang et al., 2011). These models determine different environmental factors such as terrain morphology, land cover, topography, meteorological conditions and distribution of human activities, having a significant

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effect on the presence, population and distributions of different species hence producing a potentially suitable habitat of a specie in a territory (Brotons et al., 2004; Jiang et al., 2009; Wang et al., 2009).

HSM developed for data where species absence aren't recorded (presence only data) analyzes the species locations environmental conditions, generating a statistical model to describe and analyze the environmental requirements and the species habitat suitability of the region (Baldwin, 2009; Duflot et al., 2018; Elith et al., 2011; Phillips et al., 2006; Tarabon et al., 2019). The resulting habitat suitability map could be used for several purposes such as landscape planning, identification of priority conservation area and reintroduction sites and so on (Baldwin, 2009; Thorn et al., 2009). There is a strong interconnection between species richness and its distribution with the suitability of a site/habitat.

Habitat suitability is widely known to assess the possibility of a certain location to accommodate a given species over a spectrum of environmental conditions. Several studies have focused on SDM calibration for common birds (Dong et al., 2013; Jiang et al., 2009; Vallecillo et al., 2016; Wang et al., 2009), on the same scope, efforts has been made recently to strengthen the utility of models combining habitat suitability and potential threats to assess habitat quality (HQ) as a support system for conservation planning (Di Febbraro et al., 2018). With most researches focusing on the application of this Multi Criteria Decision Analysis (MCDA) and Species Distribution Model (SDM) to analyze the suitability of a species habitat, few researches have been done to statistically analyze the suitability Hierarchy of the habitats. Several studies have employed different types of site-specific decision-making algorithms based on expert opinions (HSM and HQ).

This study however proposes a novel statistical ranking algorithm technique initiated by Richter et al., (2019) to analyze the hierarchy of an already existing water-bird (*L. relictus*) habitat site in Erdos *Larus relictus* National Nature Reserve (ELRNNR). This novel approach is proposed using GIS to incorporate RS habitat raster comprising of HSM, HQ and habitat Moisture Content (NDWI) and Vector data comprising of the species threat factors. This will be followed by the application of a ranking algorithm to provide a systematic assessment of the specie's habitat conditions. Choosing a suitable breeding site is subject to both physical and environmental constraints the site must be close to a lake or a moist region for food and low to sparse vegetated regions for possible breeding. The site must be located where potential negative environmental and anthropogenic impact are minimized.

We intend to use this study to address the relationship between the eco-environmental conditions with the breeding conditions of the water-birds. The benefit of our approach is that it provides decision makers or a conservationist framework to assist them in investigating locations appropriate for species breeding and protection during breeding seasons.

The objective of this study are: (1) Create the remote sensing habitat maps comprising of the HSM, HQ and NDWI (moisture content) and threat vector data extraction comprising of (dense vegetation, the transport network and the developed areas), (2) Combine RS and vector data in a GIS environment to assess the suitability of breeding sites and their area of influence as defined by ordinary Thiessen polygons, (3) Hierarchically analyze the suitability of the breeding site using mean and standard deviation of both the habitat and threat data (RS and Vectors respectively) within the Thiessen polygons, (4) Map, analyze and interpret the hierarchical level of each locations.

2. Materials and method

2.1. Study area

The study area for this research is Bojiang Lake Basin, situated inside the basin is ELRNNR located in Dongsheng District of Erdos City, Inner Mongolia Autonomous region in China. This region lies on the edge of Kubuqi and Maowusu desert with a geographic coordinate of longitude 109º 14′ - 109º 23′ E and latitude 39º 25′ - 34º 00′ N (Fig. 1). With an elevation ranging from 1367 to 1412m, the basic weather condition of this region consist of an annual average temperature, evaporation and precipitation of approximately 5.2ºC, 2501 mm and 325.8 mm respectively(Li et al. 2019). With more than half of the precipitation experienced between July and August in the basin, the primary vegetation type of this region comprises of shrubs and grassland (Yan et al., 2018). A wide variety of animals found in this region includes water-birds, grassland mammals, and reptiles. Amongst them are 83 species of birds, with *L. relictus* being the dominant species of this region and its breeding season is considerably larger than other birds in the region.

2.1. Target area selection

In this study, we randomly selected 61 target areas for this species using the ArcMap 10.2 Create Random Point tool which was the major parameter used in the creation of Delaunay triangulation Thiessen polygon grid used. Thiessen polygon are polygons created based on the topological relationship between points X and Y in a two-dimensional space (Mu, 2009; Richter et al., 2019). In (Eq. 1), we Mathematically assumed P to be the infinite set points in the Euclidean plane, $P=\{p_1, \ldots, p_n\}$ where $2 \le n \le \infty$ Making x to be any location in the plane, the Euclidean distance between x and pi is $d_e(x, p_i)$. Let $T(p_i)$ denote the thiessen polygon of p_i, then;

$$T(p_i) = \{x \mid d_e(x, p_i) \le d_e(x, p_i),\ for\ \ all\ \ j\ ,\ j \ne i\ \ and\ \ i, j \le n\} \tag{1}$$

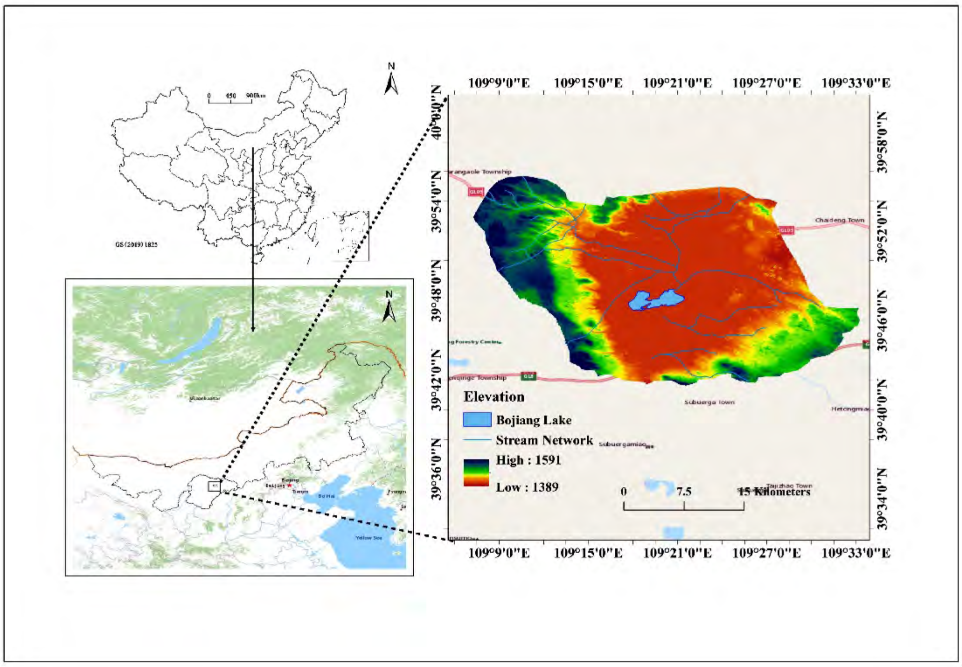


Fig. 1. Study region location

The application of thiessen polygon has been known to be quite effective in several aspects of waste management studies, (Khan et al. 2018; Richter et al., 2019) solutions to geographical issues, (Reitsma et al., 2007), hydro-analysis (Chen et al., 2014; Shen et al., 2012) and also for the evaluation of animal territory (Schlicht et al., 2014). For this study, we applied the Thiessen polygon to define the influenced area of this species around the study region. Each influenced area (polygons) in the regions were assigned an ID ranging from 0 to 60 (Fig. 2). Bojiang Lake wetland, the major breeding location for *Larus relictus* was situated at Polygon 36, 38 and 42. The remaining points represented other regions of the basin.

2.3. Data

Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) images, Digital Elevation Model (DEM) images and ancillary data were selected for this study (Table 1). The main ancillary data included road vector data, GPS location of the birds nesting positions collected from previous studies (Dongping et al., 2017; Yinsun et al., 1993) and the developed regions data.

2.4. Methods

As shown in the technical route in Fig. 3, we categorized this study into two to highlight the significance of habitat regionalization studies. These categories involved the Habitat assessment making use of the remote sensing and vector information in a GIS environment to assess the habitat in the study region which was then followed by the application of a statistical ranking analysis involving the application of a ranking function to categorize the state of the study region into multiple categories based on the suitability level of water-bird species in the region. Detailed route of the entire process in shown in Fig. 3a, b.

The next section explains the methods applied towards obtaining the remote sensing habitat information (NDWI, HSM, and HQ) and vector data (species threat data) used in this study and the zonal statistics and the ranking analysis. To get an easy result comparison, an equal interval choropleth mapping technique was applied. (Musse et al., 2018; Richter et al., 2019).

Table 1. Remote sensing data and sources

Data	***Source***
Landsat 8 OLI & TIRS images (<5% cloud)	United States Geological Survey (USGS) Earth Explorer (USGS, 2017)
DEM (30m resolution)	United States Geological Survey (USGS) Earth Explorer (USGS, 2014)
Slope	DEM
Land Cover Map (approximately 86% image accuracy)	Landsat 8 OLI & TIRS
NDVI & NDWI	Landsat 8 OLI & TIRS (Bands 4, 5 and 6 as shown in Eqs. (3-4)

2.4.1. Remote sensing indices and vector data acquisition

In this study, the remote sensing indices used were the ecological habitat raster (HSM, HQ and NDWI) (Fig. 4). The HSM (Fig. 4c) was used to predict the niche and distribution of species based on limited data, relating field observation to environmental predictor variables.

The variables used comprised of Land Use, DEM, Slope, NDVI (derived using Eq. 3 below), Water, Developed region, transport network and stream network. With water-birds widely known to strive better in a moist environment, the NDWI derived from (Eq. 4) below was used in this study to analyze the moisture content of the region.

$$NDVI = \frac{NIR\ (Band\ 5) - Red\ (Band\ 4)}{NIR\ (Band\ 5) + Red\ (Band\ 4)} \quad (2)$$

$$NDWI = \frac{NIR\ (Band\ 5) - SWIR\ (Band\ 6)}{NIR\ (Band\ 5) + SWIR\ (Band\ 6)} \quad (3)$$

where: *SWIR*, *NIR* and *R* are the reflectance in the near infrared and red bands.

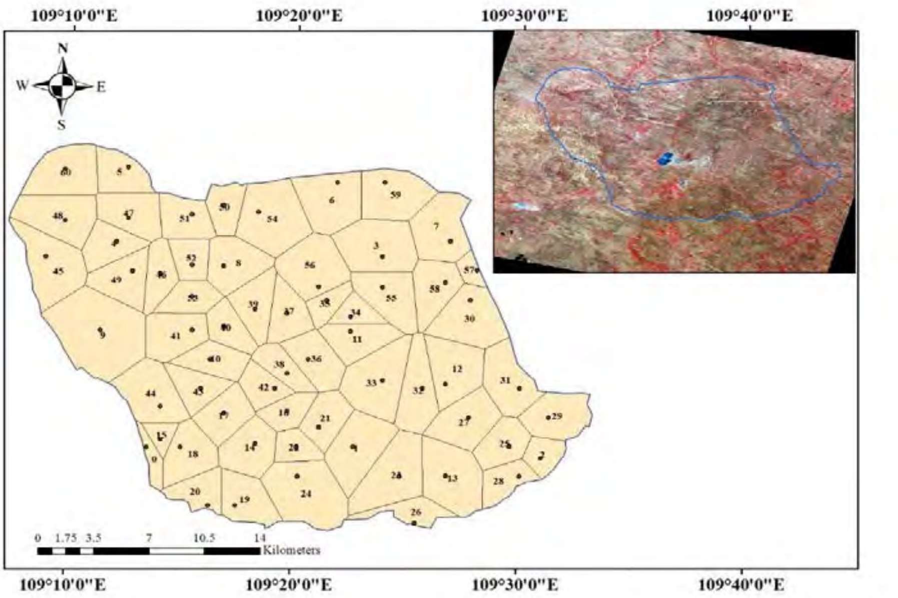
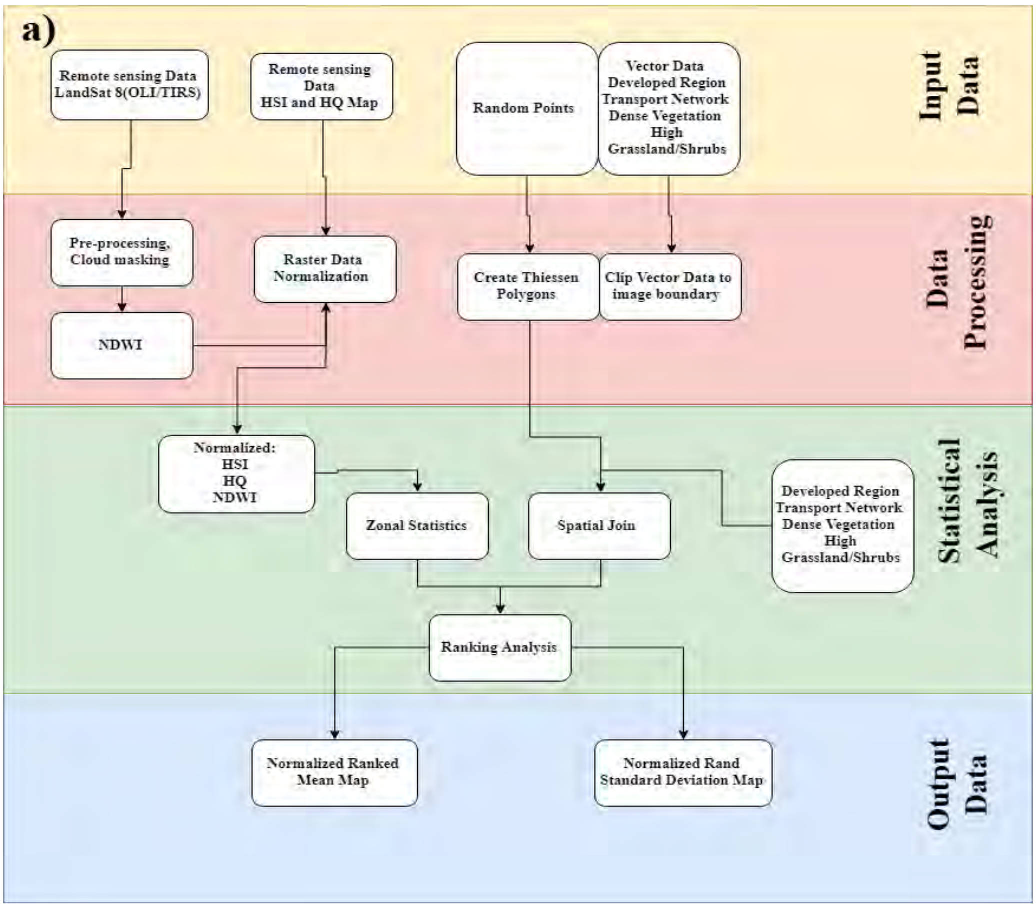


Fig. 1. Thiessen polygon of the study region



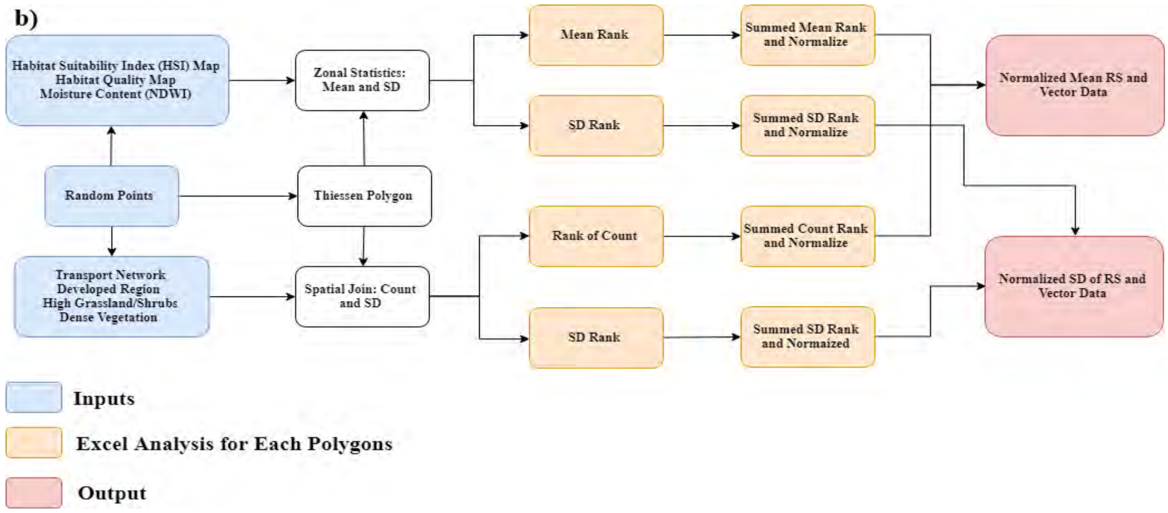


Fig. 2. Technical route of a) habitat assessment, b) statistical ranking route of habitat data (remote sensing) and the threat data (vector)

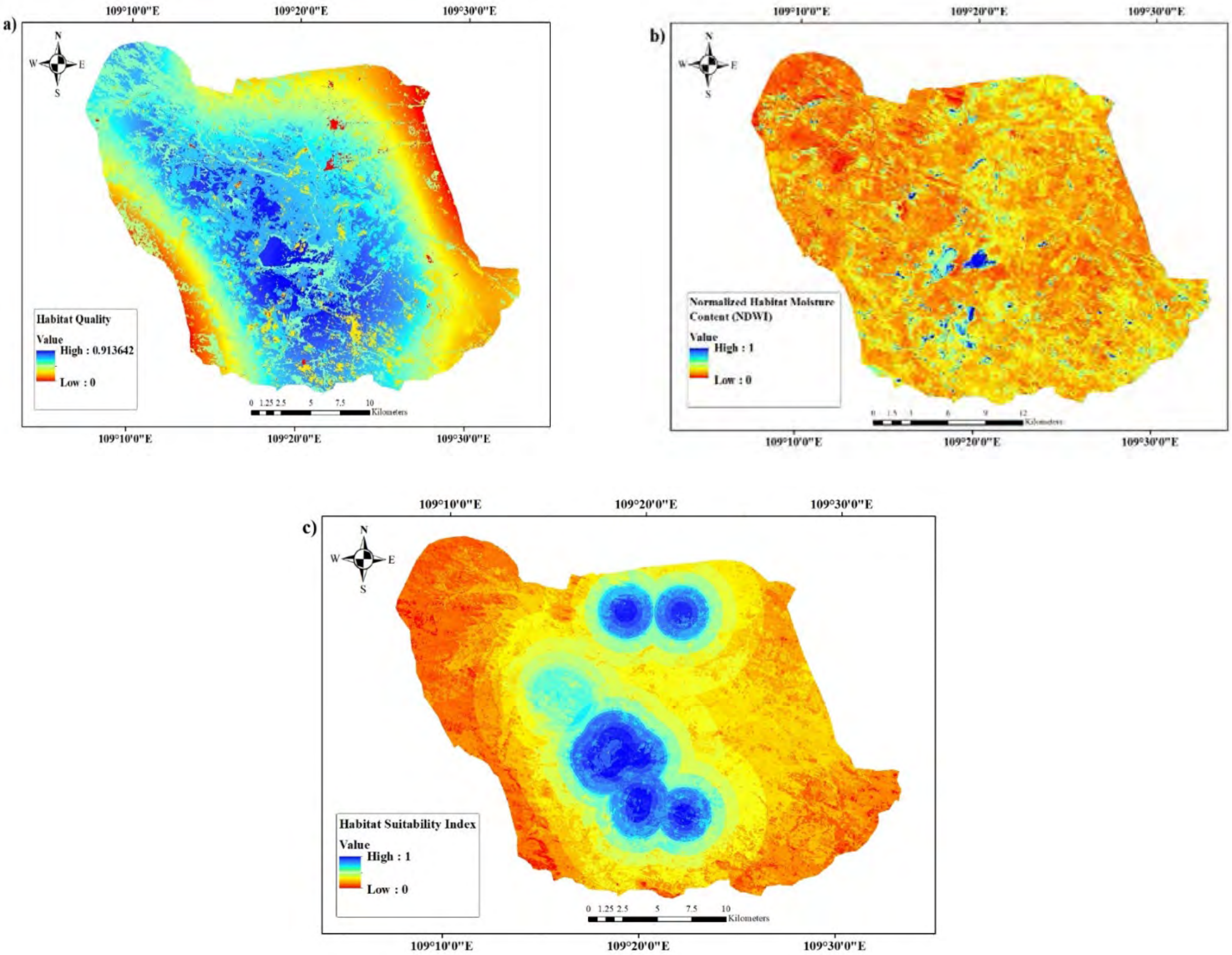


Fig. 3. Remote sensing habitat data: a) habitat quality, b) Habitat Moisture Content (NDWI), c) Habitat Suitability index (HSI)

The vector data used in this study comprises of the transport network, developed regions, both of which were derived from OSM and HR imagery.

With the increase in urbanization, the number of roads and buildings seems to have increased over the past decades and this has posed an enormous threat on the living situation of water-birds in the study region.

2.4.2. Habitat suitability analysis approach

In this study, GIS was employed to analyze and assess water-bird habitat suitability in ELRNNR at the

Bojiang Lake basin. The assessment unit were extracted from Landsat 8 OLI images acquired in the summer of 2017. By analyzing the relationships between water-birds with key habitat environmental factors, we selected indices such as the degree of disturbances, water situations, food availability and shelter conditions as the affecting factors for the species habitat. The weight for each factor was assigned based on references and by designing a questionnaire of the different parameters. The Analytical Hierarchy Process (AHP) was used afterwards to quantify the weights of the parameters. This way the key factors and the HSM for water-bird could be established. We incorporated 9 important environmental and biological variables based on the ecological requirement and natural history of *L. relictus* (Table 2) (Karanth, 2003) and based on previous research, values ranging from 0 to 100 were assigned to the 9 factors with high number indicating high suitability and lower numbers indicating otherwise (Li et al., 2007; Li et al., 2011; Li et al., 2013).

Table 2. Relict gulls priority area habitat suitability model parameters

Variables	*Names*	*Assigned Value*	*Assigned Weight*
Land Cover	Dense Vegetation	0	0.065
	High Grassland/Shrubs	20	
	Low Grassland	80	
	Sparse Vegetation	100	
	Barren Soil	60	
	Built Up	0	
	Wet Soil	100	
	Water	100	
Vegetation Cover	<0	0	0.054
	0-0.1	100	
	0.1-0.2	80	
	0.2-0.4	60	
	0.4-0.5	40	
	>0.5	20	
Elevation	<1000	100	0.10
	1000-1200	80	
	1200-1300	60	
	1300-1400	40	
	>1400	0	
Slope	0-5%	100	0.09
	5-10%	80	
	10-15%	60	
	15-20%	40	
	20-30%	20	
	>30%	0	
Transport network (Road and rail)	1km from the road	0	0.014
	3km from the road	20	
	5km from the road	60	
	7km from road	80	
	more than 7km from buildings	100	
Developed Region	1km from buildings	0	0.015
	3km from the buildings	20	
	5km from the buildings	60	
	7km from buildings	80	
	more than 7km from buildings	100	
Water	less than 800m from water	100	0.22
	800 to 1200 from water	80	
	1200 to 2km from water	40	
	more than 2km from water	0	
Habitat	0	0	0.21
	1 to 20	20	
	21-40	40	
	41-60	60	
	61-80	80	
	80-100	100	
	0- to 500	100	0.24
Core	500 to 1km	80	
	1km to 2km	60	
	2km to 3km	20	
	more than 3km	0	

2.4.3. Habitat quality assessment

To assess the ecological habitat quality of the water-birds in the study region, the InVEST Habitat Quality Module V3.4.2 was employed (Sharp et al., 2011). Based on the information on ecosystem types and anthropogenic disturbance factors generated from land use images, this technique was used to evaluate the ecological quality of water-birds habitat. With higher HQ representing regions that supports higher species richness, this model is quite effective in evaluating the suitability and threats to biodiversity of a region (Eq. 5) below shows the calculation of HQ.

$$Q_{xy} = H_j\left[1 - \left(D_{xy}^2 / D_{xy}^2 + k^2\right)\right] \quad (5)$$

where: Q_{xy} is the habitat quality of raster x in land use type j, D_{xy} is the threat level of raster x in land use type j, H_j is the habitat suitability of land use type j, and k is half the saturation constant which is half of the maximum value of D_{xy}.

Habitat threat identification is a key issue when dealing with InVEST-HQ model, this is due to the fact that there are quite a number of biophysical/ human activities which act as a degradation sources threat to the habitat. Some of the threat maps used in this study were extracted from the land use map while others were from High resolution images (HR) and Open Street Map extension tool v10.2 (OSM). The scope of influence, weight, sensitivity of the habitat types to threat factors and other parameters used in this study were selected based on the InVEST Version User's Guide (Sharp et al., 2011) and expert scoring (Table 3). Except the Built up (Developed Region), Barren soil, Dense vegetation (Forestland, woodland), and High Grassland/Shrub (High grassland coverage, shrubs, sparse woodland), low grassland, sparse vegetation, water region (Lakes), and wet soil/river were selected as habitat types (Table 4).

2.4.4. Zonal statistics and ranking

To statistically analyze the selected RS images, the ArcGIS zonal statistics tool was applied to evaluate the mean and standard deviation of the pixels of each polygons (Fig. 2). The Statistical data gotten was extracted and exported to Microsoft Excel where the data analysis Rank function was used applying the heuristics presented in (Table 5). A similar approach was applied to the vector data however, the ArcMap spatial join tool was used to estimate the count sum and standard deviation, separately. The mean is used to represent the average value of each parameter while the standard deviation indicates the variation in each polygon and probably interpreting the level of homogeneity of the mean result. The hierarchy for all 7 indicators (3 RS and 4 vectors data) are summed and normalized to enable us easily classify each region, afterwards, the rank normalized mean and standard deviation were re-joined to the thiessen polygon mesh in ArcMap. The ranking function is shown in (Fig. 3b).

Table 3. Maximum distance and weight of the threats affecting habitat quality

Max distance	***Weight***	***Threat***	***Decay***
3	0.6	High Grassland/shrubs	exponential
5	0.7	Dense Vegetation	exponential
7	0.9	Developed Region	exponential
7	0.95	Road Network	linear

Table 3. The sensitivity of habitat types to each threat factor

LULC	***Name***	***Habitat***	***High grassland***	***Dense vegetation***	***Developed region***	***Road network***
1	Water	1	0.8	0.9	0.95	1
2	Wet Soil/River	1	0.85	0.9	0.9	0.95
3	Dense Vegetation	0.2	0.4	0	0	0
4	High Grassland/Shrubs	0.4	0	0.2	0	0
5	Low Grassland	0.8	0.6	0.7	0.8	0.8
6	Sparse Vegetation	1	0.75	0.8	0.9	0.9
7	Built Up	0	0	0	0	0
8	Barren Soil	0.6	0.4	0.3	0.25	0.1

Table 4. Summary of remote sensing and vector data

Vector				***Remote Sensing***	
Vector Data	***Feature Type***	***Ranking***		***Remote sensing Data***	***Ranking***
Transport network	Line	Descending		Habitat Suitability index	Ascending
Developed Region	Polygon	Descending		Habitat Quality	Ascending
High Grassland/Shrubs	Polygon	Descending		NDWI	Ascending
Densely Vegetated	Points	Descending			

3. Results and discussion

3.1. Assessment of the habitat quality and habitat suitability and moisture content

The integrated index of HSM was calculated for water-bird based on the values ranging from 0 to 100 (0 indicating Unsuitable while 100 indicates highly suitable). To allow an easy classification, the values were normalized from 0 to 1 (Fig. 4c). The results obtained indicated a significant variation between the ecological quantity and spatial distribution of water-bird's habitat suitability with majority of the study region (about 51%) unsuitable for water-birds, only 84km^2 (13%) of the region highly suitable most of which were centered on Bojiang Lake wetland region. To reverse this trend, it is advised that the government prioritize the restoration/reconstruction of the water-bird habitats.

According to several studies, major wetland degradation like the case of the study region occurs as a result of several factors such as climate, increased anthropogenic activities like unnecessary tourism, land clearing/agricultural activities, overgrazing, mineral extractions, industrializations, river irrigations, constructions, etc. (Liang and Wang, 2010; Liang et al., 2011; Liu i et al., 2017; Xing et al., 2009; Zhang et al., 2009). With evidence indicating a close relationship between wetland/habitat loss and increased threats to biodiversity and species populations, policies and measures should be employed to control and protect the already existing water-bird habitat (Riley and William, 2005; Rodríguez and Delibes, 2003).

HQ is the ability of an ecosystem to support the conditions suitable for species (Sharp et al., 2011), for the purpose of this research, HQ was applied to analyze the ability of ELRNNR to support the accommodation of Water-birds, with high HQ value indicating a richer biodiversity and lower values indicating decline in biodiversity, the result from our study showed that a large proportion of the study region (38%) were ecologically suitable to accommodate water bird species during their breeding season. With only 16.7% (107.3 km^2) of the region unsuitable to accommodate this species, a significant portion of the region (44.8%) proved to be moderately suitable. Based on the spatial pattern analysis, the least HQ values was experienced in the developed areas having an average value of 0.14, the densely vegetated and shrubs region had an average value of 0.45 while the regions surrounding the lake including the low vegetative regions had values ranging from 0.7 and above. Although this regions has been experiencing increase in urbanization level, the developed regional coverage compared with the low vegetated regions proved to be lower which explains the high percentage of high HQ value experienced in the study region all of which falls within the prioritized conservation zone of the reserve. With several policies employed to help restore the wetland and protect species and their habitat, it is quite significant to develop a practical conservation regulation through the spatial distribution of habitat quality to support decision makers involved in ecosystem management.

The moisture content of the study region was calculated using the NDWI (Fig. 3b) and from the result obtained it was observed that 21.5% (137.6 km^2) of the study region had moisture however, majority of this moisture contained region were centered on the lake and other patches scattered around the study region.

The feeding habits of water-birds (*L. Relictus*) are widely known to be basically around aquatic regions Which is why this analysis was carried out to analyze the moisture content of the region suitable for water bird. According to survey carried out in Bojiang Lake in 1990s, *L. Relictus* are known to feed randomly with their major food being aquatic insects in the lake, beach or around moist regions (Zhang et al., 1993). Another study by Gao et al., (2008) 9 kinds of zoobenthos aquatic insects were found in *L. relictus* in Hongjiannao in 2005. Amongst them, 3 were *chironomidae* and one kind of *Coenagrionidae Kirby* whose adult is known as damselfly. The analysis of these two surveys indicates that *L. relictus* throughout the breeding season feeds mainly on *Chironomidae* Larvae (damselflies) an aquatic insects found mainly in moist regions (Wang et al., 2009). These surveys explains the significance of a moist region to water birds with a reduction in moisture content strongly indicating food insufficiency in the region.

3.1. Hierarchical analysis of different regions

The mean hierarchical contribution of each RS and vector data is shown in Figs. 5a, b with the data arrangement ranging from least to highest irrespective of the changes in Polygon ID. From Fig. 5a, Polygon 38 and 42 ranked best with a summed mean hierarchy value <20. The hierarchical order for polygon 38 was HSM & NDWI< HQ, Polygon 42 hierarchical order was HQ<HSM<NDWI. The ampersand indicates that HSM and NDWI both had the same hierarchical value. This however indicates that where the habitat tends to be suitable using one parameter, it appears to be less suitable with other parametric estimation. Polygon 5 was worst hierarchically with an order of NDWI<HSM<HQ. Here the moisture content appears to be significantly low and the HSM and the HQ ranks shows that this polygon is very much unsuitable to accommodate water-birds during breeding season. In Fig. 5b, Polygon 5 was the best with a hierarchical order of Transport network< Dense Vegetation < High Grassland/Shrubs < Developed Region. The second-best region was Polygon 38 and 42 because the threat factors for the water-bird around these regions were significantly low. Polygon 56 on the other had was the worst region hierarchically with an order of Dense vegetation < High Grassland<Transport Network< Developed Region here the threat level is enormously high, this is because compared to the other regions, Polygon 56 houses the major urban region in the study site comprising of a significantly high amount of developed buildings, Transport networks and vegetation. Since the increase in human activities including the urban development, road networks and industrialization all pose an enormous threat on the living conditions of Water-birds (Liang et al., 2011; Liang and Wang, 2010; Liu et al., 2017; Xing et al., 2009; Zhang et al., 2009), the higher the density of developed region and the transport networks, the higher the threat imposed on the water-birds. When considering the developed regions and the transport network based their proximity to the lake and other significant regions, Polygon 38 and 42 was hierarchically the best region exhibiting a low density of the water-bird's threat factors.

Polygon 38 and 42 which was hierarchically best in terms of RS images compared to polygon 5 (vectors best "10", Fig. 5b) had a much higher vector summed hierarchy (48 and 54 respectively, Fig. 5a). This may indicate more variability between the RS "habitat" parameter (sum= 7-153) and the vector "threat" data (sum=10-213) with both data distinctively capturing different aspect of the study region. Similar to the study of Musse et al. (2018) on urban environmental quality index, the approach to consolidate RS and vector data was applied to add-up the ranked data using the equal interval choropleth mapping technique (Fig. 8a). Regions in the south and south western part of the study region were relatively less suitable to accommodate water-birds during breeding season.

However based on the hierarchical sum value and the closeness to Bojiang Lake, the most suitable location for water-bird breeding was polygon 38 and 42, while the least suitable location proved to be polygon 23 (Fig. 5a). Musse et al. (2018) used 5 classes to express their data, but in this research similar principle was adopted to analyze our data. The areas are classified as follows, dark green (Highly Suitable), light green (Suitable), yellow (Moderately Suitable), Orange (Poorly Suitable), Red (Highly Unsuitable). Based on this classification, 16.79% (107.54 km^2) was highly suitable, 30.84% (197.54 km^2) suitable, 25.30% (162.06 km^2) moderately suitable, 12.50% (80.05km^2) poorly suitable and 14.58% (93.39 km^2) highly unsuitable. Fig. 6a shows a true color composite of polygon 38 and 42 (best region based on normalized hierarchical mean). The vector data were overlaid for comparison and these regions obviously surrounded Bojiang Lake with sparse vegetation and low grassland dominating this region very little amount of high vegetation also observed in these locations.

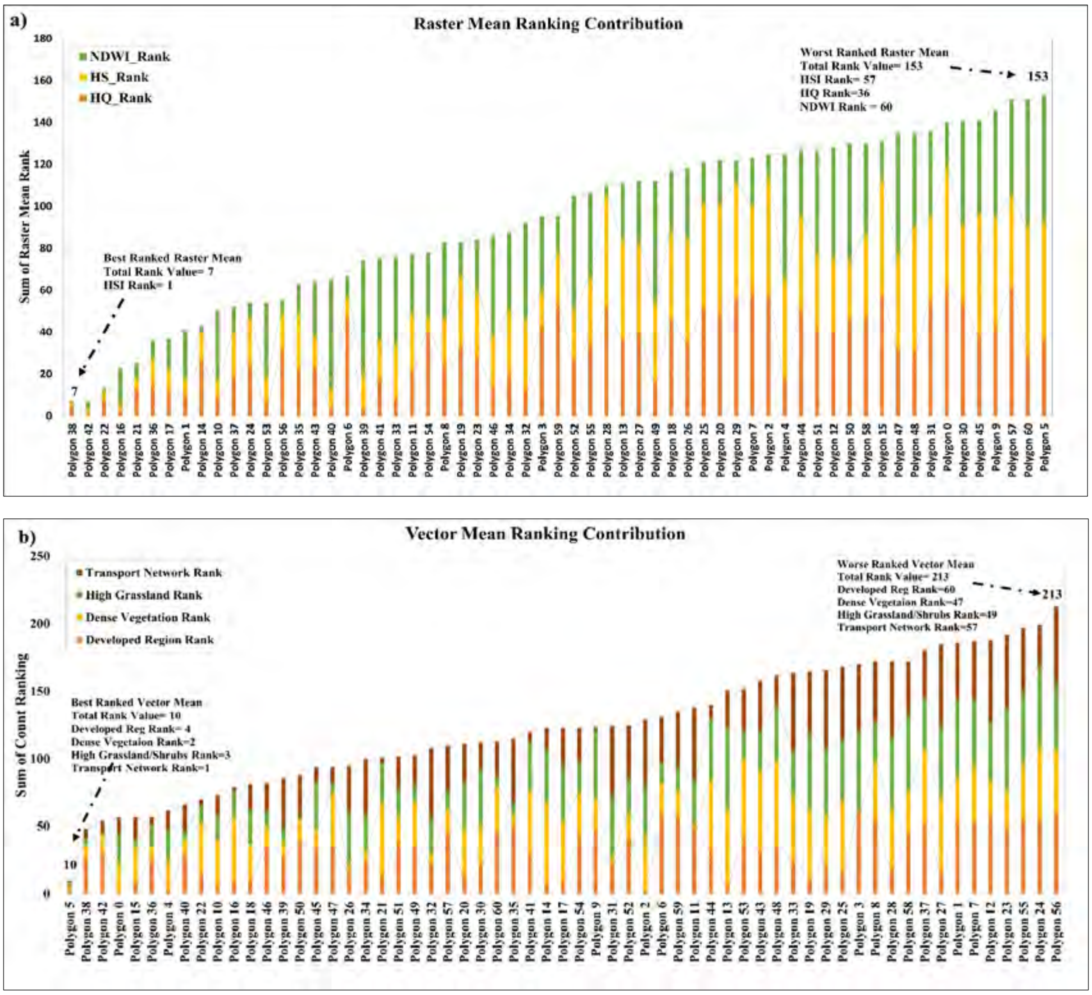


Fig. 4. Mean ranking contributions of each polygons for a) habitat data (remote sensing) b) threat data (vectors)

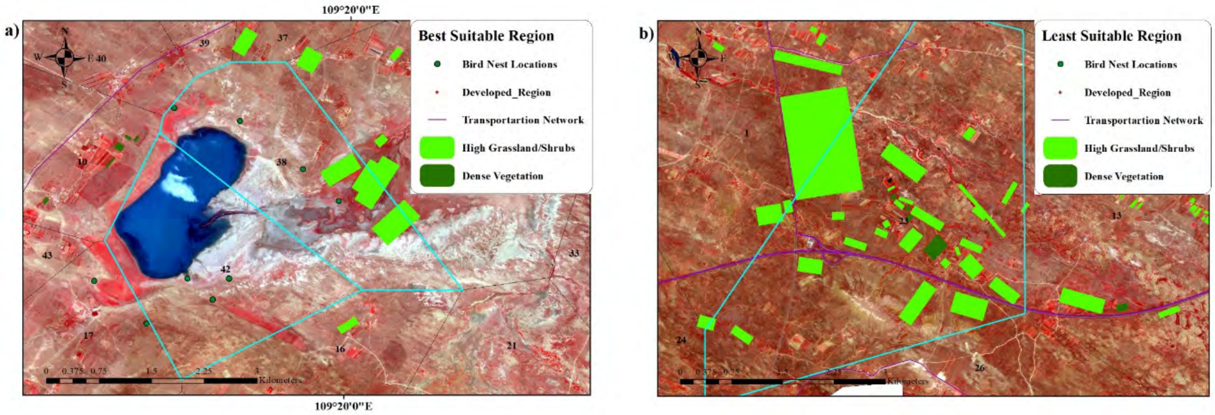


Fig. 5. Normalized mean hierarchy a) best and b) worst suitable zones

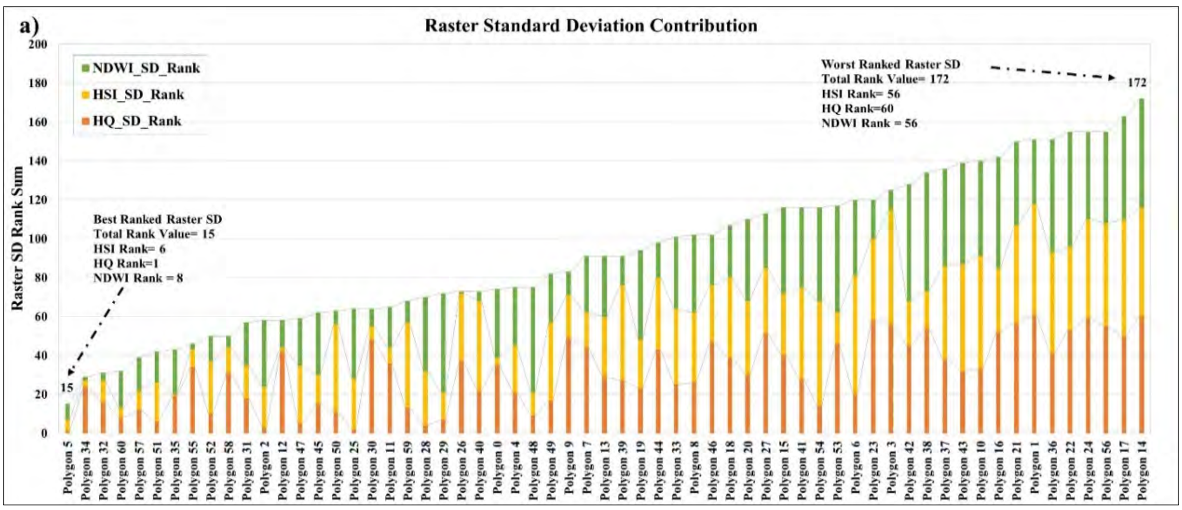
Also this region was verified using the 12 nesting positions collected from previous studies and more than 50% of these nest were situated in this region (Fig 6a). Fig. 6b shows polygon 23 (worst normalized hierarchical mean). This polygon houses highway networks and a few buildings, this region was dominated by high vegetation and shrubs which makes it highly unsuitable to accommodate any water-birds.

3.3. Level of data dispersion in different region.

The hierarchy for polygon 42 (a section of Bojiang Lake) considering the mean in Fig. 5a and STD in Fig. 7a was compared to showcase how they both support each other. In Fig 7a, the hierarchy of moisture content (NDWI) was higher for polygon 42 compared to the mean value shown in Fig. 5a. This indicates high variability with relatively high moisture in the region. However, considering just this parameter, Polygon 42 would be a good choice for water-bird breeding site due to the relatively high moisture content of the region. From Fig. 7b, 4 polygons have a normalized SD rank less than 60 compared to RS which has 5 polygons less than 40. This demonstrates that the RS indices compared to the vector data are responsible for more of the heterogeneity experienced in the polygons. The data in Fig. 7 is summed, normalized and re-joined to each respective polygons as shown in Fig. 8b. The general trend of the standard deviation map shown in Fig. 8b is similar to the mean in Fig. 8a. The STD map in Fig. 8b can be used to verify the uniformity of the data in each polygon.

Areas with high STD values may not be suitable for water-bird breeding site allocation since there is more variability in the studied parameters. For instance, breeding may be unsuitable in areas with high vegetation, developed buildings and road networks as is the case of polygon 23. In Fig. 8b, the largest variation occurred in polygon 13 which is west of the hierarchically the worst polygon (polygon 23). The least variation was however experienced in polygon 37 which is directly north of the two best polygons 38 and 42 (Fig. 8a).

Using the same class provided by Musse et al., (2018) we observed that 13.15% of the region had very small data spread, 27.63% had small spread, 25.94% spread moderately, 18.71% highly and 14.58% had the highest spread of data. In an overall scale, using the mean, polygon 38 and 42 was hierarchically the best suitable region, ranking 27th and 34th out of 61 based on STD, polygon 23 on the other hand was worst suitable region based on the mean while ranking 60th out of 61 according to STD. This however showcases the variability of the data and the relative largeness of the mean rank.



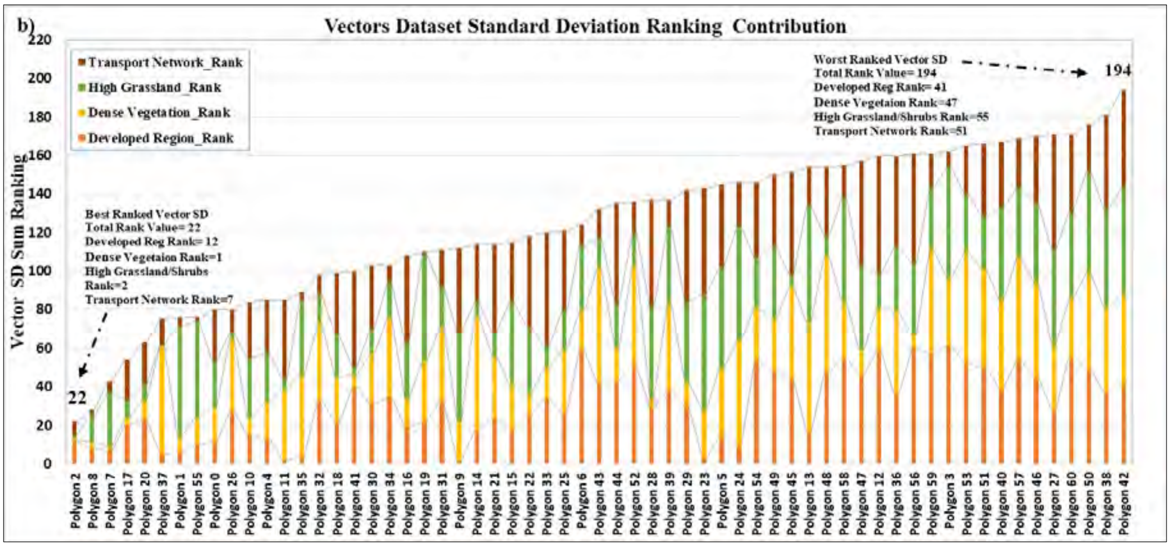


Fig. 6. Standard deviation contribution of a) habitat data (remote sensing), b) threat data (vectors)

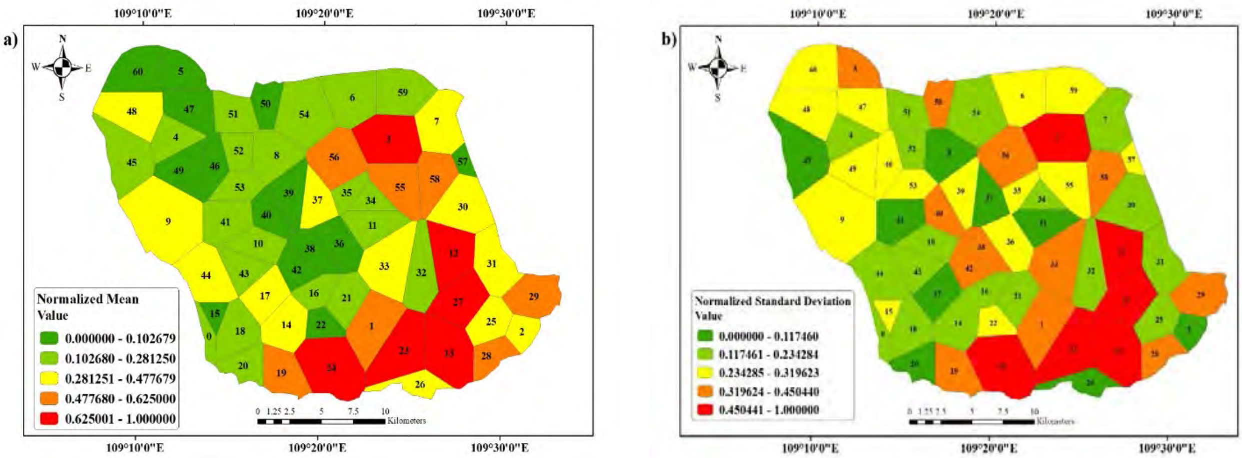


Fig. 7. Statistical data ranking analysis Map a) ranked Mean and b) ranked standard deviation for each polygons

4. Conclusions

In this study, the Thiessen polygons in combination with Remote sensing “Habitat” data and vector “Threat” data were used in GIS to analyze the suitability hierarchy of each region hence mapping out the best and worst suitable regions to accommodate water-birds during breeding season. Unlike other habitat suitability studies which defines areas as either suitable, moderately suitable or unsuitable for species, this paper applied a technique involving the combination of the Excel ranking tool and GIS to statistically analyze the hierarchical level of species habitat suitability of the study region ranging from least suitable to highly suitable. This information may be used by decision makers and conservationists as a pre or post processing tool.

The results from the study proved quite effective in showing that different aspect of data is captured distinctively by both the RS and vector data. Regions in the southern and north eastern part of the study region proved to be unsuitable to accommodate water-birds during their breeding season. Based on the statistical ranking algorithm applied in this study, the mean hierarchical sum showed that 27.08% of the study area was unsuitable while 47.63% were highly suitable for water-birds.

The level of data dispersal based on STD complemented the map of summed mean hierarchy to show us the variation in each polygon based on the data. It was observed that 33.29% of the study region had a significantly high STD indicating a less homogeneity of parameters in the region. The polygon most suitable to accommodate water-birds were polygon 38 and 42 based on the mean normalized value and they were ranked 27th and 34th respectively out of 61 in STD. According to the map in Fig. 6a, Polygons 38 and 42 were regions surrounding Bojiang Lake wetland which were mainly dominated by sparse vegetation, low grasses and barren soils. Other than that, they had a proximity of over 7km from the major threat factors such as the developed regions and road networks, it however makes it highly favorable region for the birds.

The region least favorable for the birds based on the normalized mean values and STD hierarchy

(60th out of 61) was polygon 23. This region was highly unsuitable because it was mainly dominated by high vegetation, shrubs, highways and developed buildings which are all major threat factors for the birds *(L. relictus)*.

Although the initial stage of this study requires the use of expert's opinion to create RS images used (HSM and the HQ), however, this technique is a data driven but flexible approach providing us with the option of weight application if so desired. It can also be used as a pre or post decision screening tool or when there is an inconsistency in expert opinion. Through this approach we were able to statistically narrow down the habitat hence assigning regions with the ability to accommodate water-birds (*L. relictus*).

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