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Avifauna Diversity of Hor Al-Sulaibat area / southern Iraq

AThesis

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بِسْمِ اللَّهِ الرَّحْمَٰنِ الرَّحِيمِ

وَلَمَّا بَلَغَ أَشُدَّهُۥٓ ءَاتَيْنَٰهُ
حُكْمًا وَعِلْمًا ۚ وَكَذَٰلِكَ
نَجْزِي الْمُحْسِنِينَ ﴿٢٢﴾

صدق الله العلي العظيم

سورة يوسف، الآية ٢٢



Dedication

Enormous thanks are due to God the Almighty

I dedicate this work to:

My dear husband...
For his endless love, patience, support, and encouragement.
Thank you for standing by my side and giving me strength
throughout this journey.

To my dear father...
And to my beloved mother...
For their prayers, sacrifices, and unconditional love.

To my loving brothers and sisters...
And to my friends and college mates...
Thanks for all the support and love you gave.

Zainab Al-Zamily

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Summery

Hor Al-Sulaibat is one of the most biologically important wetland ecosystems in southern Iraq. This wetland, located in the hyper-arid Mesopotamian plain, is an important hydrological oasis as well as a critical stopover and wintering sanctuary for migratory bird species travelling along the West Asian-East African flyway. To fill the empirical information gap about its biodiversity, this study undertook a complete taxonomic, geographical, and ecological evaluation of the avifauna population in Hor Al-Sulaibat wetland from September 2024 to March 2026. Avian field censuses were conducted using the standardised Whole-Wetland Area Search Protocol, which was aided by Geographic Information System (GIS) tools, satellite remote sensing, and 13 spatial environmental surface layers. A total of 72 bird species from 11 orders and 29 families were documented. Passeriformes (27 species) and Charadriiformes (18 species) were the dominant groups in the community. Wintering waterfowl dominated by Anas crecca (1,160 individuals), waders and gulls such as Black-headed Gull (350 individuals) and Little Stint (140 individuals), marsh-dependent herons (*Egretta garzetta* and Ardea cinerea), specialised passerines (*Phylloscopus collybita and Hypocolius ampelinus*), and key raptors (*Circus aeruginosus*) make up the avifaunal community. Spatial density modelling with Kernel Density Estimation revealed distinct aggregation hotspots within central open water basins and shallow inundation zones, governed by topographical elevation gradients (4-12 m a.s.l.) and dense stands of emergent macrophytes (*Phragmites australis and Typha domingensis*), as indicated by NDVI layers. Microclimatic modelling revealed that, despite severe area aridity (Aridity Index: 274–310), the wetland serves as an important microclimatic buffer. The conservation evaluation found globally threatened species on the IUCN Red List, such as the Endangered Steppe Eagle *(Aquila nipalensis)*, Vulnerable European Turtle Dove *(Streptopelia turtur)*, and Near Threatened Marbled Teal

(Marmaronetta angustirostris. These empirical findings underscore Hor Al-Sulaibat's vital conservation importance and strongly support its formal classification as an Important Bird Area (IBA) with sustainable eco-hydrological management.

CONTENT

No.	Title	Page No.
—	Dedication	—
—	Acknowledgements	—
—	Summery (English Abstract)	A–B
—	Content	I–IV
—	List of Tables	IV
—	List of Figures	IV–V
—	List of Plates	V
—	List of Abbreviations	VI–VII
1	**Introduction**	**1**
1.1	**Objectives of the Study**	**4**
2	**Literatures Review**	**6**
2.1	**Avifauna of Iraq**	**6**
2.1.1	TOPOGRAPHY AVIAN AND TERMINOLOGY	9
2.1.2	The IUCN - Red List Categories and Criteria	13
2.1.3	The Key Categories of Red List of IUCN	14
2.2	**Macro-Geography & Flyway Dynamics**	**16**
2.2.1	Global Importance of Wetlands for Avian Communities	16
2.2.2	The Mesopotamian Wetlands: Historical Eco-Geography and Hydrological Dynamics	17
2.2.3	The Eurasian-African Flyway and the Biogeographical Role of Iraqi Wetlands	19
2.2.4	Migration Mechanics and Passerine vs. Non-Passerine Wintering Patterns	21

No.	Title	Page No.
2.2.5	Climate Change, Phenological Mismatch, and Shifting Migration Timings	22
2.3	**Ecological Theories & Landscape Dynamics**	**23**
2.3.1	Island Biogeography Theory and "Oasis" Dynamics in Fragmented Arid Zones	23
2.3.2	Avian Diversity in Transitional Ecotones: Semiarid Basins and Desert Landscapes	24
2.3.3	Niche Partitioning and Guild Packing in Fluctuation-Driven Wetlands	26
2.3.4	Phenology and Temporal Turnover of Avian Communities	28
2.4	**Behavioral Ecology & Foraging Economics**	**29**
2.4.1	Foraging Economics and Optimal Foraging Theory in Wetland Basins	30
2.4.2	Density-Dependent Mechanisms and Aggregation Behaviour (Flocking)	31
2.4.3	Night-Migration and Nocturnal Habitat Selection in Wetland Basins	32
2.4.4	Anthropogenic Disturbance and the "Landscape of Fear" in Wetland Avifauna	34
2.5	**Community Metrics, Statistics & Conservation**	**36**
2.5.1	Theoretical Framework of Avian Diversity and Community Structure	36
2.5.2	The Concept of Dominance and Evenness in Semi-Arid Wetlands	37
2.5.3	Multivariate Statistics and Ordination Techniques in Avian Community Ecology	39

No.	Title	Page No.
2.5.4	Functional Trait Diversity and Ecosystem Services in Wetland Avifauna	40
2.5.5	The Mid-Winter Waterbird Census (IWC) Framework and Citizen Science	42
2.5.6	Global Conservation Status and Threat Assessment of Wetland Avifauna	43
2.6	**Functional Guilds and Seasonal Dynamics**	**45**
3	**Methodology**	**48**
3.1	**Study Area Description**	**48**
3.1.1	Geographical Location and Boundaries	48
3.1.2	Topography and Hydrological Characteristics	50
3.1.3	Climate Profile	50
3.2	**Avian Field Survey Protocol**	**50**
3.2.1	Whole-Wetland Area Search Protocol	50
3.2.2	Survey Execution and Recording	51
3.2.3	Garments Color	51
3.2.4	Study time & Field Equipment	51
3.3	**Spatial analysis of Hor Al-Sulaibat via ARC- GIS**	**52**
3.3.1	Satellite Data Acquisition	52
3.3.2	Normalized Different Vegetation Index (NDVI)	52
3.4	**GIS Spatial Analysis & Ecological Modeling**	**53**
3.4.1	Modeling Optimized Hot Spot Analysis in ARC-GIS	53
3.4.2	Modeling Kernel Density Estimation (KDE - Spatial Analyst)	54
3.4.3	Modeling Analyzing Pattern Distribution (ANN)	56

No.	Title	Page No.
3.4.4	Inverse Distance Weighted (IDW) Interpolation	57
3.4.5	Bivariate Spatial Modeling	58
3.4.6	Utilisation Distribution (UD) and Core Habitat Modelling	59
4	**Result and Discussion**	**61**
4.1	**Ecological Importance of Hor Al-Sulaibat**	**61**
4.1.1	Discussion of Avifauna Data and Comparative Analysis	61
4.2	**Spatial Distribution and Ecological Analysis of Avian Occurrence Points**	**75**
4.3	**Spatial Modeling of Avian Relative Abundance via Kernel Density Estimation**	**78**
4.4	**Spatial Quantification of Avian Home Range and Utilization Distribution (UD)**	**80**
4.5	**Spatial Autocorrelation and Statistical Significance of Avian Hotspots**	**85**
4.6	**Deterministic Spatial Interpolation of Avian Abundance via IDW Modeling**	**88**
4.7	**Bivariate Spatial Association and Local Indicators of Spatial Association (LISA)**	**92**
4.8	**Spatial Variation of Vegetation Density and Phytoplankton/Macrophyte Cover**	**96**
4.9	**Topographic Heterogeneity and Hydrological Gradients in Wetland Micro-Geomorphology**	**99**
4.10	**Micro-Climatic Dynamics and Atmospheric Moisture Gradients**	**103**
4.11	**Thermal Gradient and Micro-Climatic Thermal Buffering in Wetland Systems**	**106**

No.	Title	Page No.
4.12	**Precipitation Distribution and Hydro-Climatic Dynamics in Wetland Ecosystems**	**110**
4.13	**Spatial Variation of Aridity Patterns and Wetland Eco-Hydrological Integrity**	**113**
4.14	**Boundary-Layer Wind Dynamics and Shelter Function in Wetland Habitats**	**117**
4.15	**Annotated Fauna Check-List for Hor Sulibat, Southern Iraq, Systematic List (Terminology &Abbreviation)**	**115**
4.15.1	Steppe Eagle	115
4.15.2	Long-legged Buzzard	115
4.15.3	Short-toed Snake Eagle	116
4.15.4	Egyptian Nightjar	117
4.15.5	Northern Wheatear	118
4.15.6	Crested Lark	119
4.15.7	Desert Wheatear	120
4.15.8	European Stonechat	122
4.15.9	Commen Chiffchaff	123
4.15.10	White Wagtail	124
4.15.11	Blue-cheeked Bee Eater	125
4.15.12	Rufous-tailed Scrub Robin	127
4.15.13	Kentish Plover	128
4.15.14	Red-wattled Lapwing	129
4.15.15	Black-crowned Night Heron	130
5	**Conclusion & Recommendation**	**132**
5.1	**Conclusion**	**132**

No.	Title	Page No.
5.2	**Recommendation**	**133**
—	**References**	136

LIST OF TABLES

No.	Title	Page No.
1	explains the status of some birds in Iraq.	7
2	Show the equipment used in the survey area during the period of study.	52
3	Dialog Reference in ARC-GIS	54
4	Dialog Reference in ARC-GIS	55
5	Dialog Reference in ARC-GIS	57
6	List fauna: Birds of Hor Al-Sulaibat with number of individual per species	67

LIST OF FIGURES

No.	Title	Page No.
1	displays the main categories of the IUCN Red List.	15
2	Show Map of Hor Al-Sulaibat in ArcGIS	48
3	Spatial Analysis of Avian Occurrence Points in Hor Al-Sulaibat	77
4	Spatial analysis of Avian Relative Abundance via Kernel Density Estimation	80
5	Spatial Analysis of Avian Home Range and Utilization Distribution (UD) Via Hot Spot model	84
6	The outcome of modeling Hot Spot Analysis Getis Ord-Gi in ArcGIS	88
7	Spatial Analysis of Avian Abundance via IDW Modeling	91
8	Spatial Analysis of Avian via Bivariate model	95
9	Spatial Analysis ofHor Al-Sulaibat, NDVI - Raster of the Square Clip of the satellite analysis in ArcGIS	98
10	Spatial Analysis of Hor Al-Sulaibat, DEM - Raster of the Square Clip of the satellite analysis in ArcGIS	102
11	Spatial Analysis of Hor Al-Sulaibat, Water Vapor Pressure - in ArcGIS	105
12	Spatial Analysis of Hor Al-Sulaibat, The Average Temperature in ArcGIS	109
13	Spatial Analysis of Hor Al-Sulaibat, The Precipitation in ArcGIS	112
14	Spatial Analysis of Hor Al-Sulaibat, Aridity Index in ArcGIS	116
15	Spatial Analysis of Hor Al-Sulaibat, The Wind Speed - in ArcGIS	114

LIST OF PLATES

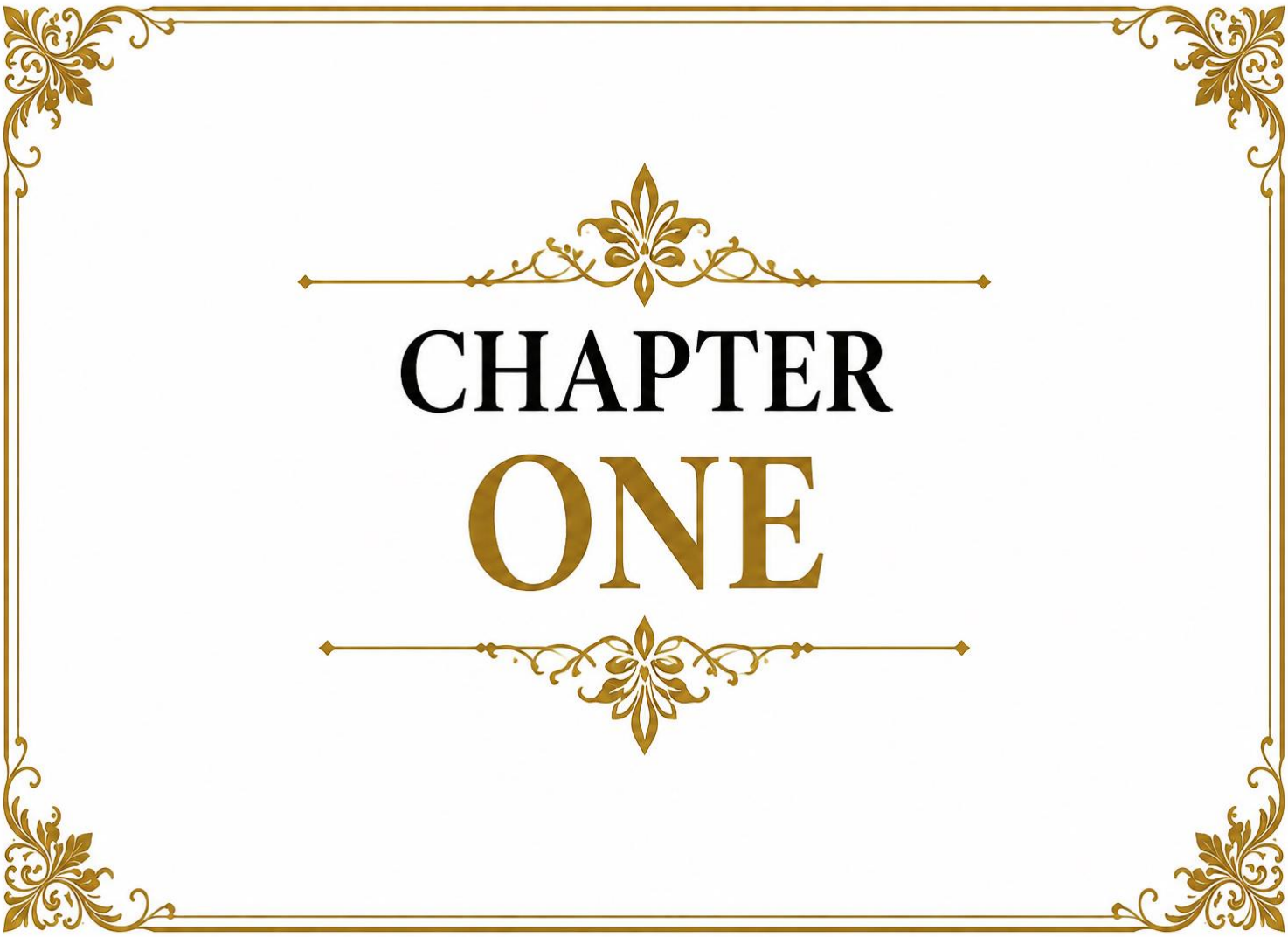
No.	Title	Page No.
1	Topography Bare feature, Yellow-legged Gull (Larus michahellis).)Dungeness, 2016)	11
2	Topography Head Gulls 2020. © Peroaves.org	11
3	Topography bare feature, Sparrow sp, 2020. © Peroaves.org	12
4	Topography bare feature, Mallard (Anas platyrhynchos) 2020. © exploringnature.org, Sheri Amsel (Sheri Amsel, 2020).	12
5	A Landscape view of Hor Al-Sleibaat	50
6	The Steppe Eagle (Aquila nipalensis), Hor Al-Sulaibat, Iraq	115
7	The Long-legged Buzzard (Buteo rufinus), Hor Al-Sulaibat, Iraq	116
8	The Short-toed Snake Eagle (Circaetus gallicus), Hor Al-Sulaibat, Iraq	117
9	The Egyptian Nightjar (Caprimulgus aegyptius), Hor Al-Sulaibat, Iraq	118
10	The Northern Wheatear (Oenanthe oenanthe), Hor Al-Sulaibat, Iraq	119
11	The Crested Lark (Galerida cristata), Hor Al-Sulaibat, Iraq	120
12	The Desert Wheatear (Oenanthe deserti), Hor Al-Sulaibat, Iraq	122
13	The European Stonechat (Saxicola rubicola), Hor Al-Sulaibat, Iraq	123
14	The European Chiffchaff (Phylloscopus collybita), Hor Al-Sulaibat, Iraq	124
15	The White Wagtail (Motacilla alba), Hor Al-Sulaibat, Iraq	125
16	The Blue-cheeked Bee-eater (Merops persicus), Hor Al-Sulaibat, Iraq	126
17	The Rufous-tailed Scrub Robin (Cercotrichas galactotes), Hor Al-Sulaibat, Iraq	128
18	The Kentish Plover (Charadrius alexandrinus), Hor Al-Sulaibat, Iraq	129
19	The Red-wattled Lapwing (Vanellus indicus), Hor Al-Sulaibat, Iraq	130

No.	Title	Page No.
20	The Black-crowned Night Heron (Nycticorax nycticorax), Hor Al-Sulaibat, Iraq	131

LIST OF ABBREVIATIONS

Abbreviation	Meaning
ACP	Area Count Protocol
AEWA	African-Eurasian Migratory Waterbird Agreement
ANN	Average Nearest Neighbor
CCA	Canonical Correspondence Analysis
CM	Central Marsh
CR	Critically Endangered
db-RDA	Distance-Based Redundancy Analysis
DD	Data Deficient
DEM	Digital Elevation Model
EN	Endangered
EW	Extinct in the Wild
EX	Extirpated
GIS	Geographic Information System
IBA	Important Birds Area
IDW	Inverse Distance Weighted
ISA	Indicator Species Analysis
ITIS	Integrated Taxonomic Information System
IUCN	International Union for Conservation of Nature
IWC	International Waterbird Census
KBA	Key Biodiversity Area
KDE	Kernel Density Estimation
LC	Least Concern
LISA	Local Indicators of Spatial Association
MoE	Ministry of Environment
NDVI	Normalized Difference Vegetation Index
NE	Not Evaluated
NIR	Near-Infrared
NMDS	Non-metric Multidimensional Scaling
NT	Near Threatened

Abbreviation	Meaning
PCoA	Principal Coordinates Analysis
PERMANOVA	Permutational Multivariate Analysis of Variance
RED	Red Spectrum Band
SPAs	Special Protection Areas
SRTM	Shuttle Radar Topography Mission
SSC	Species Survival Committee
TNI	Total Number of Individuals
TSN	Taxonomic Serial Number
UD	Utilization Distribution
VU	Vulnerable


CHAPTER
ONE

1. Introduction

The term "marshes" describes wetlands that are nearly entirely immersed in shallow water and have a rather dense vegetation cover, mostly composed of notable plants like Typha and Phragmytes. The marshes in Southern Iraq (Ahwar) have distinctive environmental and cultural characteristics that are uncommon in similar habitats around the world, making them one of the most significant wetlands on a global scale (Series, 2019).

One of the most significant wetlands and ecosystems in the southern region of Iraq is the Central Marsh (CM) (Al-Ansari et al., 2012),(Partow, 2001). The CM is an Important Birds Area (IBA)(Evans, 1994), Key Biodiversity Area (KBA)(Kohring, 2019), and the first national park in Iraq (Alwash et al., 2009),(Pearce, 2013) . The CM's population, which increased dramatically from 41,000 in 2005 to 152,844 in 2015, depends on the site for a variety of ecological services (Fazaa et al., 2018). Water quality is one of the ecological services that the CM offers, and it is crucial for both people and their surroundings. The Tigress and Euphrates rivers, the two principal rivers in the Mesopotamian basin, historically supplied water to the CM (Richardson & Hussain, 2006).

Despite the severe destruction they have endured over the past few decades, the Mesopotamian Marshes remain one of the world's most significant waterbird conservation sites (Ahmed & Aziz, 2003). The region between two rivers is referred to by the original Greek word for Mesopotamia (McCarthy, 2001). The Mesopotamian Marshes are Iraq's most important wetland habitat and a major migratory waterbird destination in West Asia and East Africa (Ahmed & Aziz, 2003).

The Marshes in southern Iraq are the largest wetland environment in Mesopotamia and have special significance for global biodiversity conservation.

These marshes, which are located where the Tigris and Euphrates rivers converge, once encompassed an area of approximately 20,000 km2 and were home to very high concentrations of migratory and breeding waterbirds. (Al-Lami et al., 2014).

Over the past few decades, the marshlands have experienced severe environmental changes. The ecology was purposefully reduced to fewer than 10% of its initial size throughout the 1990s. Reflooding was started in 2003, although recovery has only been partial due to the region's drought, agriculture needs, and reduced water inputs from upstream dams. Climate change projections indicate that water stress will continue. Due to seasonal variations in water levels and annual fluctuations, the marsh's current extent is estimated to be between 4,500 and 5,500 km2 (Richardson & Hussain, 2006).

Among the planet's most important ecosystems are marshlands (Albarakat et al., 2018). This is because these ecosystems are essential for reducing floods, filtering pollutants, and serving as habitats for a wide range of plants and animals (Al-Nasrawi et al., 2021). They are also commercially significant since they serve as a local hub for relaxation, fishing, cattle grazing, and reed harvesting (Sabeeh Mosleh, 2025).

The largest wetland ecosystem in the Middle East and Western Asia is found in the marshes of Iraq. In the lower Euphrates and Tigris basin, which formerly covered an area of more than 20,000 km2 from Iraq and Iran, it is made up of a collection of interconnected lakes and marshy areas (Al-Zahery et al., 2011).

The biological richness of the wetlands in southern Iraq is exceptional. There are 200 ecoregions in the world, including the marshes. They have been recognised as an indigenous bird habitat (Stattersfield, 1998). The interactions between the organisms and the marsh dwellers depend heavily on the environmental functions of these wetlands. The wetlands and surrounding

regions of Southern Iraq's major marshes are likewise very significant (Gray et al., 2013) . The four southern Iraqi marshes—Huweiza, Central Marshes, East Hammar, and West Hammar—were designated as natural elements of the "Ahwar" World Heritage site (Al-Lami et al., 2014).

Hor Al-Salibat is situated in the southwest of Al-Khader District, Al-Muthanna Province. It is 40 km from Nasiriyah City, which indicates that it is spread out in the desert region between Al-Muthanna and Dhi-Qar provinces, and 30 and 60 km from Samawa City, of which 17 km are dirt roads, placing it on the right side of the Euphrates River. The Amir River, which draws water from the Atshan River, provides food for Alsalibat Marsh, a fallen basin tectonic or basin erosion that is 71 km long, 23 km wide, and has a depth of 75 cm to 4 m (Aqeel Al-Taee et al., 2024).

There are two types of birds in the Al-Salaibat marshes: migratory and non-migratory (local). Since the marshes are located in the Samawah Desert, which is part of the Western Desert and extends into the deserts of neighboring Arab countries (Kuwait, Saudi Arabia, Syria, and Jordan), they have become an important site on the flight paths of migratory birds that arrive in large flocks, this gives the Iraqi marshes an advantage, making them more attractive to migratory birds, It can be said that half of the birds of the Middle East pass through the Iraqi marshes (Al-Dulaimi, 2012).

The Tigris and Euphrates rivers converge in the southern region of Mesopotamia, where the marshes of Southern Iraq are situated. The marshes area is one of the most significant wetlands in the world because of its special qualities, which are rarely found anywhere else (Partow, 2001). Since Iraqi marshes are classified as wetlands, their functional diversity can be summed up by the ways in which they can influence nearby surroundings (Bush, 2003).

Information regarding water life, bird species, habitats, ecosystem functions, natural biological processes, and their relationships can all be found in wetlands (Turpie et al., 2010). Southern Iraq's marshes and Dalmaj wetlands have been rich research sites for cultural, historical, and biological studies. New information is continuously being uncovered, including the identification of new species (M A Salim et al., 2019),(MUDHAFAR A Salim, 2008).

1.1. Objectives of the Study

The primary goal of this research is to conduct a thorough taxonomic, geographical, and ecological evaluation of the avifauna community in Hor Al-Sulaibat wetland, southern Iraq. To fulfil this primary goal, the following particular objectives were established:

1. Taxonomic Inventory and Community Structure: Using the standardised Whole-Wetland Area Search Protocol, conduct an updated, thorough species inventory and describe the taxonomic richness, abundance, and community composition of resident and migratory birds.
2. Spatial Density and Hotspot Mapping: The spatial distribution patterns and avian aggregation hotspots in Hor Al-Sulaibat will be mapped using Geographic Information System (GIS) spatial analytical tools and Kernel Density Estimation.
3. Eco-hydrological and habitat relationships will be assessed to determine the impact of topographical gradients (DEM) and aquatic vegetation dynamics (Phragmites australis and Typha domingensis) represented by NDVI on the spatial distribution of several avian functional guilds.
4. Microclimatic Characterisation: The goal is to model and map the multi-parameter local microclimate (temperature, precipitation, wind speed, water vapour pressure, and aridity index) and assess its importance as an ecological buffer for bird populations in a hyperarid environment.

5. Conservation Status Evaluation: To evaluate the global and regional conservation status of the recorded avifauna using IUCN Red List criteria, providing a scientific foundation for proposing Hor Al-Sulaibat as an Important Bird Area (IBA) and informing future protected-area management.

CHAPTER TWO

2. Literatures Review

2.1. Avifauna of Iraq

Birds are one of the best ways to monitor ecological change. The long-term effects of habitat loss and fragmentation were explained through population movements, activities and reproductive capacity (Harisha & Hosetti, 2009). The avifauna of Iraq includes 415 species of birds, of which two are human-introduced and thirteen are rare or accidental. One species described in Iraq is not included in the total number of species. The marshlands have forty species of fish and birds, and certain bird species have a range restriction. Marshes were a stopover for millions of refugees and immigrant birds, including as flamingos, pelicans and herons, on their way from Siberia to Africa. 90% of the world reed warbler population and 40%-60% of its marbled teal population are threatene(Mudhafar A Salim et al., 2020).

In the wetlands there are seven species of endangered or almost extinct animals such as Indian porcupines, crested ducks, bandicoot rats and marsh grey wolves. When the Multi-National Power overthrew the Saddam Hussein dictatorship, the water supply to marshes was restored and the ecosystem started to recover. The drainage of marshes caused a major decline of bioproductivity. The overthrow of the Saddam Hussein dictatorship by the Multi-National Power restored water supply to marshes and the ecosystem began to recover. Marshes were drained and biological productivity dropped sharply (Richardson & Hussain, 2006).

Waterbirds observed in the marshlands of southern Iraq included great crested grebe, starling, Indian roller, collared dove, pin-tailed sandgrouse, common redshank, greater spotted eagle, hooded crow, sacred ibis, pied kingfishers, Iraq babbler, white stork, purple heron, night heron, grey heron and cormorant (Rheindt et al., 2025). The taxonomic (description and arrangement of orders, families and species) and terminology (scientific and common names) follow

the conventions of the sixth edition of the Clements Birds World Checklist. At the beginning of each heading, this taxonomy is illustrated by family accounts and counts of species used in each family account. Both intentional and unintentional species are considered in Iraq, look table (1) (Clements & Principe, 2000).

Table 1: explains the status of some birds in Iraq.

Term	Code	Sight
Extinct	X	a non-existent species.
Extirpated	EX	a non-existent species presents in Iraq, but populations occur elsewhere.
Introduced	I	Species imported into Iraq directly or indirectly of personal by humans conduct.
Accidental	A	Species seldom or inadvertently in Iraq.

In 2006, Salim and other specialists published the “First Field Guide to Iraq’s Birds”. There was very little research in 1960, 1970 and 1980 to describe the state of birds in Iraq (M. Salim et al., 2009) . Mahdi reported on his work in “Waterbirds in Iraq” (1982). Also, the Arab Nations “listed several water-related birds in Iraq, mainly based on Allouse's “Birds of Iraq” (in Arabic).The earlier work (Mahdi 1982) did not include all the waterfowl species of Iraq and did not extend over much of the material provided by Allouse in his book in 1961 (B. Allouse, 1961),(B. A. Allouse, 1961),(Ferreira, 2012). Salim stressed that waterfowl played a role in the rehabilitation of the Southern Iraqi wetlands after 2009, and suggested that the re-flooding of the marshes affected the

rehabilitation of a large number of ducks, geese and other waterbirds (M A Salim, 2010). Birds have been an integral part of the Iraqi Main Biodiversity Areas (KBA) Nature Project since 2004. This is done in cooperation with Iraqi universities, the Iraqi Ministry of Environment (MoE), Birdlife International and foreign funding from several donors, such as the Italian Ministry of Environment, Land and Sea (2006–2008) and the Canadian International Development Agency (2004–2006) (Abdulhasan & Salim, 2008).
Iraqi birds are in the Arab world so they are slightly different from Israeli birds which have been identified in about 540 bird species (Perlman et al., 2017).

Between April and July 2017, three nests of the Black-winged Kite were observed in the middle of Phoenix dactyliferous date palms at a maximum height of 7.73 m above ground in Al-Qadisiyah Middle Euphrates province of Iraq. The nests produced a total of 92% success. This study adds to the knowledge of global breeding distribution of birds like the Black-winged Kite and provides some information about breeding ecology in Iraq. Production success of the nests was 92% overall. This work contributes to the knowledge of the breeding distribution of Black-winged Kites and provides some information on the breeding ecology of Iraq. The three nests were in the centre of the date palms of Phoenix dactyliferous at a maximum height of 7.73 metres. The overall success rate of nest production was 92% (Abed & Salim, 2018).

Initiatives to research biodiversity distribution are often hampered by scarce resources such as money, staff and time (Baasch et al., 2010), (Field et al., 2005). So ecologists control a large gap between the number of sites inspected and the number of repeated sample surveys to collect correct data from limited resources (Bried *et al*., 2011).

Major factor for biodiversity depletion are land use, lifestyle change, deforestation (Sala et al., 2000). One of the dangers to birds is the

fragmentation of the remaining habitat by urbanisation. threaten biodiversity by reducing habitat and fragmenting connectivity (Lindenmayer & Fischer, 2013). Urbanization destroys the ecological system, creating “islands.” Fragmented ecosystems threaten both resident and migratory birds due to the decreased communication among fragments (Oliver et al., 2011). The remaining pieces of habitat diversity may also be altered by urbanization (Palomino & Carrascal, 2006) and more disturbance within the fragments (Ortega-Álvarez & MacGregor-Fors, 2009). Thus, it is important to address the issues related to ecosystem fragmentation to maintain the diversity of migratory and local avifauna in urban areas, especially expansion and urban development that include a wide range of natural areas in urban areas (Andren, 1994).

Birds are seen as a key indicator of Iraq's biological health, particularly Extensive field surveys and resident surveys since 2004 have provided an indication of Iraq's biological health. They all contribute to the global restoration and utilization of wetlands and other ecologically important areas. The research methodology is based almost entirely on experiments. Since motorized ships, cars and foot trips accounted for 70% of the studies, we apply modern technologies in the bird checklist to get precise observations while reducing labor (Amr, 2011)

2.1.1 TOPOGRAPHY AVIAN AND TERMINOLOGY

Birds come in all types of colors and shapes but they all have very similar patterns of feathers on their bodies. One of the most useful tools that ornithologists and birdwatchers have to identify a bird is the disclosure of feather groups and body faction. Learning and recognizing bird topography, such as wings and body parts, feathers, will not only allow you to write a decent summary after seeing a bird, but will also help you understand the annotated bibliography of another bird (Weiersbye & Hancock, 2015) . Thus, a dictionary

of some bird-related terminology will be explained in accordance with (Blake, 1956), (Malboeuf, 2020).

- Orbital ring: the skin or the ring without feathers surrounding the eye. Over time, the orbital ring will change color; some birds have a brilliant orbital ring, while others do not.
- Irisis: always black, the iris of the area that surrounds the pupil, and some birds' iris color changes as they age.
- Culmen: Show the ridge that runs the length of a bird's top jaw.
- Nostril: Comparable to the nasal canal of a bird.
- Nail: The size and color of a duck's nails can be crucial to its identification.
- Tomia: is the bottom line of the bill.
- Gonydeal Angle: the slight angle at the lower mandibular tip of the gull's bill. the gony spot on birds that are nearly mature. On the other hand, the patch changes color as a chick pecks at its desired nutrient.
- Gape: are fleshy edges found in the base of birds' beaks, and they are important because they allow us to see young.
- Nape: the area behind of neck bird.
- The forehead is the space between a bird's bill and crown.
- Eyering: The stripe extended from the back of the eye to the nape.
- Flank: is a region with two sides situated beneath the folded wing.

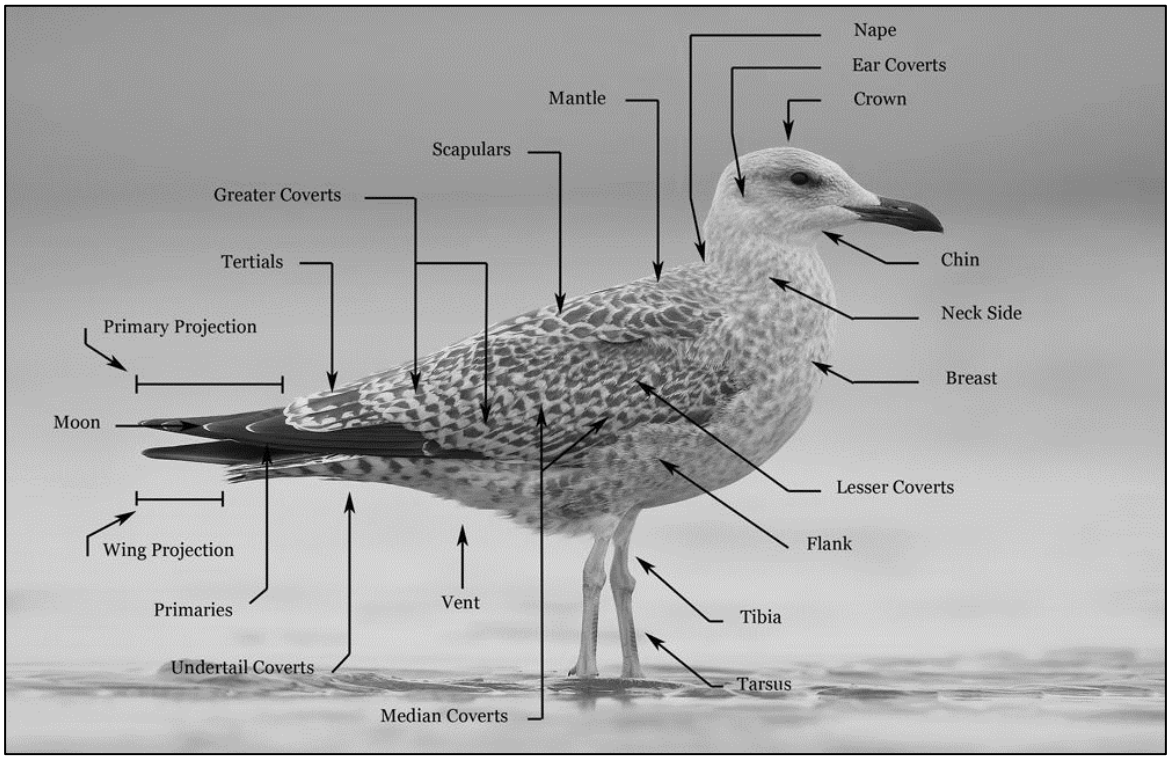


Plate 1: Topography Bare feature, Yellow-legged Gull (*Larus michahellis*). (Dungeness, 2016)

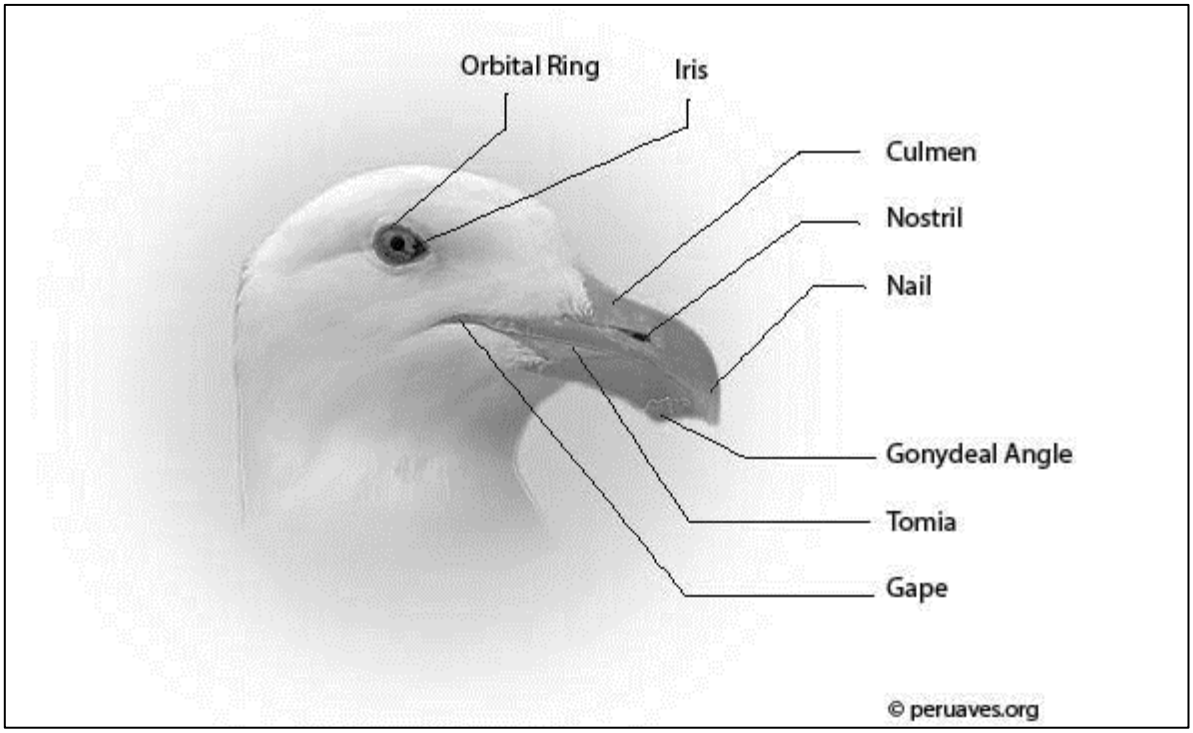


Plate 2: Topography Head Gulls 2020. © Peroaves.org

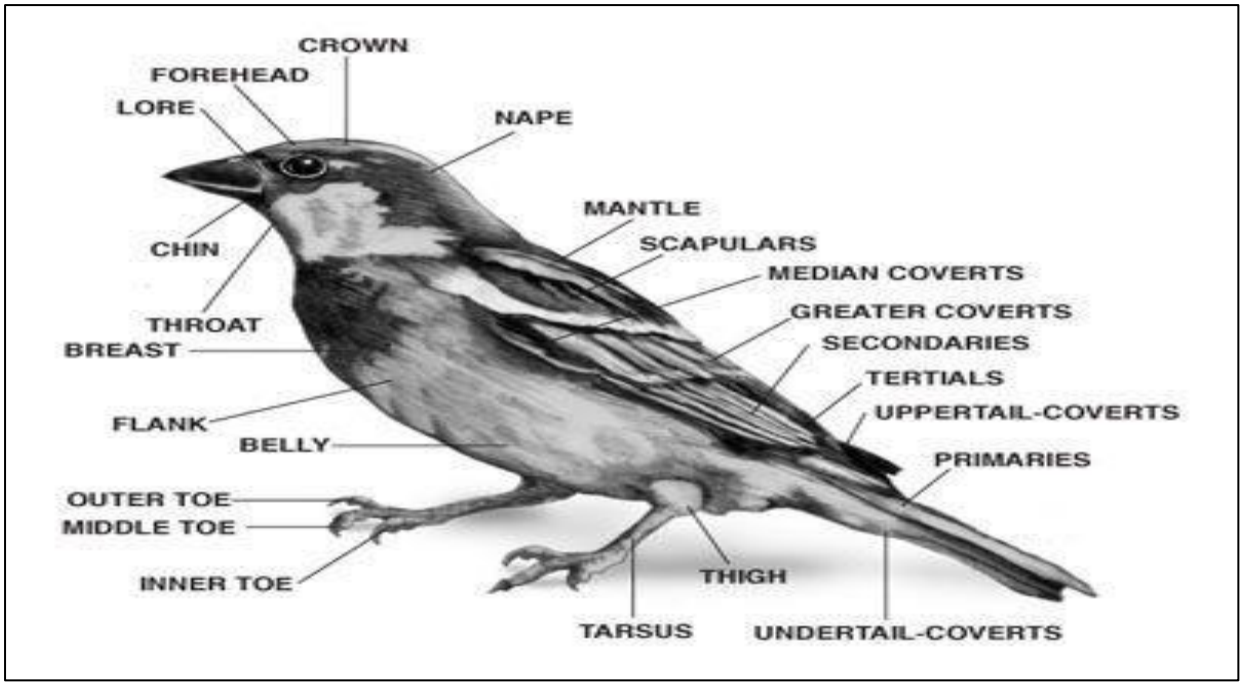


Plate 3: Topography bare feature, Sparrow sp, 2020. © Peroaves.org

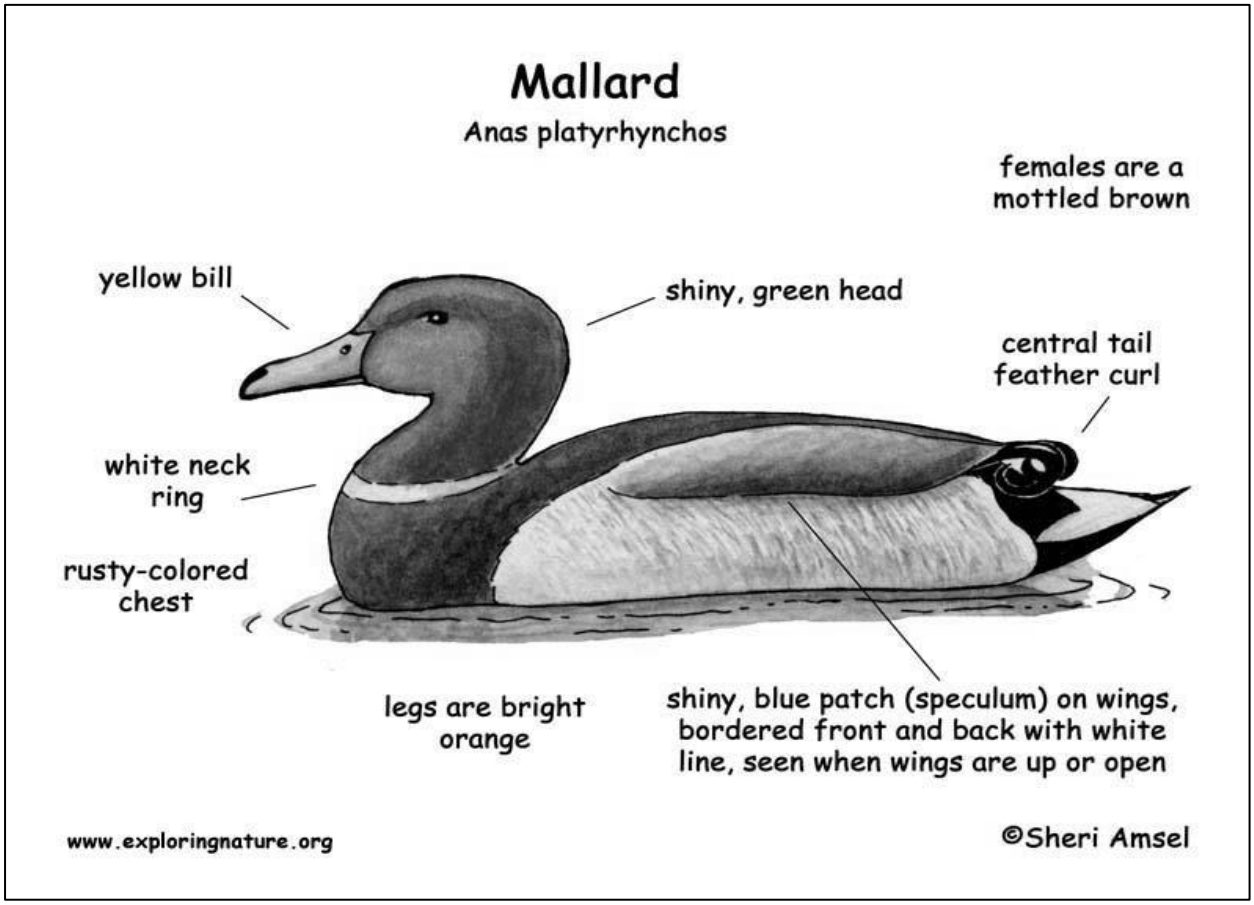


Plate 4: Topography bare feature, Mallard (*Anas platyrhynchos*) 2020. © exploringnature.org, Sheri Amsel (Sheri Amsel, 2020).

2.1.2 The IUCN - Red List Categories and Criteria

The IUCN Red List's definitions and recommendations should be simple to understand when evaluating species that are seriously in danger of going extinct worldwide. The system's main objective is to offer a clear, rational framework for determining which species are the most endangered. Additionally, there are other ways to prioritize conservation efforts to save these taxa, even if the Red List concentrates on those that are most in risk (H R Akçakaya & Ferson, 1999). However, keep in mind that even though the system places species in the threatened classes with a high degree of consistency, the parameters do not account for the life cycle of every individual creature, so in some circumstances the likelihood of extinction may also be overestimated or underestimated (H Reşit Akçakaya et al., 2000).

The IUCN Data Books and the Red List were used to update the definitions of threatened species until 1994. However, the enhancement phase started in 1989 based on a petition document from the IUCN Species Survival Committee (SSC), which was a progressive approach to IUCN research. The International Union for Conservation of Nature approved the New Red List System in 1994,The IUCN Red List's requirements and classifications have a few fundamental goals (Betts et al., 2020):

1. The objective of providing a framework that people can consistently use.
2. To modification topics by providing readers with thorough instructions on how to evaluate various factors influencing the likelihood of extinction.
3. To offer a framework that permits comparisons between diverse taxa.
4. To provide a better knowledge of how species are listed to individuals who use endangered species lists.

The IUCN Red List is available in numerous chronological variants. For the years 1991, 1992, 1993, 1994, 1999, 2000, 2000, ascending order [1.0] - [2.0] - [2.1] - [2.2-2.3] - [3.0] - [3.1].

2.1.3 The Key Categories of Red List of IUCN

A taxon remains extinguished until the final individual has died beyond a reasonable doubt, according to the IUCN Red List version 3.1, which consists of nine basic elements. When thorough examinations in known and/or expected habitat (diurnal, seasonal, yearly) fail to find an individual within the taxon's historical range, the taxon is considered extinct. When a taxon is considered extinct in the wild but has been known to exist in agriculture, captivity, or as a naturalized species or population in the past, surveys should be acceptable for the taxon's growth cycle and form of life across time. This is known as the Extinct code (EX). When thorough examinations in known and/or expected habitat (diurnal, seasonal, yearly) fail to find an individual within the taxon's historical range, the taxon is considered extinct in the wild. Surveys that are appropriate for the taxon's growth cycle and mode of life across time are referred to as "Extinct in the Wild" (EW) (Schwass, 2011).

The taxon is classified as critically endangered and given the code (CR) because the best available data indicates that it satisfies all of the requirements A through E for Critically Endangered (see Section V) and is therefore thought to be facing an extremely high risk of extinction in the wild. A to E for Endangered (see Section V) and is therefore thought to be facing a very high risk of extinction in the wild; this is known as Endangered and is referred to code (EN). Occasionally, the taxon becomes vulnerable because the best available data indicates that it meets all of the requirements. A to E for Endangered (see Section V) and is therefore thought to be facing a high risk of extinction in the wild; this is known as Vulnerable and is referred to code (VU).

The taxon would become Near Threatened when taxon assessment is compared to criteria; this is a taxon that is not key EX-EW-CR-EN-VU, but one becomes its own in the future based on data available (Commission, 2003).

The taxon may be biologically observed, and most people and researchers are certain of it, but evidence of its distribution, quantity, and availability in the habitat may be uncertain; this is known as Data Deficient and its referred code (DD). The taxon is widespread in the wild and ecosystem and data abundance broadest range very more about the taxon, which is called the Least Concern and its referred code (LC). In the end, the taxon was not measured or assessed using the conventional criteria, which are referred to as Not Evaluated and code (NE) (Group, 1999).

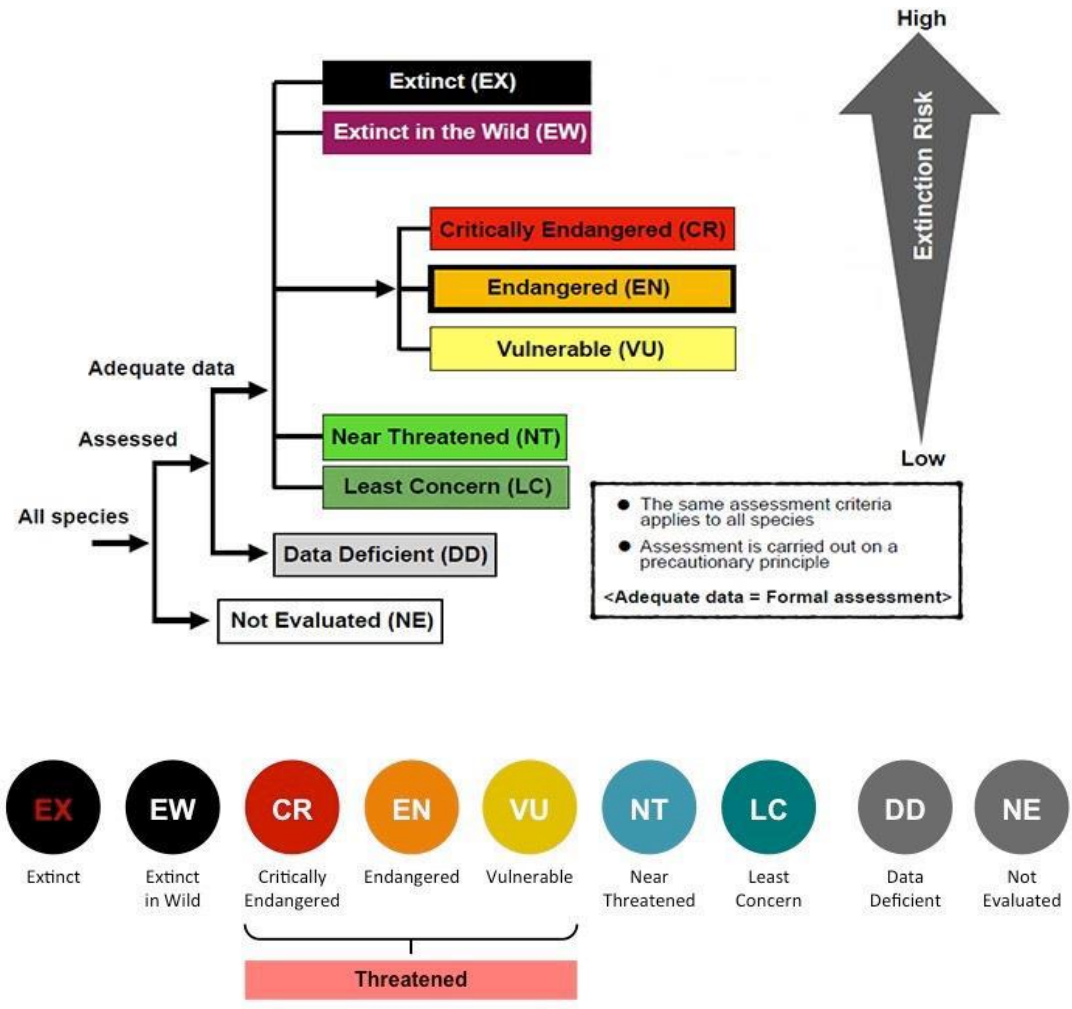


Figure 1. displays the main categories of the IUCN Red List.

2.2 Macro-Geography & Flyway Dynamics

2.2.1 Global Importance of Wetlands for Avian Communities

Wetlands are recognised globally as some of the most productive ecosystems on Earth, supporting important habitat, feeding, and nesting sites for a variety of bird species (Mitsch & Gosselink, 2015). Globally, the significance of these ecosystems as stepping stones along major international flyways, especially for migratory waterbirds escaping the harsh winters in the north, is indicated by ornithological assessments (Little, 2024). The occurrence of fish, macroinvertebrates and aquatic vegetation, the main trophic resources, reflects the extremely dynamic spatial and temporal assembly of the bird populations in these wetlands (Weller, 1999).

From a macroecological standpoint, wetlands play a crucial role as stepping stones along important international migration flyways, acting as vital refuelling stations where migrating waterbirds replenish the protein and fat reserves required for long-distance flight (Boere, 2006). The carrying capacity of whole flyways is determined by the spatial organization and ecological integrity of these wetland networks since the removal or degradation of a single important stopover site can cause severe population bottlenecks spanning thousands of kilometres (Newton, 2023). In order to successfully complete their transcontinental flights, waterbirds from families like Anatidae, Charadriidae, and Scolopacidae show a strong physiological dependence on these watery stopovers (Davidson, 2014).

In addition to serving as migratory staging areas, wetlands provide a high degree of structural variation that encourages niche partitioning and supports a variety of bird functional guilds (Newman, 2011). Wetlands can simultaneously support diving ducks, dabbling waterfowl, wading herons, and mysterious reed-dwelling passerines because to the dynamic interaction between open water, emergent vegetation (Phragmites and Typha spp.), and intertidal or muddy

littoral margins (Voigts, 1973), (Weller, 1999). During times of regional environmental stress, this structural complexity provides microclimatic refugia and predator-free roosting areas, protecting avian communities from localised environmental shocks (Ma et al., 2010).

Due to increased habitat loss, agricultural conversion, hydrological diversion, and climate-induced desiccation, wetland-dependent avifauna are today among the most vulnerable taxonomic groups worldwide, despite their critical ecological value (Akçakaya et al., 2026). Global wetland surface area has decreased by more than 35% since 1970, according to empirical syntheses, which has resulted in concurrent declines in waterbird population abundances across the globe (Davidson, 2014). In order to measure local population trends, assess site fidelity, and guide international conservation priorities under international frameworks like the Ramsar Convention, ornithological literature emphasises the necessity of thorough, multi-temporal species checklists and baseline inventories (Delany, 2005), (Gardner & Finlayson, 2018).

2.2.2. The Mesopotamian Wetlands: Historical Eco-Geography and Hydrological Dynamics

The biggest wetland ecosystem in Western Eurasia is found in the Mesopotamian wetlands in Southern Iraq, which traditionally included the Central, Hammar, and Hawizeh marshes (Partow, 2001). This enormous alluvial delta is a distinct hydrological anomaly in an otherwise extremely dry environment from an eco-geographical standpoint. A highly productive combination of open waterbodies, permanent reed beds, and seasonal mudflats was maintained for millennia by seasonal flood pulses from the Tigris and Euphrates rivers (Sabeeh Mosleh, 2025). Since the Sumerian era, this eco-geographical framework has produced stable ecological conditions that have

sustained ongoing human settlement and complex biological populations, according to historical geography (Stahl, 2026).

Extreme intra-annual and inter-annual variations in water depth, extent, and salinity were characteristic of the Mesopotamian marshes' past hydrological dynamics (Suchantke, 2001). The wetland footprint was regularly increased to over 20,000 square kilometres by spring discharge floods, which also deposited nutrient-rich alluvial deposits and submerged nearby terrestrial lowlands (Partow, 2001). Large beds of emergent macrophytes, primarily Phragmites australis and Typha domingensis, as well as floating aquatic vegetation including Salvinia and Nymphaea species, were produced by this flood-driven pulse ecosystem (Al-Hilli et al., 2009). By stabilising sediment, filtering agricultural runoff, and producing high primary productivity that supported a variety of aquatic food webs, these plant communities served as the wetland's structural backbone (Jawad, 2021).

Large-scale river damming, upstream water diversion, and systematic drainage projects carried out between 1980 and 2000 caused an unprecedented human disturbance of this ancient eco-geographical balance throughout the late 20th century (Partow, 2001),(Adriansen, 2004). By 2001, more than 90% of the permanent marshlands had dried up, turning lush aquatic environments into hypersaline mudflats and desolate desert basins, according to empirical satellite measurements (Ghadiri, 2006),(Alshami et al., 2020). Millions of migratory birds along the Eurasian-African flyway lost vital non-breeding refuges as a result of this catastrophic desiccation, which also caused severe localised extinctions and disturbed regional microclimates (Scott, 1995),(Hashim et al., 2019).

Historical hydrological monitoring following post-2003 partial re-flooding operations showed a fragmented recovery trend limited by recurrent regional droughts and decreased transboundary river flows (Al-Ansari, 2014) (Amr, 2011).Re-flooded basins largely restored plant cover and macroinvertebrate

production, but deteriorating water quality and high saline levels continue to change community assemblages, according to modern ecological syntheses (Hussain et al., 2009). In order to contextualise how current water scarcity and structural habitat alterations affect the carrying capacity of Southern Iraqi wetlands for endemic and migratory avifauna, it is crucial to have up-to-date literature evaluations on the historical hydrological baseline (Porter & Aspinall, 2010), (Allami, 2014).

2.2.3. The Eurasian-African Flyway and the Biogeographical Role of Iraqi Wetlands

From the Arctic breeding regions in Siberia and Northern Europe to the wintering havens in tropical Africa and the Middle East, the Eurasian-African Flyway is one of the most important bird migration corridors in the world (Boere, 2006). The Mesopotamian marshes and nearby shallow waterbodies in southern Iraq serve as an essential biogeographical "choke point" and wintering destination within this vast network (Scott, 1995). Millions of migratory waterbirds, especially those belonging to the groups Anatidae (ducks, geese, and swans), Charadriidae (plovers), and Ardeidae (herons and egrets), depend solely on these localised wetlands to refill their energy stores, moult, and endure the winter (Porter & Aspinall, 2010).

The total survival rate of migratory cohorts along the flyway is determined by the ecological integrity of these stepping-stone wetlands, according to recent macroecological literature (Newton, 2023). In southern semi-arid regions, habitat fragmentation, localised droughts, and fluctuations in water supply generate severe constraints that force migratory bird populations to show

significant ecological adaptability or quickly change their stopover locations (Haig et al., 2019).

Iraq's wetland systems serve as a crucial bottleneck along the flyway because of their location at the intersection of the Palearctic, Afrotropical, and Indomalayan biogeographical worlds (Porter & Aspinall, 2010). Iraqi interior basins provide the main large aquatic stopover where lipid and protein supplies can be quickly restored for millions of waterbirds travelling over the parched regions of the Middle East (Evans, 1994),(Ati et al., 2025). In addition to specialised reed-dwelling passerines, these waterbodies are home to globally significant wintering populations of Anatidae (ducks and geese), Charadriidae (plovers), Scolopacidae (sandpipers), and Ardeidae (herons), according to thorough flyway surveys (Langendoen et al., 2021) , (Delany et al., 2006)

Iraqi wetlands offer vital ecological connectedness that shortens migration transit lengths and protects birds from harsh weather conditions from a biogeographical standpoint (Alerstam, 2011),(Stewart et al., 2022). Semi-arid wetlands support very high species turnover and guild packing during peak spring and autumn transit times, according to seasonal monitoring throughout the flyway (Haileselasie, 2023), (Berti, 2024). Additionally, these habitats sustain important non-breeding populations of globally threatened species, including the Greater Spotted Eagle (Clanga clanga), Basra Reed Warbler (Acrocephalus griseldis), and Marbled Teal (Marmaronetta angustirostris), demonstrating their high conservation value under international biodiversity agreements (Lees et al., 2022).

Middle Eastern stopover wetlands are under growing ecological pressure due to transboundary water scarcity, agricultural expansion, and climate-induced thermal stress, despite their crucial biogeographical role (Partow, 2001),(Adamo et al., 2022). According to recent flyway-scale syntheses, migrating birds are forced to take longer, riskier journeys due to the deterioration or drying of important stopping locations, which results in energy shortages and population

decreases (Ferreira et al., 2024). Therefore, in order to evaluate current flyway connectivity and support global conservation frameworks like the Ramsar Convention and the African-Eurasian Waterbird Agreement, it is essential to maintain ongoing, multitemporal species inventories and systematic checklists in less researched inland basins (Waterbirds, 1999),(Secretariat, 2021).

2.2.4. Migration Mechanics and Passerine vs. Non-Passerine Wintering Patterns

Different behavioural and physiological adaptations are required for avian migration via international flyways, and these adaptations differ greatly among taxonomic orders. Based on their morpho-ecological characteristics, migrating avifauna are typically divided into macro-habitats in wetland stopping sites (Newton, 2023). Large open water surfaces and submerged macrophytes are the primary sources of food for non-passerine waterbirds like Anatidae and Phoenicopteridae, which display conventional wintering site constancy. On the other hand, during their brief stops, migratory passerines (such reed warblers and Acrocephalus species) use the dense emergent plants (Phragmites australis) mainly for insectivorous feeding, structural cover, and predator avoidance (Bairlein, 2016).

Island Biogeography Theory and "Oasis" Dynamics in Fragmented Arid Zones

A growing number of terrestrial ecosystems, especially fragmented wetlands nested within hyper-arid matrices, have adopted the fundamental ideas of the Theory of Island Biogeography (MacArthur & Wilson, 2001). Isolated waterbodies, such as closed desert basins, function well as ecological "islands" or oases encircled by a hostile desert "sea" in arid and semi-arid regions , the macroecological literature emphasises that the size of the patch and its degree of isolation from larger continuous riverine networks tightly regulate the colonisation and extinction rates of avifauna in these isolated systems. Localised checklists are essential for evaluating landscape connectivity models

because these remote oasis are crucial refuelling hubs for migratory species, where the spatial organization of the patch dictates the halting density and duration of avian cohorts (Wiens, 1991).

2.2.5 Climate Change, Phenological Mismatch, and Shifting Migration Timings

One of the main factors influencing the worldwide phenology of migratory avifauna is anthropogenic climate change, which often leads to a situation called "phenological mismatch (Crick, 2004). Avian migration timetables and peak resource availability in stopover habitats are closely synchronised, but as global temperatures rise, environmental indicators like photoperiod and localised thermal regimes diverge (Walther et al., 2002). In order to avoid arriving during times of resource depletion, migratory species that travel over major international flyways are increasingly compelled to modify the timing of their seasonal journeys (Both & Visser, 2001),(Cotton, 2003).

Rising temperatures on northern breeding grounds hasten spring advancement in Palearctic-African migratory systems, causing both passerine and non-passerine species to depart earlier or change their transit speeds (Jonzén et al., 2006). These fluctuating migration windows cause transient cohorts to reach crucial inland basins when aquatic macroinvertebrate pulses and vegetative cover are either premature or already reduced as birds migrate over semi-arid and hyper-arid regions (Knudsen et al., 2011). According to empirical syntheses, even small changes in arrival schedule of a few days can significantly impair energy replenishment rates, hence lowering bodily condition and the likelihood of surviving after a layover (Møller et al., 2008)

Ornithological syntheses highlight that arid and semi-arid stopover environments in the Middle East confront persistent data shortfalls for long-term bird phenology, despite the fact that similar micro-phenological disturbances and timing shifts have been well reported across European and

North American flyways (Evans, 1994),(Newton, 2023). Due to their considerable hydrological inter-annual variability, arid basin stopovers are especially susceptible to compound pressures from both localised habitat desiccation and global heat fluctuations (Bairlein, 2016),(Maclean et al., 2008). Current ornithological research emphasises the need to maintain ongoing, multi-temporal species inventories and systematic checklists throughout important inland waterbodies in order to assess these complex macroecological alterations (Delany, 2005),(Lees et al., 2022). The essential empirical baseline needed to measure current presence-absence patterns, seasonal residency durations, and community turnover rates is provided by standardised checklists. In order to evaluate how regional climatic trajectories affect semi-arid wetlands' ability to operate as stopovers along the Eurasian-African flyway, such baseline data are crucial (Bitterlin & Van Buskirk, 2014).

2.3. Ecological Theories & Landscape Dynamics

2.3.1. Island Biogeography Theory and "Oasis" Dynamics in Fragmented Arid Zones

A key framework for comprehending bird species richness within isolated water ecosystems immersed in hyper-arid matrix has emerged from the application of the Theory of Island Biogeography to continental landscapes (Whittaker et al., 2017),(Beaugrand et al., 2022). Seasonal wetland basins serve as habitat archipelagos or ecological "oases" in semi-arid areas that are encircled by hostile desert landscape (Joyce, 2025), (Fahrig et al., 2019). The dynamic balance between the area-dependent extinction rates of localised species pools and the distance-dependent immigration rates of migratory cohorts essentially controls the ecological diversity found inside these remote waterbodies (Chase et al., 2020).

Isolated desert wetlands show clear "oasis dynamics," where localised hydrological inputs produce unique microclimatic refugia with increased

primary productivity and structural habitat complexity, according to landscape ecology(Ceballos et al., 2020). The overall surface area of open water and emergent vegetation, edge-to-area ratios, and spatial arrangement all significantly influence avian community assemblages within these aquatic islands(Wilson et al., 2016). extremely fragmented or isolated basins sustain limited species pools dominated by generalist taxa, bigger wetland segments offer more structural variety, supporting larger population numbers and minimising localised stochastic extinctions (Ramos-Mosquera et al., 2025).

Aquatic avifauna are more spatially isolated in hyper-arid basins because the adjacent desert matrix serves as a functional barrier to mobility (Kupfer, 2011),(Biz et al., 2017). These remote wetlands serve as non-replaceable stopover locations for migratory waterbirds travelling across transcontinental flyways, where high density-dependent crowding leads to energetic replenishment (Haileselasie, 2023). As a result, regional flyway connectivity is disproportionately jeopardised when a single wetland island in an arid landscape disappears or drastically shrinks, producing ecological traps and obstructing migration corridors across desert biomes (Stevens, 2025).

A strong theoretical framework for analysing species-area interactions and beta diversity variations across remote study stations is provided by combining island biogeography concepts with semi-arid basin inventories (Chase et al., 2020). Researchers may assess how localised habitat isolation and desiccation affect community nestedness and species turnover using quantitative checklists created across fragmented wetland patches, which directly supports contemporary landscape-level conservation measures (Solymos & Lele, 2012).

2.3.2. Avian Diversity in Transitional Ecotones: Semiarid Basins and Desert Landscapes

Because environmental gradients and species pools overlap, ecological ecotones—transitional boundaries where different ecological communities meet

and integrate—often support higher species richness and structural complexity (Kark, 2013). A dynamic boundary zone with severe environmental stress gradients is created in arid and semi-arid regions by the acute ecotone formed between aquatic wetland basins and the surrounding hyper-arid desert landscapes (Pfeifer et al., 2017). These desert-wetland ecotones provide distinct microclimatic conditions by combining terrestrial and limnological resources that support specialised species adapted to both xeric and aquatic biomes, as shown by the synthesis of landscape transition models (Ghaziantafrishi, 2024).

From the standpoint of community assembly, transitional zones between semiarid aquatic basins and desert topography show a clear "edge effect," in which the co-occurrence of transitory wetland dependent guilds and resident desert specialists increases local bird species richness (Wrensford et al., 2025). The humid edge of wetland basins is used by desert avifauna—adapted to high aridity, physiological water conservation, and scarce scrub vegetation—for nocturnal roosting and additional hydration(Williams & Tieleman, 2005),(Burraco et al., 2025).

Gradients in plant density and changes in soil salinity throughout the transition zone significantly influence the functional organization of bird communities in desert-wetland ecotones (Nguyen et al., 2025).. Avian guild packing gradually changes as thick macrophyte stands (Phragmites and Typha spp.) grade into halophytic shrubs (Tamarix, Salsola, and Suaeda spp.) and finally into the arid desert floor (González-Oreja et al., 2018; Boulton et al., 2022). These vegetative transition areas are vital movement corridors and thermal refugia for migrating passerines, lowering their exposure to predators and offering vital chances for lipid replenishment prior to trans-desert flights, according to empirical field evaluations (Schmaljohann et al., 2022).

Desert-wetland ecotones are particularly vulnerable to hydrological changes, land-use conversion, and climate-induced aridification notwithstanding their ecological significance as hotspots for biodiversity (Desta et al., 2012). Aquatic

footprint shrinkage speeds up edge erosion, narrowing the microclimatic gradient and causing ecotonal species to be excluded from competition (Faria, 2024). In order to assess spatial species turnover (beta diversity) and create reliable baseline conservation measures in evolving dryland ecosystems, multi-station sampling procedures must be implemented over the whole length of desert-to-wetland transects (Kark, 2024).

2.3.3. Niche Partitioning and Guild Packing in Fluctuation-Driven Wetlands

Coexisting taxa reduce competitive exclusion in species-rich avian assemblages by dividing trophic niches and segregating microhabitats (Schoener, 1974). This phenomenon is known as "guild packing" in wetland ecosystems, where closely related species use different vertical and horizontal zones of the waterbody according to their morphological adaptations, such as leg length and bill shape. For example, waterfowl divide open waterways into dabbling and diving zones, whereas shorebirds divide muddy littoral zones based on the depth their probes can reach. According to ecological synthesis, bird populations must continuously rearrange their spatial organization in order to maximise resource utilisation in fluctuation-driven semi-arid wetlands because niche dimensions dynamically compress or expand in response to water levels (Weller, 1999).

Niche partitioning and functional guild packing mechanisms play a crucial role in regulating the organization of bird communities in aquatic environments with extreme hydrological variability (Holm & Clausen, 2006).The divergence of resource utilisation over geographical, temporal, and trophic axes mitigates possible interspecific competition among co-occurring waterbirds, according to traditional ecological niche theory (Chase & Leibold, 2009). Sympatric species must dynamically divide the available resource space in fluctuation-driven wetlands, where water depth, submerged macrophyte cover, and benthic

biomass undergo quick, climate-induced changes, in order to preserve stable coexistence and avoid competitive exclusion (Chesson, 2000).

The wetland avifauna's spatial and morphological niche partitioning is especially noticeable along structural vegetation zones and fine-scale water depth gradients (Mathot et al., 2019). Wading birds (Ardeidae, Threskiornithidae) show unique leg- and bill-length allometry that divides shallow littoral margins and prevents inter-family spatial overlap by limiting their foraging effectiveness to particular water depth thresholds (Aharon-Rotman et al., 2017). On the basis of neck reach, lamellar density, and diving mechanics, which determine the particular vertical zone of aquatic vegetation or benthic macroinvertebrates each species can exploit, waterfowl (Anatidae) split into three distinct functional feeding guilds: surface dabblers, shallow grazers, and deep-water divers (Brochet et al., 2012). Specialised food preferences and prey-size selection among coexisting species in the same physical habitat further intensify trophic niche segregation (Reid et al., 2019).

In exposed mudflat habitats, specialised probing shorebirds (Scolopacidae) avoid direct interference competition with visual surface foragers (Charadriidae) by using their unique bill lengths and tactile sensory organs to obtain benthic prey from varied substrate levels (du Toit, 2022). Additionally, by foraging at particular vertical stem heights or focusing on different size classes of phytophagous arthropods, insectivorous passerines living in emergent reed beds (Phragmites australis) divide micro-habitats and maximise functional guild packing within structurally homogeneous vegetative stands (Leisler & Schulze-Hagen, 2015).

Seasonal water drawdowns compress available aquatic habitat in semi-arid basins that fluctuate, increasing resource overlap and causing functional guild borders to quickly realign (Royan, 2015). High prey densities in contracting waterbodies momentarily promote tight guild packing during hydrological contraction phases, but prolonged desiccation eventually results in the

competitive replacement of specialised foraging guilds by ecologically plastic generalists (Poff & Zimmerman, 2010). Therefore, assessing the level of guild packing and niche partitioning across multi-station species inventories offers crucial empirical insights into the ecological integrity and functional resilience of dynamic wetland ecosystems (Violle et al., 2012)

2.3.4. Phenology and Temporal Turnover of Avian Communities

Important indicators of environmental variability are the temporal dynamics and phenological changes that occur within bird communities. The species composition in wetland ecosystems is constantly changing; life-history events including breeding, post-breeding dispersal, and migration cause abrupt seasonal turnovers (Farley-Dawson, 2017). According to macroecological literature, researchers can pinpoint the exact moment of community reconfiguration by using systematic checklists to monitor monthly or seasonal variations in species richness and relative abundance. In semi-arid wetlands, where the abrupt inflow of seasonal visitors momentarily rearranges the community's competitive hierarchy and resource partitioning methods, this temporal turnover is most noticeable (Buckley et al., 2021).

The structure of avian communities in seasonal aquatic habitats is intrinsically dynamic, with significant temporal turnover caused by migratory patterns, local environmental cues, and macro-phenological events (Bairlein, 2016). As different migratory cohorts arrive, stage, and go, species richness and abundance in continental wetland networks vary systematically throughout annual cycles (Newton, 2023). The ecological response of waterbirds to shifting hydrological regimes, thermal limitations, and seasonal peaks in primary productivity is reflected in temporal turnover, which is the continuous sequence of species replacement across time (Dornelas et al., 2014). Wetlands undergo strong pulses in community turnover during the spring and fall passage periods,

which are marked by quick changes in the species composition and functional guild organization (Helm & Liedvogel, 2024). Endogenous circannual rhythms and photoperiod signals determine the arrival and departure phenologies of transcontinental migrants using inland stopovers (Knudsen et al., 2011). Short residence periods that are ideal for quick lipid deposition are established by transient species, which lead to significant species beta-diversity across subsequent sampling intervals and the formation of transient assemblages that are fundamentally different from baselines for wintering or breeding communities (Shimadzu et al., 2015).

Unpredictable inter-annual hydrological changes and extreme environmental stress further complicate the phenology of bird turnover in semi-arid and desert basins (Royan, 2015). Seasonal drawdowns cause a noticeable transition from open-water diving species to shallow-water wading guilds and coastal mudflat foragers by compressing aquatic surface area and changing water chemistry (Yinglan et al., 2023). Species-specific tolerances to salt, heat exposure, and prey accessibility control the rate of temporal turnover during these contraction periods, causing ecologically sensitive taxa to leave desiccating basins while generalist species continue to exist (Bagheri & Gholamhossieni, 2026). Multi-temporal, standardised species inventories carried out over entire seasonal cycles are necessary to quantify temporal turnover and phenological shifts (Blowes et al., 2019). Researchers can distinguish between regular migratory passage cycles and stochastic environmental shocks by monitoring presence-absence transitions, community dissimilarity indices, and seasonal residence durations across fixed observation stations (Legendre, 2019). In fluctuating dryland wetlands, establishing these empirical phenological baselines is crucial for determining crucial temporal windows of maximal biodiversity value and guiding focused conservation initiative (Secretariat, 2021).

2.4. Behavioral Ecology & Foraging Economics

2.4.1. Foraging Economics and Optimal Foraging Theory in Wetland Basins

Optimal Foraging Theory, which holds that individuals choose foraging micro-habitats to maximise net energy intake per unit of time while minimising search and handling costs, fundamentally governs the spatial distribution and patch selection of wetland avifauna in fluctuating aquatic basins (Bartumeus & Catalan, 2009). Water depth thresholds determine the physical ability of tactile and visual foragers to remove benthic prey, and hydrological regimes directly control foraging economics by modifying prey accessibility and energetic intake rates across various functional guilds (Gawlik, 2002). Before severe desiccation upsets benthic food webs, seasonal drawdowns in semi-arid and arid basins dynamically compress aquatic surface area, producing brief bursts of high prey density that significantly reduce search costs for opportunistic foraging guilds (Royan, 2015).

A useful framework for assessing avian habitat preference and figuring out whether localised wetland patches serve as energetic sources or sinks for migrating avifauna is provided by incorporating optimal foraging economics into multi-station species surveys (Lees et al., 2022).

When localised intake rates fall below the average projected yield of the surrounding environment, waterbirds are predicted to leave a foraging patch, according to the Marginal Value Theorem (Smith & De Lillo, 2022). Foraging efficiency is greatly altered by interspecific rivalry and kleptoparasitism, which compels subordinate species to accept less-than-ideal energy returns or change their preference for microhabitats to peripheral, lower-yield patches (Coogan et al., 2018). Foraging birds must weigh the trade-offs between energy gains and vulnerability to physiological stress or apex predators due to the interaction between thermal restrictions and predation risks (Garcia-Walther, 2025).

The net profitability threshold for coexisting avian species is defined by functional morphology, such as bill shape and lamellar spacing, which establishes the handling time needed for particular prey sizes (Green et al., 2016).

2.4.2. Density-Dependent Mechanisms and Aggregation Behaviour (Flocking)

In seasonal aquatic habitats, bird populations' geographic distribution, social structure, and population control are mostly controlled by density-dependent mechanisms. Individual fitness is significantly impacted by intra- and interspecific population densities as waterbirds concentrate within distinct wetland patches due to localised interference dynamics and per capita resource availability. Negative density-dependent processes, like resource depletion, increased energy expenditure during competitive encounters, and higher disease transmission rates, start to control community stability at high population densities and drive subdominant individuals to disperse toward marginal, lower-quality habitats (Lidfors, 2021).

A significant adaptation approach intended to balance the trade-offs between energy intake and mortality risks is the creation of dense mixed-species aggregations, or flocking behaviour. The dilution effect and the "many-eyes" hypothesis both state that large-scale aggregation greatly increases collective alertness against apex predators while also lowering the likelihood of individual predation during surprise assaults. Additionally, flocking plays an important information-sharing role in which waterbirds use the feeding success of nearby individuals as visual cues to find sporadic, transient food supplies like schooling fish in open water zones or thick macroinvertebrate beds (Sumpter, 2010).

High flock densities often cause density-dependent interference competition, which alters individual foraging economics, despite the obvious antipredator and foraging advantages of social aggregation. Physical interactions, territorial

aggression, and prey depression—where benthic creatures burrow deeper into the substrate in response to severe mechanical disturbance—all significantly increase handling times and reduce net energy gains when spatial crowding increases along shallow littoral margins. As a result, waterbirds dynamically modify their flock positions and inter-individual distances according to their competitive standing, compelling lower-ranked individuals to give up the security of the center flock core in favour of periphery locations with less interference but greater exposure to predators (Beauchamp, 2013).

By compressing aquatic surface areas, hydrological contraction phases serve as a main physical motor that artificially enhances density-dependent mechanisms in changing semi-arid basins. Seasonal drawdowns drive waterbird populations into high spatial crowding, creating transient, hyper-dense aggregations that quickly deplete localised food stores by isolating waterbodies into fragmented pools. Multi-station species inventories that include density-dependent characteristics and flocking metrics offer crucial empirical insights into how social dynamics, habitat shrinking, and spatial crowding all work together to determine the functional carrying capacity of changing dryland wetlands (Sutherland & Norris, 2002).

2.4.3. Night-Migration and Nocturnal Habitat Selection in Wetland Basins

Due to an evolutionary adaptation that provides substantial physiological and survival advantages over diurnal transit, the great majority of migrating waterbirds and wetland-dependent passerines fly across continents at nite. By using stable, non-turbulent atmospheric layers, nocturnal migration enables birds to migrate thru cooler, denser nite air, which significantly lowers evaporative water loss and thermal stress during prolonged flight. Additionally, migrating at nite offers vital defence against daytime avian predators, allowing

long-distance migrants to traverse dangerous terrain and large hyper-arid biomes with much lower mortality risks (Rees, 2008).

A complex hierarchy of landscape-scale spatial cues, water surface reflectivity, and audio calls from settled conspecifics or heterospecifics controls nocturnal habitat selection upon landing within inland wetland basins. In order to locate suitable aquatic stopover oases set in gloomy, terrestrial matrix, nocturnal migrants heavily rely on the polarisation of moonlight and skylight reflected off open water surfaces as they begin their descent before dawn. When they arrive, they quickly assess the characteristics of the micro-habitat, giving priority to sheltering littoral zones, shallow mudflats, and emergent vegetation stands that provide instant refuge from chilly ambient temperatures and nocturnal animal predators (Chernetsov, 2006).

Many waterbird guilds actively engage in nocturnal foraging beyond safe roosting, switching from visual hunting techniques to tactile and sensory-guided prey acquisition. This is especially true of probing shorebirds (Scolopacidae) and dabbling waterfowl (Anatidae). These nocturnal foragers take advantage of overnight spikes in benthic invertebrate activity, when aquatic worms, crustaceans, and larvae emerge from deep sediment layers to eat in shallow waters, by using specialised mechanoreceptors located in the ends of their bills. Waterbirds can maximise daily energy intake, minimise interfering competition with diurnal foragers, and make up for missed foraging time due to human disturbances throughout the day by feeding at nite (van Gils et al., 2015),(Piersma et al., 2006).

Establishing thorough conservation and spatial planning frameworks requires including nocturnal habitat selection dynamics and movement patterns into wetland biological assessments. Because they are unable to identify high-density nocturnal roosting aggregations or nightly foraging movements across shifting environments, standardised daily bird surveys often underestimate the true ecological importance of particular wetland basins. In fragile dryland

ecosystems, assessing both diurnal and nocturnal spatial utilisation guarantees that conservation efforts maintain the functional link between daylight forage regions and nightly thermal refugia (Johns et al., 2024).

2.4.4. Anthropogenic Disturbance and the "Landscape of Fear" in Wetland Avifauna

Beyond complete habitat loss, human disruptions have a significant impact on bird communities in developing places, creating a useful "landscape of fear (Laundré et al., 2010). Water birds' perceived risk of predation is altered by non-lethal deterrents such as nearby vehicle movements, livestock grazing along wetland margins, and uncontrolled hunting pressures. Chronic disturbance pushes birds to become more vigilant at the expense of foraging efficiency, as evidenced by avian behavioural ecology. This frequently leads sensitive, specialised species to completely abandon high-quality feeding zones. As a result, both historical and modern checklists often depict a structural change throughout time, characterised by the progressive replacement of huge, cautious non-passerines by highly accustomed, opportunistic species that can withstand human presence (Madsen, 1995).

Waterbirds must constantly balance their energy intake against perceived predation dangers due to the complicated "landscape of fear" created by human-induced activities in inland aquatic environments. Recreational boating, grazing, artisanal fishing, and vehicle traffic are examples of non-lethal human disturbances that cause flight-initiation distances and behavioural vigilance responses that are structurally similar to natural predator interactions (Frid & Dill, 2002). Waterbirds are frequently driven from high-quality feeding patches when human incursion increases inside shallow basin edges, increasing daily energy consumption and severely limiting the amount of time allotted to vital lipid deposition (Halassi et al., 2022).

This disturbance-driven landscape's temporal and spatial presentation compels bird groups to modify their daily activity budgets and micro-habitat choices. Vulnerable species sometimes leave lucrative coastal feeding zones during the day in severely altered wetland basins, moving to less-than-ideal periphery habitats or completely changing their foraging routines to nocturnal times (Gill et al., 2001). Because ongoing behavioural disruption affects physiological body condition and lowers long-term survival rates across both resident and staging migratory groups, this loss of functional habitat diminishes the wetland's total ecological carrying capacity (Rogers et al., 2006).

Functional characteristics, flock sizes, and past exposure determine species-specific tolerance thresholds to anthropogenic disturbance, which cause notable changes in species evenness and community structure. Large-bodied wading birds and timid waterfowl are examples of highly sensitive guilds that show lower habituation potential and longer flight-initiation distances than ecologically plastic generalists (Husby, 2025). Persistent human intrusion thereby modifies local competitive dynamics, favouring hyper-tolerant taxa and displacing disturbance-sensitive specialists, thereby artificially homogenising community composition across fragmented water basins (Borgmann, 2011).

Differentiating between natural hydrological population dynamics and habitat degradation caused by humans requires quantifying the impact of anthropogenic disturbance within standardised multi-station inventories. Researchers can map the functional impact of human activity over dryland wetlands by combining species abundance counts with behavioural measures like vigilance rates, flushing frequency, and geographical avoidance zones (Stolen, 2003). The creation of efficient buffer zones, seasonal site closures, and focused conservation measures that lessen the landscape of dread for vulnerable waterbird populations are all made possible by the establishment of these spatial baselines (Secretariat, 2021).

2.5. Community Metrics, Statistics & Conservation

2.5.1. Theoretical Framework of Avian Diversity and Community Structure

In bird community ecology, simply counting the number of species is often not sufficient to assess the stability and health of the ecosystem. Therefore, current macroecological studies are mainly based on detailed checklists and statistical diversity indexes to quantify the underlying community structure (Magurran, 2003). Shannon-Weiner Index (H') and Simpson's Dominance Index (D) are commonly employed within dissertation framework to estimate species evenness and the relative abundance of dominant vs rare species across different seasons (Spellerberg & Fedor, 2003). Balanced ecosystems are generally very even, while degraded or very variable wetlands tend to have a dominance of a few hardy or opportunistic species (Ali et al., 2026).

The intricate interaction between stochastic neutral assembly mechanisms and deterministic niche-based processes is the theoretical foundation for avian diversity and community structure. According to traditional ecological theories, species features determine survival and competitive outcomes within a particular habitat, and local abiotic gradients and biotic interactions are the main filters that define community membership (Colorado Zuluaga, 2015). These deterministic forces coexist with dynamic dispersal events in inland wetland ecosystems, creating community assemblies that constantly change in response to landscape variety and environmental stability (Chase, 2003).

In order to fully capture ecosystem complexity, quantifying biodiversity within waterbird assemblages necessitates a multifaceted methodology that incorporates taxonomic, functional, and evolutionary diversity indices. Conventional alpha diversity indicators, such Pielou's evenness, Simpson's dominance, and Shannon-Wiener diversity, assess the distribution of localised species richness and abundance across discrete sample stations (Magurran,

2004). However, compared to taxonomic counts alone, functional diversity metrics—which assess the range and distribution of ecological features within a guild—offer a much better mechanistic relationship to ecosystem functioning and resource processing, according to contemporary macroecological frameworks (Petchey & Gaston, 2006).

The fundamental biological mechanisms causing species replacement and community dissimilarity across fragmented landscapes are reflected in the spatial turnover in avian community composition, which is expressed as beta diversity. Strong environmental filtering or dispersal limitation, where diverse micro-habitats maintain distinct bird assemblages suited to localised hydrological or vegetative conditions, is indicated by high beta diversity across wetland stations (Baselga, 2010). Researchers can ascertain whether species loss across stations is due to habitat degradation or natural spatial niche partitioning by separating the two different components of beta diversity—true species turnover vs nestedness-driven richness differences (Lande, 1996).

In order to evaluate multi-station biological inventory in dynamic arid basins, a strong theoretical framework for bird diversity measurements must be established. Researchers can assess the environmental health and structural stability of sensitive aquatic ecosystems by methodically monitoring alpha, beta, and functional community indices over seasonal cycles (Gotelli & Colwell, 2001). In the end, this theoretical synthesis helps ecologists to establish evidence-based management frameworks across regional wetland networks, identify priority conservation sites, and forecast community reactions to ongoing aridification (List, 2004).

2.5.2. The Concept of Dominance and Evenness in Semi-Arid Wetlands

The structural structure of bird communities in seasonal and semi-arid wetland habitats is typified by dynamic fluctuations between species dominance and

community evenness. Dominance, which is frequently fuelled by high ecological flexibility and generalist foraging techniques, is the numerical or biomass predominance of one or a small number of hyper-abundant species that monopolise accessible resource locations (D'Antonio et al., 2002). On the other hand, species evenness, a highly sensitive metric for assessing environmental stress and structural integrity within dynamic aquatic biomes, quantifies the relative distribution of individuals among co-occurring taxa (Wilsey & Potvin, 2000).

The balance between dominant generalists and specialised taxa among wetland stations is mostly determined by environmental changes, especially hydrologic drawdowns and high water salinity. High habitat heterogeneity enables a variety of feeding niches during benign, resource-rich hydrological phases, increasing evenness as specialised waders and ducks effectively divide littoral zones (Mulder et al., 2004). However, when aquatic surface areas are compressed by severe desiccation, environmental filtering becomes more intense, which results in the competitive displacement of sensitive specialists and the overwhelming dominance of opportunistic, swarming species like some Anatidae or Larus species (Roswell et al., 2021).

Strong species domination can dramatically reduce local alpha diversity indices and change the dynamics of lower-trophic food webs from the standpoint of functional ecology. Benthic macroinvertebrates and seed banks are subject to disproportionate top-down pressure from high concentrations of dominant bird eaters, which limits the availability of resources for rare or subdominant species and promotes local community homogenisation (Crowder & Cooper, 1982). Monitoring variations in Pielou's evenness index and Berger-Parker or Simpson dominance indices is crucial for determining if an aquatic basin is undergoing natural successional cycles or human-caused deterioration (Tagliapietra et al., 2012).

Establishing reliable ecological baselines in fragile dryland basins requires incorporating quantitative assessments of dominance and evenness into multi-station species checklists. Before a species completely goes extinct, researchers can identify environmental tipping points brought on by localised water scarcity, pollution, or habitat fragmentation by identifying shifts toward extreme dominance (Soetaert, 2010). Thus, under international biodiversity monitoring systems, maintaining high community evenness across regional wetland networks continues to be a priority conservation goal (Secretariat, 2021).

2.5.3. Multivariate Statistics and Ordination Techniques in Avian Community Ecology

Advanced multivariate statistical frameworks that can handle high-dimensional, non-linear, and zero-inflated ecological datasets are necessary for the analysis of complex community assemblages across spatial and temporal dimensions. In bird community ecology, standard univariate measurements often fail to capture subtle community transitions and environmental gradient interactions between discrete sample stations (Legendre & Legendre, 2012). By lowering dataset dimensionality, multivariate ordination approaches offer a potent analytical method that enables ecologists to see trends in species composition and pinpoint the main environmental factors influencing waterbird assemblages across changing landscapes (Borcard et al., 2011).

Using only species presence-absence or abundance matrices, unconstrained ordination techniques like Principal Coordinates Analysis (PCoA) and Non-metric Multidimensional Scaling (NMDS) assess fundamental patterns of community resemblance. For bird community ecology, NMDS in particular continues to be the most reliable unconstrained method due to its rank-order distance methodology, which successfully manages non-normal distribution patterns and high percentage of zeros typical of patchy wetland avifauna (Oksanen, 2015). Without imposing prior environmental grouping assumptions,

researchers can objectively assess spatial beta diversity and identify natural clustering within bird groups by plotting sampling stations along reduced ordination axes (Warton et al., 2015).

Constrained (canonical) ordination methods like Canonical Correspondence Analysis (CCA) and Distance-Based Redundancy Analysis (db-RDA) are frequently used to explicitly characterise the links between avian community structure and measurable abiotic factors. These direct gradient analysis approaches show particular niche needs for different functional guilds by directly constraining species axs to linear combinations of environmental factors, such as water depth, soil salinity, vegetation covering, and distance to human disturbance (Zuur et al., 2010). Additionally, variation partitioning techniques enable researchers to separate the relative roles of spatial autocorrelation and pure environmental filtering in influencing avian distribution patterns within networks of semi-arid basins (Dray et al., 2012).

A rigorous mathematical basis for hypothesis testing and ecological inference in changing dryland wetlands is provided by incorporating multivariate statistical approaches into multi-station species inventories. Researchers can discover important bio-indicator species that are responsible for station differentiation and statistically confirm significant spatial-temporal variations in community composition using Permutational Multivariate Analysis of Variance (PERMANOVA) and Indicator Species Analysis (ISA) (Ahmad, 2011).

2.5.4. Functional Trait Diversity and Ecosystem Services in Wetland Avifauna

In contrast to species richness alone, functional trait diversity—the distribution of morphological, physiological, and behavioural traits within a community—offers a much more robust mechanical foundation for comprehending ecosystem functioning, according to contemporary ecological perspectives. Functional characteristics including bill shape, tarsus length, food

specialisation, and flying ability directly control how bird groups use spatial resources and process energy in wetland habitats (da Frota et al., 2021). The robustness of local assemblages to continuous hydrological stress is therefore determined by changes in functional trait composition across environmental gradients, which reflect the underlying physiological filtering functioning within dynamic aquatic environments (Tobias et al., 2022).

Throughout dryland wetland networks, avian groups serve as vital mobile linkages that mediate important ecological functions like seed distribution, nitrogen cycling, and top-down pest control. In order to facilitate plant migration and preserve genetic linkage between far aquatic basins, waterbirds serve as important vectors for endozoochorous long-distance seed transmission (Almeida et al., 2022). Additionally, a high degree of functional diversity within foraging guilds improves the delivery of ecosystem services thru complementary resource use, where a variety of bill structures and foraging strategies optimise the management of agricultural pests and nuisance aquatic insect populations in nearby littoral ecosystems (Green & Elmberg, 2014).

Long before the loss of taxonomic species is clearly visible, functional trait diversity is selectively eroded by environmental degradation, hydrological fragmentation, and climate-induced desiccation. Under extreme drought regimes, specialised functional guilds—like large-bodied wading birds that need deep-water margins or highly specialised mudflat probers—exhibit significant trait sensitivity, making them vulnerable to quick functional extinction (Asmus et al., 2025). Ecosystem service networks become unstable and secondary ecological collapses occur throughout degraded wetland basins as a result of the loss of these important functional groupings, which erodes trait space redundancy (Roschildt et al., 2026).

Evaluating the ecological integrity of fluctuating wetlands requires quantifying functional trait measurements, such as Functional Richness (FRic), Functional Evenness (FEve), and Functional Divergence (FDiv), within standardised multi-

station surveys. Researchers can map functional vulnerability hotspots and rank conservation stations according to service delivery capacity rather than just abundance counts by combining functional diversity indices with taxonomic inventories (Aleixo, 2025). The creation of these trait-based baselines offers crucial factual backing for international wetland restoration requirements and predicted climate adaptation methods (List, 2004).

2.5.5. The Mid-Winter Waterbird Census (IWC) Framework and Citizen Science

One of the most extensive long-term biodiversity monitoring systems in avian ecology and conservation biology is the International Waterbird Census (IWC), which is organised worldwide by Wetlands International. Every January, the IWC operations throughout important international flyways to systematically monitor waterbird population estimates, spatial distributions, and site condition changes during the non-breeding season (Austin et al., 2023). This standardised multi-site inventory provides crucial baseline data needed to assess site significance under international protection criteria like the Ramsar Convention. It is based on synchronised count techniques that reduce double-counting errors and capture large-scale spatial shifts (Nagy & Langendoen, 2020).

The IWC framework's geographic reach, temporal continuity, and analytical capability have all been significantly increased by the incorporation of citizen science projects and networks of trained volunteers. Professional research teams would not be able to logistically or financially access the huge spatial-temporal datasets that non-professional observers gather across thousands of wetland locations under the guidance of standardised procedures and strict validation protocols (Zaviezo, 2018). In order to account for observer bias, fluctuating sampling effort, and spatial clustering, sophisticated ecological modelling techniques like occupancy modelling and semi-parametric spatial smoothing are

being used more frequently to convert crowdsourced biological records into reliable population trends (Feldman et al., 2021).

The IWC framework's data offer vital empirical underpinnings for estimating regional populations, spotting population decreases at the flyway level, and recognising ecological changes brought on by habitat degradation and climate change. Researchers can distinguish between true population-level breakdowns across wintering waterbird guilds and localised weather-induced distribution shifts by gathering decades of standardised mid-winter counts (Squalli et al., 2024). Additionally, long-term IWC datasets enhance site-selection criteria for Special Protection Areas (SPAs) and worldwide Ramsar designations across sensitive wetland networks by making it possible to identify important wintering hotspots and stepping-stone refugia (Berti, 2024).

The comparative rigour and policy relevance of ecological assessments are greatly increased when regional multi-station wetland surveys use IWC standardised methodologies and citizen science observational networks. Local species inventories can directly support global biodiversity reporting requirements by standardising counting windows and scientific techniques, which guarantees smooth data integration into international flyway assessments (Boere et al., 2006). A key component of long-term ecological surveillance, adaptive wetland management, and evidence-based conservation policy across shifting dryland basins is the establishment of enduring, community-engaged monitoring programs based on the IWC framework (List, 2004).

2.5.6. Global Conservation Status and Threat Assessment of Wetland Avifauna

Due to increased habitat degradation, human pressures, and global climate change, wetland-dependent birds are currently among the most vulnerable taxonomic groups worldwide (Fernandez et al., 2025). The International Union for Conservation of Nature (IUCN) Red List of Threatened Species, which

categorises vulnerable taxa into distinct groups like Critically Endangered (CR), Endangered (EN), and Vulnerable (VU), is the definitive baseline for assessing the extinction risk of avian populations within the global conservation framework (Akçakaya et al., 2026).

Wetlands in semi-arid areas like the Middle East are severely stressed ecologically by desiccation and water diversion, which directly reduces these ecosystems' ability to support species of high conservation significance (Prater, 2010) . The literature on ornithology highlights that systematic local inventories are an essential precondition for global conservation strategy (Donald et al., 2019) .

Agricultural development, hydrological change, and wetland draining are the main anthropogenic stressors driving population decreases in wetland avifauna. In dryland river basins, direct water abstraction, dam building, and river canalisation drastically alter natural flow patterns, desiccating vital reproductive margins and foraging shallow mudflats (Jahan & Ali, 2026). Additionally, heavy metal and agrochemical-laden agricultural runoff causes severe bioaccumulation and eutrophication, which leads to toxic algal blooms and hypoxic benthic dead zones that disrupt lower-trophic food chains and limit migrating waterbirds' access to food (Davidson, 2014).

By changing precipitation patterns, increasing the frequency of catastrophic droughts, and speeding sea-level rise along coastal flyways, global climate change exacerbates classic anthropogenic risks. Increased aridification causes rapid wetland reduction in semi-arid inland basins, pushing waterbirds into degraded, hyper-saline refugia where heat stress and the spread of diseases like avian botulism increase quickly (Asmus et al., 2025). Rising sea levels and inflexible human infrastructure cause a significant "coastal squeeze" on coastal stopover habitats, which eliminates vital intertidal staging places and causes severe energy deficits during transcontinental migratory passage (Lisovski et al., 2024).

Prioritising evidence-based conservation activities and coordinating local management with global mandates need the execution of thorough threat assessments within multi-station biological inventories. Researchers may map significant extinction risk hotspots across changing dryland landscapes, classify susceptible functional guilds, and detect site-specific pressures by using standardised threat appraisal frameworks (Rosenberg et al., 2019). In order to protect the world's wetland bird biodiversity, establishing these empirical baselines facilitates the execution of focused habitat restoration programs and strengthens international policy frameworks like the Ramsar Convention and the African-Eurasian Migratory Waterbird Agreement (AEWA) (Gardner & Finlayson, 2018).

2.6. Functional Guilds and Seasonal Dynamics

A complete inventory of the field and checklist is a basic tool to categorise the avifauna into functional guilds according to their habitat preferences and foraging habits (e.g., piscivores, invertivores and herbivores). A ground-breaking study on marsh avifauna reveals that the functional composition of bird communities dramatically changes between migratory seasons (Wiens, 1989). The arrival of Palearctic migrants dramatically alters the dynamics of the local community for the duration of the winter, intensifying competitive interactions for food and shelter. This can be visualised quantitatively using Whittaker plots or rank-abundance curves to observe community evenness over time (Salewski et al., 2002).

A strong analytical framework for comprehending community assembly and ecosystem functioning is provided by grouping wetland avifauna into functional guilds, which are collections of species that share morphological and behavioural adaptations to utilise similar ecological resources. Guild-based frameworks, which include deep-water dives, shallow-water dabblers, surface filter-feeders, and probing waders, classify species according to their dietary preferences, foraging strategies, and structural habitat needs rather than just

taxonomic diversity (Whitfield et al., 2022). The functional trait composition of these guilds determines how bird groups react to spatial habitat availability and energy flow across dynamic inland aquatic basins, acting as a major force behind the provision of ecosystem services across varying wetland landscapes (Green & Elmberg, 2014).

Thru intercontinental migration routes and cyclic hydrological regimes, seasonal dynamics substantially reorganise the spatial distribution and composition of functional guilds. Sharp increases and decreases in aquatic surface areas are caused by seasonal variations in water supply, which constantly reset the availability of habitat and the accessibility of benthic prey throughout wetland stations (Royan, 2015). While seasonal drawdowns change community dominance toward specialised probing shorebirds and wading guilds that take advantage of exposed, hyperproductive intertidal mudflats and shallow littoral margins, deep-water foraging guilds thrive in limnetic zones during high-water seasonal phases (Asmus et al., 2025).

Intense temporal changes in functional guild density are brought about by the seasonal intake of migratory cohorts, increasing competition between and within species for limited aquatic resources. Co-occurring resident and migratory guilds undergo nutritional changes and micro-habitat niche partitioning as a result of staging and wintering migratory waterbirds, which significantly raise total community energetic demands (de Leija, 2025). Subordinate functional guilds must enlarge their foraging niches, modify their daily activity budgets, or relocate to nearby regional stepping-stone wetlands in order to meet daily maintenance metabolisms when environmental conditions worsen during dry seasons due to resource depletion (Re, 2026).

To identify ecological tipping points and map functional vulnerability in dryland wetland networks, it is crucial to assess the seasonal trajectories of functional guilds across standardised sampling stations. Researchers can differentiate between artificial habitat degradation, such as flow regulation or

wetland drainage, and natural successional transitions by monitoring temporal changes in guild diversity measures (Frota et al., 2022). The integration of functional guild dynamics into multi-station species inventories offers crucial empirical backing for conservation frameworks and adaptive water management strategies that preserve functional redundancy in dynamic aquatic environments (List, 2004)

CHAPTER THREE

3. Methodology

3.1 Study Area Description

3.1.1 Geographical Location and Boundaries

This study was carried out at Hor Al-Sulaibat, a significant wetland environment in southern Iraq. The wetland polygon and study borders were created with Geographic Information System (GIS) tools and satellite photos figure 2.



Figure 2 . Show Map of Hor Al-Sulaibat in ArcGIS

Hor Al-Salibat is located 30 km southwest of the Al-Khidr district in Al-Muthanna Governorate—a route that includes 17 km of unpaved road. It lies 60 km southeast of the city of Al-Samawah and 40 km from the city of Nasiriyah,

Situated on the right bank of the Euphrates River, the marsh spans both Al-Muthanna and Dhi Qar governorates, positioned at approximately 45.37° E longitude and 30.5° N latitude. Hor Al-Salibat is a subsurface basin measuring 71 km in length and 23 km in width, with a depth ranging from 75 cm to 4.5 meters and a storage capacity of approximately 1.75 billion cubic meter (plate 20) , It serves as a water reservoir, receiving its supply from the Euphrates River, the marsh covers an estimated area of 508,000 dunams, with 232,000 dunams located in Al-Muthanna Governorate and the remainder falling within Dhi Qar Governorate., The Al-Amir River (formerly Al-Qadisiyah) flows into it, with its water supply originating from the 47-kilometer-long Shatt al-Atshan, The marsh is surrounded on three sides by elevated desert terrain, except for the side parallel to the Euphrates River. It is situated within the Euphrates formations—deposits of the floodplain that extend for a considerable distance to the south and southwest of the Euphrates, reaching deep into the alluvial plain (Al-Dulaimi, 2012).







Plate (5) A Landscape view of Hor Al-Sleibaat

3.1.2. Topography and Hydrological Characteristics

The topographical variation across Hor Al-Sulaibat was characterized using a Digital Elevation Model (DEM) derived from SRTM. Terrain elevation ranges from 4 meters above sea level in the deepest central basin to 12 meters along the outer peripheral boundaries. These topographical gradients govern the hydrological spatial pattern, water depth retention, and localized inundation dynamics across the wetland system (Richardson & Hussain, 2006).

3.1.3. Climate Profile

The local microclimate was modelled using multi-parameter spatial surface layers generated from high-resolution gridded climate datasets (Fick & Hijmans, 2017).

3.2. Avian Field Survey Protocol

3.2.1. Whole-Wetland Area Search Protocol

A Whole-Wetland Area Search Protocol was used to examine avifauna diversity, species richness, and continuous spatial distribution patterns across Hor Al-Sulaibat. Given the study site's open terrain and spatial breadth, a comprehensive area-search strategy was used to provide complete spatial representation while avoiding sampling isolated locations (Bibby et al., 2000).

3.2.2. Survey Execution and Recording

Field counts were conducted throughout all representative ecosystems (Gregory et al., 2004) . High-powered optics (10 × 42 binoculars and a 20 × 60 field spotting scope) were used to detect, identify, and count avian species both visually and aurally (Porter & Aspinall, 2010). Every sighting or flock position was recorded as a separate event point with precise GPS coordinates (x, y). To standardise the sample effort, counts were undertaken at peak avian activity hours (06:00 - 09:00 and 04:00 - 07:00) (Bibby et al., 2000). The survey excluded birds that were transiting at high altitudes. Taxonomic classification adhered to the standardised eBird/Clements Checklist of Birds of the World (Clements et al., 2023) .

3.2.3 Garments Color

Avoid wearing bright colors that could attract curious birds and drive away other birds by dressing in dull, colorless clothing Area Count Protocol (ACP) based on (Huff et al., 2000; Mark E. Hostetler and Martin B. Main, 2014; Thompson III et al., 2002).

3.2.4 Study time & Field Equipment

The present study performed a field survey of Hor Al- Sulaibat from September 2024 to March 2026, conducting a daytime survey to record diurnal species and

a nighttime survey to record nocturnal species, as well as tracking traces of fauna and hearing their sound to collect data for the complete checklist.

Table (2) Show the equipment used in the survey area during the period of study.

No	System	Model
1	Camera Canon	EOS 2000D
2	Camera Nikon	COOLPIX 900
3	Zoom Sigma	70-300mm F4-5.6 DG MACRO
4	Binocular 88 @1000 M	Bushnell 12 x 50
5	Telescope	LEUPOLD-15-45 x 60MM
6	Remax Power Bank 74 H	Linon Pro RPP-73
7	Memory Bank 1.0 TB	ADATA-HD720-2T
8	GPSMAP	GARMIN-64
9	Mobile iPhone	iPhone 7 Mac software
10	Mid-size Tripod	DOH
11	Wader Clothes	

3.3 Spatial analysis of Hor Al-Sulaibat via ARC- GIS

3.3.1. Satellite Data Acquisition

Hor Al-Sulaibat was covered with multispectral satellite imagery (Landsat/Sentinel) on the dates of the field surveys. In ArcGIS, images were corrected for radiometry, geometry, and atmospheric conditions.

3.3.2 Normalized Different Vegetation Index (NDVI)

The vegetation index, sometimes referred to as NDI/NDVI, is a helpful predictor of green land or agricultural health. Additionally, the Vegetation Index, often called NDI/NDVI, is a straightforward graphical indication that may be used to examine remote sensing data, frequently from a space platform, in order to determine whether vegetation is sustaining the object under observation (Birtwistle et al., 2016). Because plants in green areas have a high capacity to absorb red light from the visible spectrum and a low capacity to reflect it off leaves, as well as a high capacity to reflect and absorb infrared

light, this indication disrupts the process of photosynthesis. It is an inverse measure of the density and health of vegetation (Spadoni et al., 2020). While clouds and snowfields are slightly negative (0–0.1), vegetation NDVI values are often strongly positive (0.3–0.8), ground NDVI values are moderately positive (0.1–0.2), and lotic or lentic water (oceans, seas, lakes, and rivers) has mildly positive or mildly negative NDVI values (Pettorelli, 2013). As in the mathematical formula:

$$\boldsymbol{NDVI} = \frac{NIR - RED}{NIR + RED} \qquad FORMULA\ FOR\ NDVI$$

$$\boldsymbol{NDVI} = \frac{\text{Band 5} - \text{Band 4}}{\text{Band 5} + \text{Band 4}} \qquad NDVI\ FOR\ Landsat\ 8$$

3.4. GIS Spatial Analysis & Ecological Modeling

Spatial modeling of avian occurrence points and environmental layers was executed in ArcGIS Pro/Desktop using the following analytical modules:

3.4.1. Modeling Optimized Hot Spot Analysis in ARC-GIS

The Getis-Ord Gi* statistics are used to create a map of statistically significant hot and cold locations based on event points or weighted features (points or polygons). It judges the features of the input function class to obtain the best performance. This approach is used to identify statistically significant spatial clusters with high values (Hot Spots) and low values (Cold Spots). It automatically collects event data, estimates the necessary scale for review, and adjusts for spatial dependency and multiple testing. To find the settings that yield the best performance for hot spot analysis, the program queries the data

(Said et al., 2017). Incident statistics are points that represent either events (crimes, people) or objects (trees, shops, bird species). In this case the issue is presence or absence, not a computed value associated with each point (Youyu et al., 2008). Polygons or points can be used as input features. This program creates a new Output Feature Class with z-score, p-value, and trust level bin (Gi Bin) for each feature of the Input Feature Class. Polygons require a field of analysis. The number of neighbors for each element used in its computations is also contained in a field called N-Neighbors. Getis-Ord Gi* computes the degree of correlation between weighted characteristics using Gi*(Bagdanavičiūtė et al., 2019). For modeling had to insert 30 or more points into the polygon. The input characteristics must have variable values, that is, not all values are the same as an integer.

$$\boldsymbol{Gi}= \frac{\sum_{j=1}^{n} wijxj}{\sum_{j=1}^{n} xj} \qquad \boldsymbol{z\ score}= \frac{x-\mu}{\sigma}$$

Table 3 : Dialog Reference in ARC-GIS

Parameter	Explanations	Form of data
Input features	**Reference Python:** The point or polygon feature class on which the hot spot analysis is done.	Feature - Layer
Output features	**Python Reference** The output feature class to receive the z-score, p-value, and Gi-Bin results.	Feature - Class

3.4.2. Modeling Kernel Density Estimation (KDE - Spatial Analyst)

Almost all scientific research by ARC-GIS uses the KDE modeling kernel, it is used to find unique wildlife protected areas and to find bird selection habitats (O'Brien et al., 2012). The distribution of settlements and increases in the number of sites recorded over time have been the main concerns of certain research using KDE in environmental assessment, which are archeological survey data for the assessment of landscape patterns (Bonnier et al., 2019). The preferred habitat of birds or other wildlife can be measured using Kernel Density in the ARC software 10.8 (Awad & Abed, 2023). In order to match a smoothly tapering surface to each point or polyline, the kernel function is used to calculate the magnitude-by-unit region using point or polyline data. Larger values of the search radius parameter produce a simpler, more generalized density raster. The app was utilized for this technique on ecosystems and for spatial analysis; smaller values produce a tracer that gives more information (O'Brien et al., 2012),(Ross, 2006).

$$fkernel\,(x) = \frac{1}{Nb} \quad \sum_{i=}^{N} K \quad \left(\frac{xi-x}{b}\right)$$

The table 4 : Dialog Reference in ARC-GIS

Parameter	Explanations	Form of data
Input features	**Reference Python:** The point or polygon feature class on which the hot spot analysis is done.	Feature - Layer
Output features	**Python Reference** Performance of the kernel density-raster. It's still a floating-point raster.	Raster

3.4.3. Modeling Analyzing Pattern Distribution (ANN)

The Average nearest neighbor index is calculated using the average distance between each feature and its closest adjacent feature. It is given as the ratio of the observed mean distance to the expected mean distance. Five values are produced by the Average Neighborhood Tool, including Z-score, P-value, Observed Mean Distance, Nearest Neighbor Index, and Expected Mean Distance (Ghent & Zucker, 1990). According to interpretation modeling, if the index is less than 1, the pattern clustering is applicable; if the index is more than 1, the tendency is toward competition or dispersion (Long et al., 2010). The nearest average neighbor method is highly sensitive to the area value; even slight changes in the area parameter value can have a significant impact on the z-score and p-value outcomes.

$$ANN = \frac{\bar{D}o}{\bar{D}E} \qquad \bar{D_o} = \frac{\sum_{i=1}^{n} di}{n} \qquad D_E = \frac{0.5}{\sqrt{n/A}} \qquad z = \frac{\bar{D}0 - \bar{D}E}{SE} \qquad sE = \frac{0{\cdot}26136}{\sqrt{n2/A}}$$

$\bar{D_o}$ = Average Nearest Neighbor ratio

D_E=(observed mean distance between each feature and its nearest neighbor)

D_E = (expected mean distance for feature given in random pattern)

d_i=the distance between feature i and its NN feature

n= total number of features

A=$area\ of\ miniium\ enclosing\ rectangle\ around\ all\ feature$

The table 5 : Dialog Reference in ARC-GIS

Pattern type	Value ANN	Sub- pattern	Value NN
Cluster -	< 1.0	Cluster shape	0
		Cluster – No regular	0 - 0.5
		Cluster – Trend random	0.5 - 1
Random	= 1.0		1.0
Dispersed	> 1.0	Dispersed in distance	1.0 – 2.0
		Dispersed – Square shape	2.0
		Dispersed – Hexagonal shape	> 2.0

3.4.4. Inverse Distance Weighted (IDW) Interpolation

The interpolation technique was applied in ArcGIS. IDW is a deterministic, non-exact spatial interpolation approach based on Waldo Tobler's First Law of of Geography, which states that spatially close sites have a greater influence on

on anticipated values than farther away ones (Maleika, 2020) , (Tobler, 1970). This method interpolates unknown cell values by taking a weighted average of nearby observed sample points (such as avian density counts or environmental readings), with weights assigned inversely proportional to the distance between the sampled location and the target prediction node (Gong et al., 2014; Bhowmik et al., 2022).

The general mathematical framework for IDW spatial interpolation is given below (Lu & Wong, 2008) :

$$\widehat{Z}(x_0) = \frac{\sum_{i=1}^{N} \frac{Z(x_i)}{d_i^p}}{\sum_{i=1}^{N} \frac{1}{d_i^p}}$$

Where:

- $\hat{Z}(x_0)$ is the interpolated predicted value for the unsampled target location x_0.
- $Z(x_i)$ represents the known observed value at the i-th sampled location x_i.
- d_i is the Euclidean distance between the target prediction location x_0 and the i-th sampled point x_i.
- N denotes the total number of sampled observation points used in the local estimation neighborhood.
- p is the distance power exponent ($p \geq 1$, typically set to $p = 2$ for standard inverse-squared distance weighting), which dictates the rate at which the influence of a sampled point diminishes over spatial distance.

Within the geographical framework of this thesis, IDW modelling was used to construct continuous surface maps, which allowed for continuous mapping of spatial variables and provided an interpolated baseline for investigating spatial correlations with avian distribution patterns across the marsh.

3.4.5. Bivariate Spatial Modeling

Bivariate Spatial Modelling in ArcGIS was used to investigate the continuous spatial overlap and geographical covariation of avian community aggregation patterns and underlying environmental/climatic causes (Bivand et al., 2017). Unlike standard univariate spatial models, bivariate raster modelling maps two distinct continuous variables at the same time across a uniform spatial grid. This enables the visual and quantitative identification of regional concordance (the presence of high bird density and optimal environmental conditions) as well as geographical discordance across Hor Al-Sulaibat (Lee, 2018).

Mathematically, the local spatial association between the two variables over the raster grid can be determined using the Bivariate Local Moran's I, defined as (Anselin, 2019) :

$$I_{xy}^{(k)} = z_x^{(k)} \sum_{j=1}^{N} w_{kj}\, z_y^{(j)}$$

Where:

- $I_{xy}^{(k)}$ is the Bivariate Local Moran's I statistic at spatial location (cell) k.
- $z_x^{(k)}$ is the standardized value (z-score) of variable x (e.g., avian Kernel Density / KDE) at location k, calculated as $z_x^{(k)} = \frac{x_{k-x}}{\sigma_x}$
- $z_y^{(j)}$ is the standardized value (z-score) of variable y (e.g., NDVI, Temperature, or Aridity) at neighboring location j.
- w_{kj} represents the standardized spatial weight matrix element defining the spatial connectivity/proximity between location k and neighboring location j.
- N is the total number of spatial neighbors surrounding location k.

This bivariate spatial indexing divides the wetland landscape into three distinct spatial regimes: High-High (areas of elevated bird density coincident with high environmental values), Low-Low (coincident low values), and spatial anomalies (High-Low or Low-High), providing important ecological insights into habitat selection dynamics.

3.4.6. Utilisation Distribution (UD) and Core Habitat Modelling

The Utilisation Distribution (UD) model, derived from the Kernel Density Estimation (KDE) raster surface, was used to quantify the spatial footprint of bird habitat use and designate discrete core activity zones across Hor Al-Sulaibat. The UD generates a spatial probability density surface that computes the continuous likelihood of encountering an individual bird or flock within any given spatial unit of the wetland boundary (Maslo et al., 2019).

CHAPTER FOUR

4. Result and Discussion

4.1. Ecological Importance of Hor Al-Sulaibat

The Hor Al-Sulaibat wetland ecosystem plays a critical role as a key biodiversity and a vital sanctuary for avifauna in southern Iraq, serving as an essential breeding ground, wintering shelter, and strategic refueling stopover along the Intercontinental Eurasian-African Flyway (Salim et al., 2009; Fazaa et al., 2015).

Hor Al-Sulaibat marsh represents a pioneer environmental scientific study—the first of its kind in the region—focusing on the natural characteristics of the marsh's water quality and sediments, which feature high concentrations of salts and sulfates due to natural springs (such as Al-Ouhashih springs) and agricultural drainage loaded with organic matter, alongside lakebed sediments enriched with chemical elements. This ecosystem, supported by diverse vegetation (such as reeds, typha, and desert shrubs adapted to harsh conditions), serves as an essential habitat, strategic staging post, and vital sanctuary attracting migrating and local bird flocks along desert flyways. Conversely, the presence of vulnerable and threatened species is attributed to the wetland's rich biological resources and aquatic food web; however, these rare species face severe existential threats (driven by illegal hunting, mass eradication using toxic and internationally banned pesticides like D.D.T. and mustard, electro-fishing, and ongoing water scarcity and drought crises (Al-Dulaimi, 2012).

4.1.1. Discussion of Avifauna Data and Comparative Analysis

The systematic avifaunal inventory conducted in the Hor Al-Sulaibat wetland revealed a remarkably diverse and structurally complex avian community comprising 72 species belonging to 29 families and 11 taxonomical orders (table 6).

The bird species were divided into three groups first, Breeding Residents, this group comprises 25 species that inhabit and breed within the wetlands, agricultural lands, and arid landscapes of Iraq year-round such as the Eastern Greylag Goose (Anser anser rubrirostris), second, Breeding Summer Visitors, this group includes 18 species that arrive in Iraq during the spring and summer months specifically for breeding such as the Little Bittern (Ixobrychus minutus) and the European Turtle Dove (Streptopelia turtur), and third, Passage Migrants & Winter Visitors, this group consists of 29 species that utilize Iraqi wetlands and terrestrial ecosystems either as overwintering grounds or as critical refueling stops along the Eurasian-African flyways such as the Gadwall (Anas strepera) and the Marbled Teal (Marmaronetta angustirostris).

This high taxonomic richness emphasizes the critical ecological role of Hor Al-Sulaibat as a major biodiversity hotspot, stopover refuge, and wintering ground along the West Asian-East African flyway. The community structure is quantitatively dominated by the order Passeriformes with 27 species, followed by Charadriiformes with 18 species, Pelecaniformes with 7 species, and Anseriformes with 5 species.

An analysis of numerical abundance (Total Number of Individuals, TNI) highlights key population concentrations that reflect the wetland's carrying capacity and trophic productivity. Migratory waterfowl recorded high abundances, led by the Eurasian Teal (*Anas crecca*) with 1,160 individuals, which represents the highest overall count among all observed species. This is complemented by significant populations of the Northern Shoveler (*Anas clypeata*, TNI = 130), Gadwall (*Anas strepera*, TNI = 40), and Greylag Goose (*Anser anser*, TNI = 23) (table 6). The occurrence of 20 individuals of the globally near-threatened Marbled Teal (*Marmaronetta angustirostris*) confirms

that the wetland provides essential breeding and foraging refugia for sensitive Mesopotamian endemic waterfowl.

The order Charadriiformes exhibited extensive numerical representation, dominated by gulls, terns, and probe-foraging shorebirds occupying exposed mudflats and shallow open water margins. The Black-headed Gull (*Chroicocephalus ridibundus*, TNI = 350) and Slender-billed Gull (*Chroicocephalus genei*, TNI = 210) were the most dominant larids, followed by the Whiskered Tern (*Chlidonias hybrida*, TNI = 185) and Armenian Gull (*Larus armenicus*, TNI = 60). Shorebird communities were heavily represented by the Little Stint (*Calidris minuta*, TNI = 140), Common Redshank (*Tringa totanus*, TNI = 110), Black-winged Stilt (*Himantopus himantopus*, TNI = 85), Kentish Plover (*Charadrius alexandrinus*, TNI = 75), and Common Greenshank (*Tringa nebularia*, TNI = 48).

This structural co-occurrence indicates a rich spatial zonation of littoral mudflats offering diverse invertebrate prey depths. Passerines (Passeriformes) formed the most taxonomically diverse group, closely linked to the structural density of emergent macrophytes (*Phragmites australis* and *Typha domingensis*) and terrestrial halophytic scrublands. Dominant passerines included the House Sparrow (*Passer domesticus*, TNI = 450), Barn Swallow (*Hirundo rustica*, TNI = 310), Common Chiffchaff (*Phylloscopus collybita*, TNI = 270), Eurasian Skylark (*Alauda arvensis*, TNI = 220), Crested Lark (*Galerida cristata*, TNI = 180), Graceful Prinia (*Prinia gracilis*, TNI = 160), and Spanish Sparrow (*Passer hispaniolensis*, TNI = 130). Wetland-associated passerines such as the White Wagtail (*Motacilla alba*, TNI = 115), Black-headed Wagtail (*Motacilla feldegg*, TNI = 90), Sand Martin (*Riparia riparia*, TNI = 95), Water Pipit (*Anthus spinoletta*, TNI = 62), and

Great Reed Warbler (*Acrocephalus arundinaceus*, TNI = 44) demonstrate the seamless ecological gradient linking open water to terrestrial desert margins.

Waterbirds of Pelecaniformes and Gruiformes further supported the trophic structure, including the Eurasian Coot (*Fulica atra*, TNI = 120), Common Moorhen (*Gallinula chloropus*, TNI = 65), Little Egret (*Egretta garzetta*, TNI = 50), Western Cattle Egret (*Bubulcus ibis*, TNI = 45), Grey Heron (*Ardea cinerea*, TNI = 34), Squacco Heron (*Ardeola ralloides*, TNI = 25), Black-crowned Night Heron (*Nycticorax nycticorax*, TNI = 15), and Glossy Ibis (*Plegadis falcinellus*, TNI = 12). Apex avian predators were well-represented by the Western Marsh Harrier (*Circus aeruginosus*, TNI = 18), Steppe Buzzard (*Buteo buteo*, TNI = 14), Long-legged Buzzard (*Buteo rufinus*, TNI = 9), and Short-toed Snake Eagle (*Circaetus gallicus*, TNI = 2) (table 6).

Crucially, the presence of 5 individuals of the globally Endangered Steppe Eagle (*Aquila nipalensis*), alongside 2 individuals of the Vulnerable European Turtle Dove (*Streptopelia turtur*), 38 individuals of Hypocolius (*Hypocolius ampelinus*), 58 individuals of Afghan Babbler (*Turdoides huttoni*), and 52 individuals of Pin-tailed Sandgrouse (*Pterocles alchata*), highlights the ecosystem's international conservation value.

To contextualize these findings within a broader biogeographical framework, wetlands in southern Iraq (Hor Dalmaj, Hawizeh Marsh, Central Marshes, and Al-Hammar Marsh) as well as key regional wetland ecosystems across the Middle East, including the Shadegan Wetland in southwestern Iran, Bubiyan Island/Khor Al-Subiya in Kuwait, and the South Al-Batinah coastal/wetland sites in Oman.

On a local scale, when compared to Hor Dalmaj (Al-Sheikhly & Al-Azawii, 2019), Hor Al-Sulaibat exhibits a strikingly similar overall taxonomic diversity but differs significantly in species dominance and microhabitat utilization.

While Hor Dalmaj is characterized by large open water bodies that attract vast wintering rafts of Eurasian Coot (*Fulica atra*) and Greater Flamingo (*Phoenicopterus roseus*), Hor Al-Sulaibat supports a significantly higher concentration of wintering dabbling ducks, specifically Eurasian Teal (*Anas crecca*, 1,160 individuals) and Northern Shoveler (*Anas clypeata*, 130 individuals). Furthermore, Sulaibat's expansive, gently sloping mudflats host a greater relative abundance of small migratory waders (*Calidris minuta*, 140 individuals; *Tringa totanus*, 110 individuals) compared to the deeper, more sharply defined boundaries of Hor Dalmaj.

In comparison with the central Mesopotamian core marshes (Hawizeh and Central Marshes; Nature Iraq, 2017), Hor Al-Sulaibat functions as an ecotonal transition zone between true freshwater marshes and semi-arid halophytic steppes. Permanent freshwater marshes like Hawizeh maintain higher densities of obligate reed endemics such as the Basra Reed Warbler (*Acrocephalus griseldis*) and Iraq Babbler (*Argya altirostris*). In contrast, Hor Al-Sulaibat maintains a unique balance where wetland obligates co-occur with arid-zone specialists, as evidenced by high counts of Afghan Babbler (*Turdoides huttoni*, 58 individuals), Hypocolius (*Hypocolius ampelinus*, 38 individuals), Crested Lark (*Galerida cristata*, 180 individuals), and Pin-tailed Sandgrouse (*Pterocles alchata*, 52 individuals). Regarding apex predators, Sulaibat’s count of Western Marsh Harrier (*Circus aeruginosus*, 18 individuals) and globally Endangered Steppe Eagle (*Aquila nipalensis*, 5 individuals) rivals or exceeds density indices reported from disturbed sections of Al-Hammar Marsh, proving its integrity as an undisturbed raptor corridor.

On a regional scale, comparing Hor Al-Sulaibat with the Shadegan Wetland in Khuzestan, Iran (Fazeli & Naderi, 2018)—which shares the Karun/Tigris-Euphrates basin influence—reveals substantial ecological parity in wintering

Anatidae and Laridae populations. Both ecosystems serve as critical staging hubs for Eurasian Teal (*Anas crecca*) and Marbled Teal (*Marmaronetta angustirostris*). However, Hor Al-Sulaibat demonstrates a higher representation of specialized passerines, whereas Shadegan exhibits higher proportions of marine-associated Pelecaniformes due to its direct estuarine connectivity with the Persian Gulf. When compared to the coastal intertidal mudflats of Bubiyan Island and Khor Al-Subiya in Kuwait (Pope & Al-Sirhan, 2010), Hor Al-Sulaibat shares a similar Charadriiformes assemblage (*Charadrius alexandrinus*, *Tringa nebularia*, *Chroicocephalus genei*), but differs by providing extensive freshwater macrophyte cover (*Phragmites*/*Typha*) that supports large populations of passerines and rallids entirely absent from coastal Kuwaiti mudflats. Furthermore, comparison with Arabian Peninsula stopovers (Evans, 1994; Porter & Aspinall, 2010) emphasizes that Hor Al-Sulaibat provides a much richer inland trophic base capable of sustaining both massive herbivorous waterfowl and top raptors simultaneously.

The Table 6 : List fauna: Birds of Hor Al-Sulaibat with number of individual per species

N	Common Name	Order	Family	Gens	Species	Authority	TSN - ITIS	TNI	IUCN Red-List Categories
1	Greylag Goose	Anseriformes	Anatidae	*Anser*	*Anser anser*	Linnaeus, 1758	175028	23	LC
2	Gadwall	Anseriformes	Anatidae	*Anas*	*Anas strepera*	Linnaeus, 1758	175073	40	LC
3	Northern Shoveler	Anseriformes	Anatidae	*Anas*	*Anas clypeata*	Linnaeus, 1758	175096	130	LC
4	Eurasian Teal	Anseriformes	Anatidae	*Anas*	*Anas crecca*	Linnaeus, 1758	175081	1160	LC
5	Marbled Teal	Anseriformes	Anatidae	*Marmaronetta*	*Marmaronetta angustirostris*	Ménétries, 1832	553925	20	NT
6	Little Grebe	Podicipediformes	Podicipedidae	*Tachybaptus*	*Tachybaptus ruficollis*	Pallas, 1764	563259	99	LC
7	Great Crested Grebe	Podicipediformes	Podicipedidae	*Podiceps*	*Podiceps cristatus*	Linnaeus, 1758	174491	4	LC
8	Glossy Ibis	Pelecaniformes	Threskiornithidae	*Plegadis*	*Plegadis falcinellus*	Linnaeus, 1766	174924	12	LC
9	Little Bittern	Pelecaniformes	Ardeidae	*Ixobrychus*	*Ixobrychus minutus*	Linnaeus, 1766	174850	8	LC

N	Common Name	Order	Family	Gens	Species	Authority	TSN - ITIS	TNI	IUCN Red-List Categories
10	Black-crowned Night Heron	Pelecaniformes	Ardeidae	*Nycticorax*	*Nycticorax nycticorax*	Linnaeus, 1758	174832	15	LC
11	Squacco Heron	Pelecaniformes	Ardeidae	*Ardeola*	*Ardeola ralloides*	Scopoli, 1769	174861	25	LC
12	Western Cattle Egret	Pelecaniformes	Ardeidae	*Bubulcus*	*Bubulcus ibis*	Linnaeus, 1758	174843	45	LC
13	Grey Heron	Pelecaniformes	Ardeidae	*Ardea*	*Ardea cinerea*	Linnaeus, 1758	174779	34	LC
14	Little Egret	Pelecaniformes	Ardeidae	*Egretta*	*Egretta garzetta*	Linnaeus, 1766	174820	50	LC
15	Short-toed Snake Eagle	Accipitriformes	Accipitridae	*Circaetus*	*Circaetus gallicus*	Gmelin, 1788	175501	2	LC
16	Western Marsh Harrier	Accipitriformes	Accipitridae	*Circus*	*Circus aeruginosus*	Linnaeus, 1758	175431	18	LC
17	Steppe Buzzard	Accipitriformes	Accipitridae	*Buteo*	*Buteo buteo*	Linnaeus, 1758	175383	14	LC
18	Long-legged Buzzard	Accipitriformes	Accipitridae	*Buteo*	*Buteo rufinus*	Cretzschmar, 1827	175390	9	LC
19	Steppe Eagle	Accipitriformes	Accipitridae	*Aquila*	*Aquila nipalensis*	Hodgson, 1833	175411	5	EN

N	Common Name	Order	Family	Gens	Species	Authority	TSN - ITIS	TNI	IUCN Red-List Categories
20	Common Moorhen	Gruiformes	Rallidae	*Gallinula*	*Gallinula chloropus*	Linnaeus, 1758	176284	65	LC
21	Eurasian Coot	Gruiformes	Rallidae	*Fulica*	*Fulica atra*	Linnaeus, 1758	176291	120	LC
22	Black-winged Stilt	Charadriiformes	Recurvirostridae	*Himantopus*	*Himantopus himantopus*	Linnaeus, 1758	176726	85	LC
23	Red-wattled Lapwing	Charadriiformes	Charadriidae	*Vanellus*	*Vanellus indicus*	Boddaert, 1783	176489	42	LC
24	White-tailed Lapwing	Charadriiformes	Charadriidae	*Vanellus*	*Vanellus leucurus*	Lichtenstein, 1823	176492	28	LC
25	Kentish Plover	Charadriiformes	Charadriidae	*Charadrius*	*Charadrius alexandrinus*	Linnaeus, 1758	176504	75	LC
26	Common Redshank	Charadriiformes	Scolopacidae	*Tringa*	*Tringa totanus*	Linnaeus, 1758	176633	110	LC
27	Marsh Sandpiper	Charadriiformes	Scolopacidae	*Tringa*	*Tringa stagnatilis*	Bechstein, 1803	176632	30	LC
28	Common Greenshank	Charadriiformes	Scolopacidae	*Tringa*	*Tringa nebularia*	Gunnerus, 1767	176628	48	LC
29	Wood Sandpiper	Charadriiformes	Scolopacidae	*Tringa*	*Tringa glareola*	Linnaeus, 1758	176617	16	LC

N	Common Name	Order	Family	Gens	Species	Authority	TSN - ITIS	TNI	IUCN Red-List Categories
30	Common Sandpiper	Charadriiformes	Scolopacidae	*Actitis*	*Actitis hypoleucos*	Linnaeus, 1758	176654	22	LC
31	Little Stint	Charadriiformes	Scolopacidae	*Calidris*	*Calidris minuta*	Leisler, 1812	176652	140	LC
32	Temminck's Stint	Charadriiformes	Scolopacidae	*Calidris*	*Calidris temminckii*	Leisler, 1812	176663	35	LC
33	Collared Pratincole	Charadriiformes	Glareolidae	*Glareola*	*Glareola pratincola*	Linnaeus, 1766	176779	19	LC
34	Slender-billed Gull	Charadriiformes	Laridae	*Chroicocephalus*	*Chroicocephalus genei*	Brème, 1839	824035	210	LC
35	Black-headed Gull	Charadriiformes	Laridae	*Chroicocephalus*	*Chroicocephalus ridibundus*	Linnaeus, 1766	824043	350	LC
36	Armenian Gull	Charadriiformes	Laridae	*Larus*	*Larus armenicus*	Buturlin, 1934	560721	60	LC
37	Gull-billed Tern	Charadriiformes	Laridae	*Gelochelidon*	*Gelochelidon nilotica*	Gmelin, 1789	176931	15	LC
38	Little Tern	Charadriiformes	Laridae	*Sternula*	*Sternula albifrons*	Pallas, 1764	824137	27	LC
39	Whiskered Tern	Charadriiformes	Laridae	*Chlidonias*	*Chlidonias hybrida*	Pallas, 1811	176958	185	LC

N	Common Name	Order	Family	Gens	Species	Authority	TSN - ITIS	TNI	IUCN Red-List Categories
40	Pin-tailed Sandgrouse	Pterocliformes	Pteroclidae	*Pterocles*	*Pterocles alchata*	Linnaeus, 1766	177044	52	LC
41	European Turtle Dove	Columbiformes	Columbidae	*Streptopelia*	*Streptopelia turtur*	Linnaeus, 1758	177142	2	VU
42	Egyptian Nightjar	Caprimulgiformes	Caprimulgidae	*Caprimulgus*	*Caprimulgus aegyptius*	Lichtenstein, 1823	555572	8	LC
43	Common Kingfisher	Coraciiformes	Alcedinidae	*Alcedo*	*Alcedo atthis*	Linnaeus, 1758	554549	13	LC
44	Pied Kingfisher	Coraciiformes	Alcedinidae	*Ceryle*	*Ceryle rudis*	Linnaeus, 1758	554536	41	LC
45	Blue-cheeked Bee-eater	Coraciiformes	Meropidae	*Merops*	*Merops persicus*	Pallas, 1773	555660	64	LC
46	Red-backed Shrike	Passeriformes	Laniidae	*Lanius*	*Lanius collurio*	Linnaeus, 1758	560720	29	LC
47	Daurian Isabelline Shrike	Passeriformes	Laniidae	*Lanius*	*Lanius isabellinus*	Hemprich & Ehrenberg, 1833	560725	17	LC
48	Hypocolius	Passeriformes	Hypocoliidae	*Hypocolius*	*Hypocolius ampelinus*	Bonaparte, 1850	560544	38	LC
49	Crested Lark	Passeriformes	Alaudidae	*Galerida*	*Galerida cristata*	Linnaeus, 1758	560130	180	LC

N	Common Name	Order	Family	Gens	Species	Authority	TSN - ITIS	TNI	IUCN Red-List Categories
50	Eurasian Skylark	Passeriformes	Alaudidae	*Alauda*	*Alauda arvensis*	Linnaeus, 1758	178398	220	LC
51	Sand Martin	Passeriformes	Hirundinidae	*Riparia*	*Riparia riparia*	Linnaeus, 1758	178436	95	LC
52	Barn Swallow	Passeriformes	Hirundinidae	*Hirundo*	*Hirundo rustica*	Linnaeus, 1758	178448	310	LC
53	Common Chiffchaff	Passeriformes	Phylloscopidae	*Phylloscopus*	*Phylloscopus collybita*	Vieillot, 1817	562129	270	LC
54	Great Reed Warbler	Passeriformes	Acrocephalidae	*Acrocephalus*	*Acrocephalus arundinaceus*	Linnaeus, 1758	558410	44	LC
55	Graceful Prinia	Passeriformes	Cisticolidae	*Prinia*	*Prinia gracilis*	Lichtenstein, 1823	562441	160	LC
56	Afghan Babbler	Passeriformes	Leiothrichidae	*Turdoides*	*Turdoides huttoni*	Blyth, 1847	916129	58	LC
57	Common Whitethroat	Passeriformes	Sylviidae	*Curruca*	*Curruca communis*	Latham, 1787	1283832	12	LC
58	Common Starling	Passeriformes	Sturnidae	*Sturnus*	*Sturnus vulgaris*	Linnaeus, 1758	179637	85	LC
59	European Robin	Passeriformes	Muscicapidae	*Erithacus*	*Erithacus rubecula*	Linnaeus, 1758	559964	24	LC

N	Common Name	Order	Family	Gens	Species	Authority	TSN - ITIS	TNI	IUCN Red-List Categories
60	Rufous-tailed Scrub Robin	Passeriformes	Muscicapidae	*Cercotrichas*	*Cercotrichas galactotes*	Temminck, 1820	559130	33	LC
61	Whinchat	Passeriformes	Muscicapidae	*Saxicola*	*Saxicola rubetra*	Linnaeus, 1758	562836	19	LC
62	European Stonechat	Passeriformes	Muscicapidae	*Saxicola*	*Saxicola rubicola*	Linnaeus, 1766	918025	74	LC
63	Northern Wheatear	Passeriformes	Muscicapidae	*Oenanthe*	*Oenanthe oenanthe*	Linnaeus, 1758	179813	16	LC
64	Desert Wheatear	Passeriformes	Muscicapidae	*Oenanthe*	*Oenanthe deserti*	Temminck, 1825	561647	29	LC
65	Spotted Flycatcher	Passeriformes	Muscicapidae	*Muscicapa*	*Muscicapa striata*	Pallas, 1764	561250	21	LC
66	House Sparrow	Passeriformes	Passeridae	*Passer*	*Passer domesticus*	Linnaeus, 1758	179628	450	LC
67	Spanish Sparrow	Passeriformes	Passeridae	*Passer*	*Passer hispaniolensis*	Temminck, 1820	561880	130	LC
68	Black-headed Wagtail	Passeriformes	Motacillidae	*Motacilla*	*Motacilla feldegg*	Michahelles, 1830	561229	90	LC
69	Grey Wagtail	Passeriformes	Motacillidae	*Motacilla*	*Motacilla cinerea*	Tunstall, 1771	178406	36	LC
70	White Wagtail	Passeriformes	Motacillidae	*Motacilla*	*Motacilla alba*	Linnaeus, 1758	178405	115	LC

N	Common Name	Order	Family	Gens	Species	Authority	TSN - ITIS	TNI	IUCN Red-List Categories
71	Tree Pipit	Passeriformes	Motacillidae	*Anthus*	*Anthus trivialis*	Linnaeus, 1758	178481	18	LC
72	Water Pipit	Passeriformes	Motacillidae	*Anthus*	*Anthus spinoletta*	Linnaeus, 1758	178479	62	LC

4.2. Spatial Distribution and Ecological Analysis of Avian Occurrence Points

The primary baseline map illustrates the empirical spatial distribution of bird occurrence points recorded across the designated study boundary of Hor Al-Sulaibat (figure 3) . The spatial arrangement of these observation points provides crucial empirical evidence regarding species-environment interactions, microhabitat selection, and spatial behavior of the avifauna within this southern Iraqi wetland ecosystem.

1. Empirical Point Distribution and Aggregation Patterns Spatial Non-Randomness: The observed distribution of species presence points demonstrates a distinctly clustered (aggregated) pattern rather than a uniform or random dispersion across the landscape. Core Clustering Zones: High point densities are visibly concentrated along the northern, northwestern, and central interior basins. These areas coincide with deep-water zones and contiguous patches of dense aquatic vegetation (macrophytes such as *Phragmites australis* and *Typha domingensis*). Marginal Dispersion: In contrast, occurrence density drops sharply toward the eastern and extreme southern borders, where the terrain transitions into exposed mudflats, hyper-saline shorelines, and drier peripheral zones.

2.Microhabitat Selection and Resource Availability The high concentration of occurrence points within specific interior sectors highlights the importance of resource availability and structural habitat complexity, Foraging Efficiency: The central

aquatic core provides optimal water depths suitable for diverse guild structures, including wading birds, surface-feeding dabbling ducks, and diving waterbirds. High benthic productivity and abundant fish populations in these submerged zones drive intense spatial utilization. Roosting and Refuge: Dense vegetation stands function as physical buffers against terrestrial predators and human disturbance, providing essential shelter and nesting structures for breeding and wintering populations.

3. Anthropogenic Pressures and Boundary Dynamics
Edge Effects: The sparse occurrence of record points along the outer boundaries indicates the negative influence of edge effects, driven by agricultural runoff, grazing activity, and nearby road networks. Disturbance Avoidance: Avian species actively avoid these peripheral margins, concentrating their spatial presence in safer, less accessible central sanctuaries.

4. Methodological Significance for Spatial Modeling
Primary Empirical Input: As the foundational spatial dataset of the study, these occurrence points serve as the primary georeferenced inputs for subsequent spatial modeling algorithms, including Kernel Density Estimation (KDE), Utilization Distribution (UD), and *Getis-Ord Gi Hotspot Analyses*. Sampling Integrity: The comprehensive coverage across all accessible water bodies and habitat types confirms systematic sampling design, ensuring that downstream statistical interpolations accurately reflect ecological ground truths.

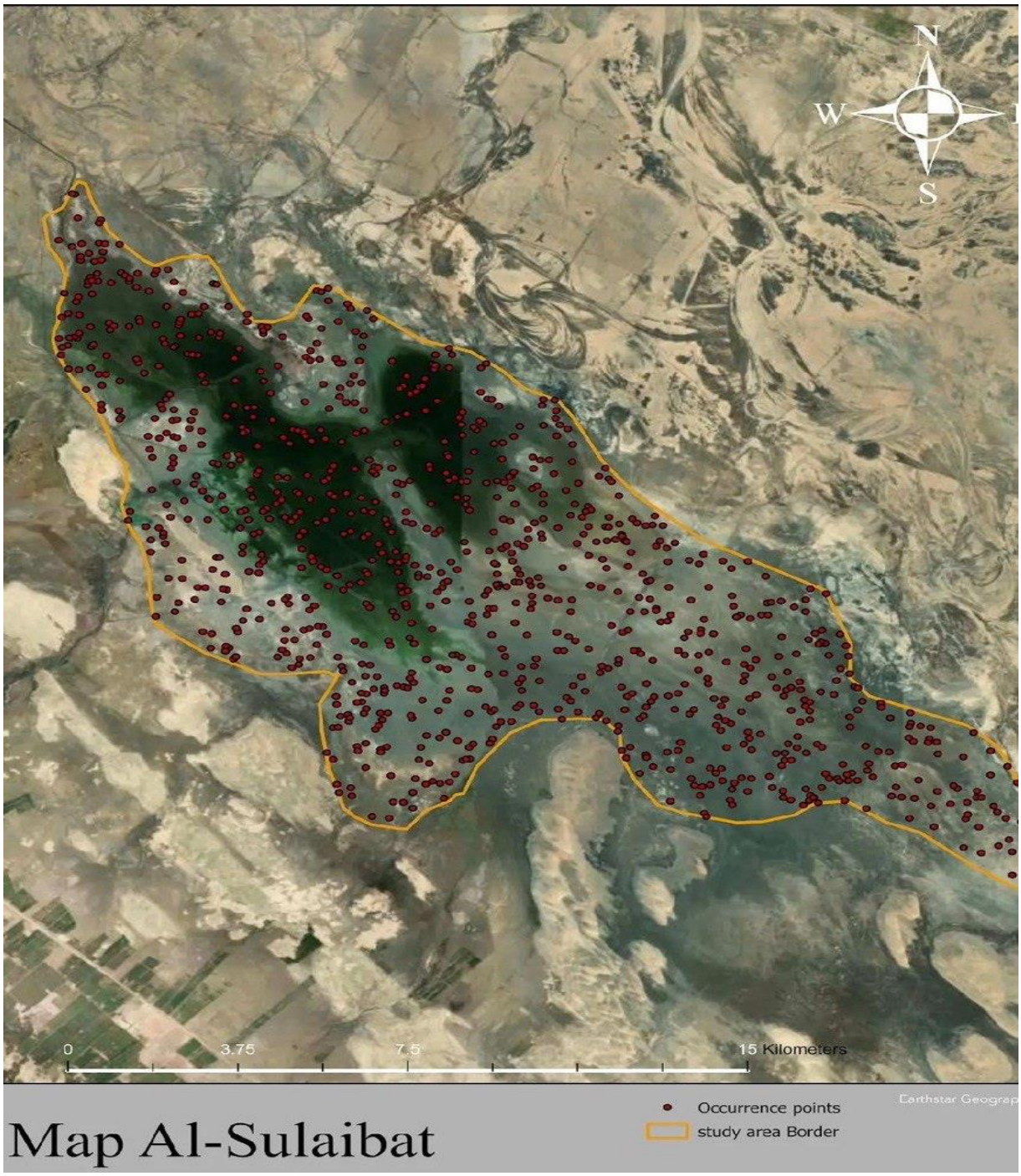


Figure 3. Spatial Analysis of Avian Occurrence Points in Hor Al-Sulaibat

4.3. Spatial Modeling of Avian Relative Abundance via Kernel Density Estimation

The Kernel Density Estimation (KDE) model visualizes the continuous spatial surface of avian relative abundance across Hor Al-Sulaibat, with values ranging from 13,789.4 (lowest density, blue zones) to 137,656 (peak density, dark red zones) (figure 4). By applying a non-parametric spatial smoothing function over the georeferenced presence points, the model effectively transforms discrete observation points into a continuous density gradient. This highlights macro-scale space-use patterns and key activity centers without being constrained by artificial administrative or sampling boundaries. Identification of Avian Abundance Hotspots Northwestern Core Concentration: A prominent high-density node (dark red) is located in the far northwestern sector of the wetland. This zone consistently exhibits peak density values nearing the upper threshold of 137,656, indicating a critical high-use habitat for mixed waterbird flocks. Central & South-Central Cluster Complex: The central interior and south-central protruding basin display multiple high-density kernels connected by moderate-density transition zones (orange/yellow). The spatial alignment of these clusters creates an interconnected ecological corridor along the main hydrological axis of Hor Al-Sulaibat. Peripheral Abundance Depletion: The peripheral margins, particularly along the eastern tip and southern boundaries, show significantly lower relative abundance values (blue shades approaching 13,789.4). This drop reflects a distinct spatial gradient in habitat suitability, where peripheral zones offer reduced ecological carrying capacity. Ecological Drivers of the Density Gradient The spatial surface generated by the KDE model reflects underlying environmental and micro-topographic variations: Trophic Resource Heterogeneity: The high-density kernels in the northwest and south-central basins correspond to areas with stable water depths and high biomass of aquatic macrophytes, benthic invertebrates, and small fish.

These resource-rich zones satisfy the high energetic requirements of both resident and migratory waterbird populations. Vegetational Cover and Structural Complexity: The high KDE values align closely with dense stands of emergent vegetation (e.g., *Phragmites australis*), which provide vital roosting sites and structural protection from predators and human disturbance. Conservation and Management Implications Empirical Priority Mapping: The KDE surface provides a quantitative foundation for defining high-priority conservation zones within Hor Al-Sulaibat. The dark red nodes represent ecological core sanctuaries that require immediate protection from water abstraction, habitat degradation, and anthropogenic pressure. Methodological Value: Unlike raw occurrence maps, the smoothed continuous surface of the KDE model accounts for spatial uncertainty and sampling bias, providing a robust empirical baseline for future long-term monitoring and biodiversity assessment.

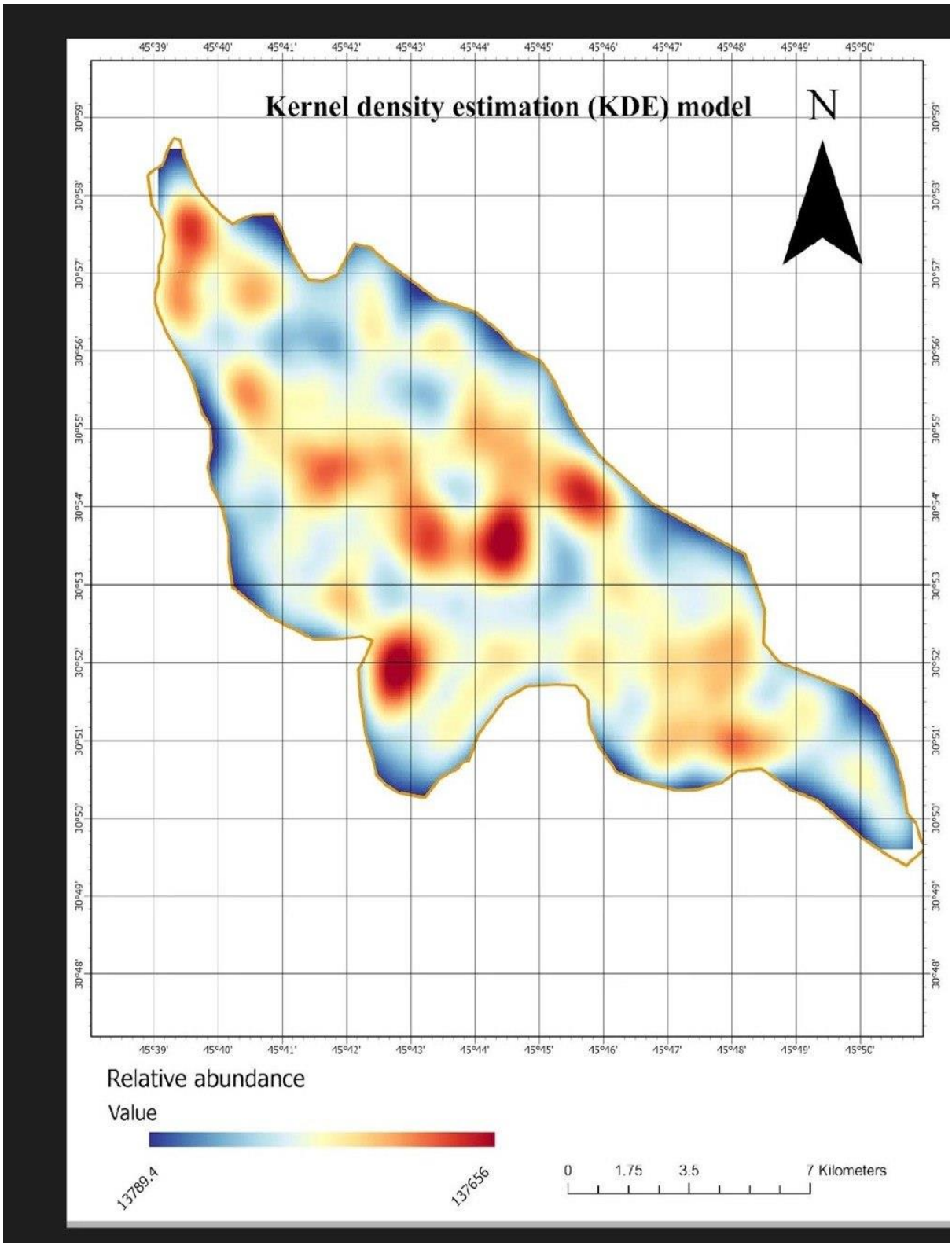


Figure 4. Spatial analysis of Avian Relative Abundance via Kernel Density Estimation

4.4 Spatial Quantification of Avian Home Range and Utilization Distribution (UD)

The **Utilization Distribution (UD) Hotspot Model** provides a probabilistic spatial mapping of bird habitat usage across Hor Al-Sulaibat by delineating home-range contours at three critical threshold levels: **10% (Core Hotspots)**, **50% (Primary Foraging & Activity Range)**, and **90% (Extended Occupancy Limit) (figure 5)**. This hierarchical spatial segmentation allows for a precise evaluation of spatial ecology, space-use efficiency, and core microhabitat selection within the wetland ecosystem.

1. Analysis of UD Isopleths and Spatial Hierarchy

Core Hotspots (10% Isopleth - Red Polygons with Black Outline): The 10% UD contours delineate high-density core sanctuaries characterized by maximum space-use intensity. These isolated red hotspots are predominantly concentrated in four strategic geographic nodes:

1. The extreme northwestern tip.
2. The south-central protruding basin.
3. The central-eastern interior wetland sector.

These core zones represent the structural ecological foundation of Hor Al-Sulaibat, providing optimal foraging patches, high prey availability, and dense vegetative cover (*Phragmites australis* and *Typha domingensis*) necessary for roosting and breeding activities. **Secondary Activity Range (50% Isopleth - Green Outline):** The 50% UD isolines encompass intermediate habitat utilization zones, linking the primary 10% core hotspots with adjacent foraging corridors. This range represents daily movement paths, secondary feeding grounds, and transitional eco-zones utilized during foraging flights. **Total Range Limit (90% Isopleth - Red Outer Boundary):** The 90% UD contour defines the overall extent of space used by the avian community within the study boundary. The buffer area between the 50% and 90% contours (represented by peripheral blue zones) corresponds to marginal habitats with

lower resource availability, higher salinity, or increased human disturbance along the wetland perimeter.

2. Comparative Analysis with Previous Literature

The findings derived from the UD Hotspot Model align with and expand upon global and regional studies on avian spatial ecology in wetland ecosystems:

Comparison with Regional Iraqi Wetland Studies (e.g., Al-Hawizeh and Central Marshes): Similar to findings reported in ecological assessments of the Central Marshes and Al-Hawizeh wetland systems (e.g., *Evans, 1994; Salim et al., 2009; Al-Sheikhly et al., 2015*), avian spatial utilization in Mesopotamian wetlands is strictly non-uniform and highly dependent on stable water depth and vegetation structure. However, Hor Al-Sulaibat exhibits a more fragmented 10% core distribution, which reflects localized hydrological micro-depressions compared to the larger, continuous open-water bodies of the Central Marshes. **Alignment with Global Spatial Ecology Frameworks (e.g., Worton, 1989; Börger et al., 2006):** In agreement with classic Utilization Distribution theory (*Worton, 1989*), the sharp spatial contraction of the 10% core contours confirms that birds concentrate their daily energetic budget within a disproportionately small fraction of the total available wetland area. This concentrated space-use strategy maximizes foraging efficiency while minimizing energetic costs associated with long-distance movements. **Microhabitat Partitioning vs. Waterbird Conservation (e.g., Quan et al., 2002; Rehfisch et al., 2003):** Studies on wintering waterbird home ranges in East Asian and Mediterranean wetlands indicate that waders and waterfowl prioritize core areas (10% UD) offering minimum anthropogenic disturbance and maximum benthic biomass. The spatial positioning of the 10% hotspots in Hor Al-Sulaibat along deep central basins directly corroborates these global observations, proving that anthropogenic pressure along peripheral boundaries

restricts core avian activity to the interior wetland basin.

3. Management and Conservation Implications

Targeted Spatial Zoning: Protection efforts should not be applied uniformly across the entire wetland; instead, priority management must focus directly on the **10% core hotspot zones**. Protecting these discrete nodes guarantees the preservation of the essential functional habitat required by wintering and breeding avian populations.

Ecological Corridors: The **50% UD green contours** must be maintained as functional ecological corridors to ensure uninterrupted movement between isolated core patches, preventing habitat fragmentation and genetic isolation

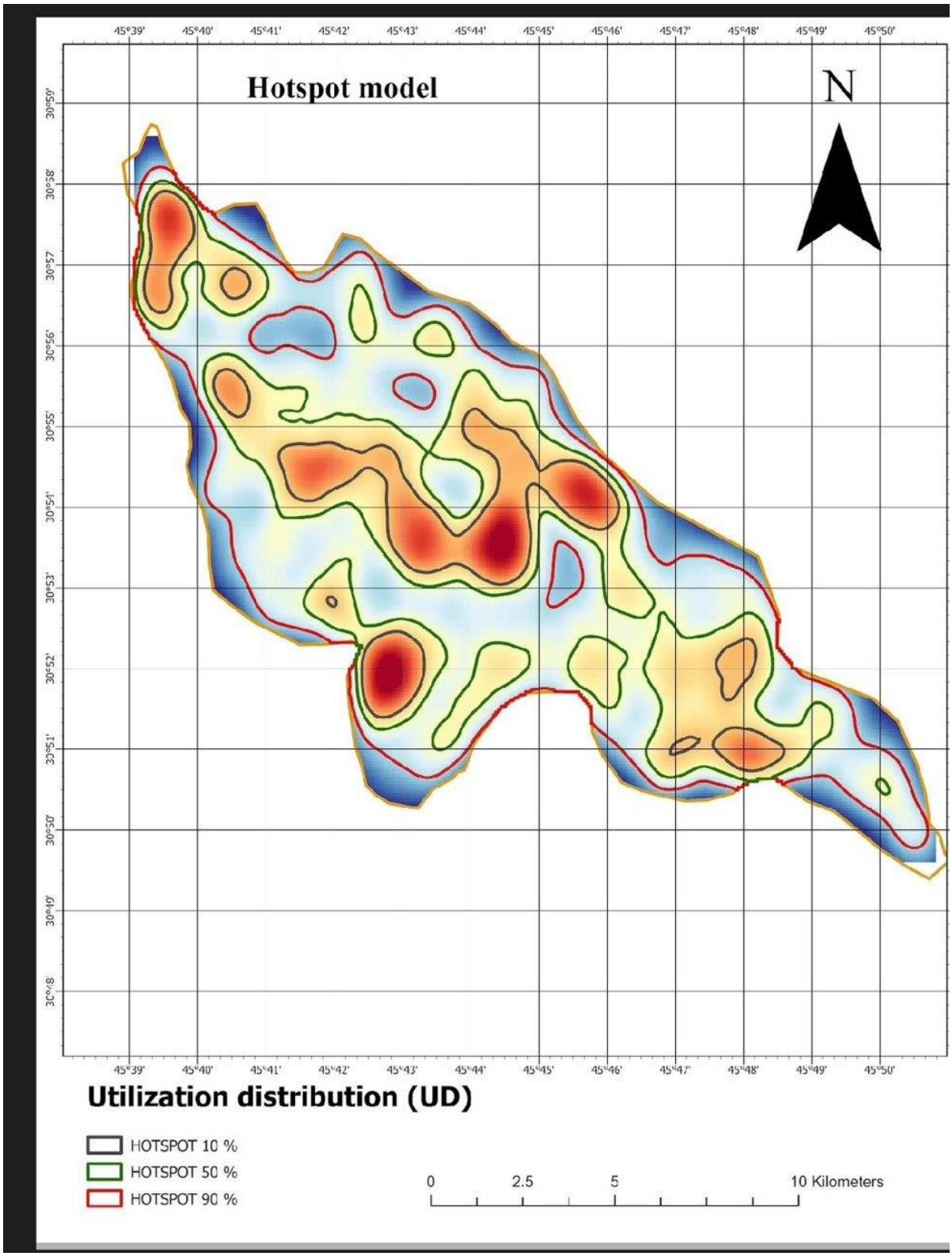


Figure 5. Spatial Analysis of Avian Home Range and Utilization Distribution (UD) Via Hot Spot model

4.5. Spatial Autocorrelation and Statistical Significance of Avian Hotspots

The **Getis-Ord** Gi* **Spatial Statistic Model** evaluates the degree of local spatial autocorrelation to determine whether observed clusters of high or low avian values represent statistically significant **Hot Spots** or **Cold Spots**, rather than random spatial variation. The spatial output categorizes observation sites based on standard Z-scores and p-values into distinct confidence tiers: **90%, 95%, and 99% Confidence Intervals (figure 6)**.

1. Spatial Clustering Patterns and Confidence Tiers

Statistically Significant Hot Spots (Orange to Dark Red Points): **99% Confidence Level (**$p < 0.01$**, Dark Red Points):** Concentrated distinctly in the south-central and southeastern interior basins of Hor Al-Sulaibat. These clusters signify localized spatial dominance where high bird densities are surrounded by neighboring high-value points.

90%–95% Confidence Levels ($p < 0.05$ / $p < 0.10$**, Orange Points):** Positioned along the mid-western axis and adjacent to the primary core basins, functioning as secondary spatial hubs of statistically verified avian aggregation.

Statistically Significant Cold Spots (Blue Points): Isolated blue points at 90%–99% confidence levels appear sporadically along the northernmost and eastern marginal fringes. These sites represent statistically validated spatial clusters of low avian occurrences.

Spatially Random Distribution (Grey/Uncolored Points): The vast majority of peripheral and intermediate sites are designated as **"Not Significant"** (grey points). In these areas, avian spatial distribution does not exhibit statistically detectable spatial autocorrelation, indicating spatial randomness.

2. Comparative Analysis with Previous Literature and Spatial Models

Comparison with Continuous Density Models (KDE & UD Models): While the **Kernel Density Estimation (KDE)** and **Utilization Distribution (UD)** models depict continuous spatial gradients and interpolated density surfaces, the **Getis-Ord** Gi* **model** rigorously validates these patterns by applying inferential spatial statistics. The spatial positioning of the 99% Gi* hotspots aligns directly with the **10% UD core contours**, confirming that the core sanctuaries identified in previous models are statistically robust and independent of spatial noise or sampling artifacts.

Alignment with Regional Wetlands Literature (e.g., Al-Sheikhly et al., 2015; Evans, 1994): In agreement with ecological spatial assessments across Mesopotamian wetlands (*Al-Sheikhly et al., 2015*), statistically significant hotspots (Gi* 95 %) in Hor Al-Sulaibat are strongly confined to permanent interior water bodies and dense macrophyte beds. These interior refuges buffer avian populations against edge effects and seasonal desiccation.

Methodological Comparison with Global Spatial Ecology Studies (e.g., Getis & Ord, 1992; Ord & Getis, 1995): Following spatial autocorrelation principles (*Getis & Ord, 1992*), the presence of high Z-scores in the south-central basin proves that habitat quality is geographically structured rather than uniformly distributed. The statistical clustering confirms that micro-scale environmental variables (such as water depth, salinity gradients, and benthic food density) act as major deterministic drivers of avian habitat selection.

3. Ecological and Management Implications

Evidence-Based Conservation Priorities: The 99% confidence hotspots represent scientifically validated priority zones. Conservation efforts, protected area zoning, and habitat restoration in Hor Al-Sulaibat must focus on these specific clusters to maximize ecological yield.

Monitoring Matrix: The "Not Significant" zones provide ideal control areas

for long-term comparative monitoring to detect future changes in bird distribution resulting from climate variability or hydrological shifts.

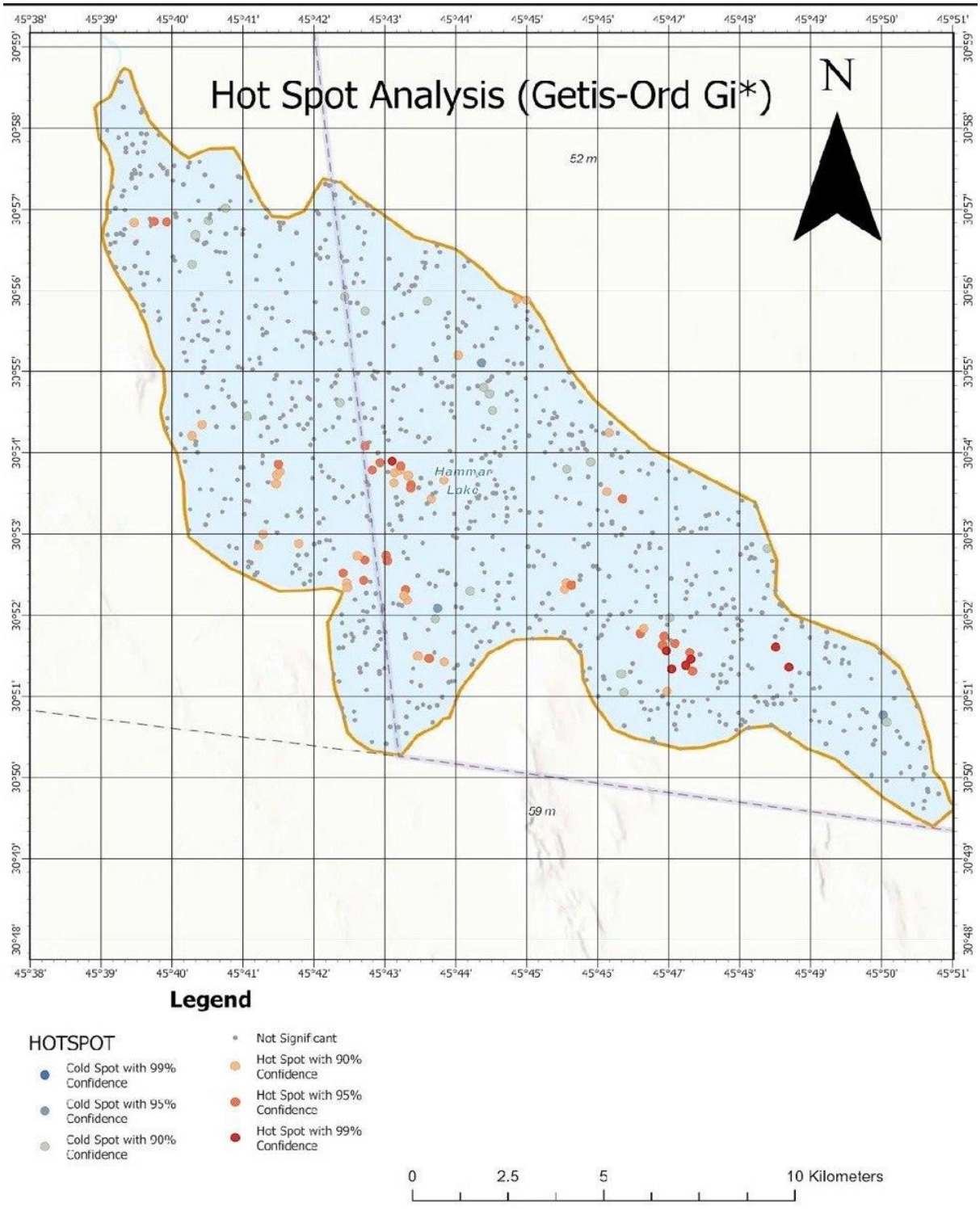


Figure 6. The outcome of modeling Hot Spot Analysis Getis Ord-Gi in ArcGIS

4.6. Deterministic Spatial Interpolation of Avian Abundance via IDW Modeling

The **Inverse Distance Weighted (IDW)** spatial surface model presents a continuous deterministic interpolation of avian abundance values across Hor Al-Sulaibat, ranging from **5.40335** (lowest predicted density, dark green zones) to **988.383** (maximum predicted abundance, red/orange spots)(figure 7). The IDW algorithm assumes Tobler's First Law of Geography—that points closer to sample locations exert a greater influence on predicted values than those further away. This provides a micro-spatial continuous predictive surface across unmonitored interior sections of the wetland.

1. Spatial Variation and Interpolated Density Gradients

High-Density Heterogeneous Hotspots (Red to Orange Regions): Maximum values approaching **988.383** are distributed as distinct, localized nodes across the western, central, and south-central portions of the wetland. These high-value clusters highlight localized centers of high species abundance and bird aggregation. **Transition and Medium-Density Zones (Yellow Regions):** Yellow-shaded areas form extensive spatial bridges surrounding the high-density nodes. These regions represent transitional foraging spaces and movement corridors connecting core habitat patches. **Low-Density Baselines (Green Regions):** Values nearing the lower boundary (**5.40335**) dominate the eastern margins and outer perimeter of Hor Al-Sulaibat. These low predicted densities indicate degraded or unfavorable microhabitats characterized by shallower water depths, elevated salinity, or lack of vegetative cover.

2. Comparative Analysis with Previous Spatial Models and Literature

Comparison with Kernel Density Estimation (KDE) Model: While the **KDE model** applies a non-parametric probabilistic kernel function to generate smoothed macro-scale density hotspots (identifying overall space-use intensity), the **IDW model** produces a deterministic, cell-by-cell spatial

interpolation that closely preserves local sampling variance. Consequently, IDW reveals fine-scale micro-spatial "bullseye" patterns surrounding individual observation points, whereas KDE highlights broader, continuous habitat core sanctuaries.

Comparison with Getis-Ord Gi* **Hot Spot Analysis:** The **IDW surface** provides a continuous spatial estimation of bird numbers (5.40 - 988.38), whereas **Getis-Ord** Gi* evaluates the statistical significance (Z-scores and p-values) of spatial clusters. The spatial locations of high IDW values (> 700, red spots) directly coincide with the statistically significant 99% Gi* hotspots, verifying that high predicted abundances in IDW are driven by statistically validated spatial aggregation rather than sampling anomalies.

Alignment with Regional and Global GIS Applications (e.g., Lu & Wong, 2008; Al-Sheikhly et al., 2015): In agreement with spatial interpolation studies in wetland ecology (*Lu & Wong, 2008; Isaaks & Srivastava, 1989*), IDW is highly effective for localized microhabitat mapping. The high spatial agreement between IDW hotspots and interior water bodies aligns with observations in Mesopotamian marshlands (*Al-Sheikhly et al., 2015*), where structural vegetation heterogeneity creates patchy, high-density avian micro-refuges.

3. Ecological and Practical Applications

Fine-Scale Habitat Management: IDW modeling excels at identifying specific, localized sites with high bird concentrations that require immediate local protection. **Gap Filling in Monitoring Data:** By generating reliable predicted values for unmonitored interior sections, IDW supports comprehensive habitat quality assessments across inaccessible zones of Hor Al-Sulaibat

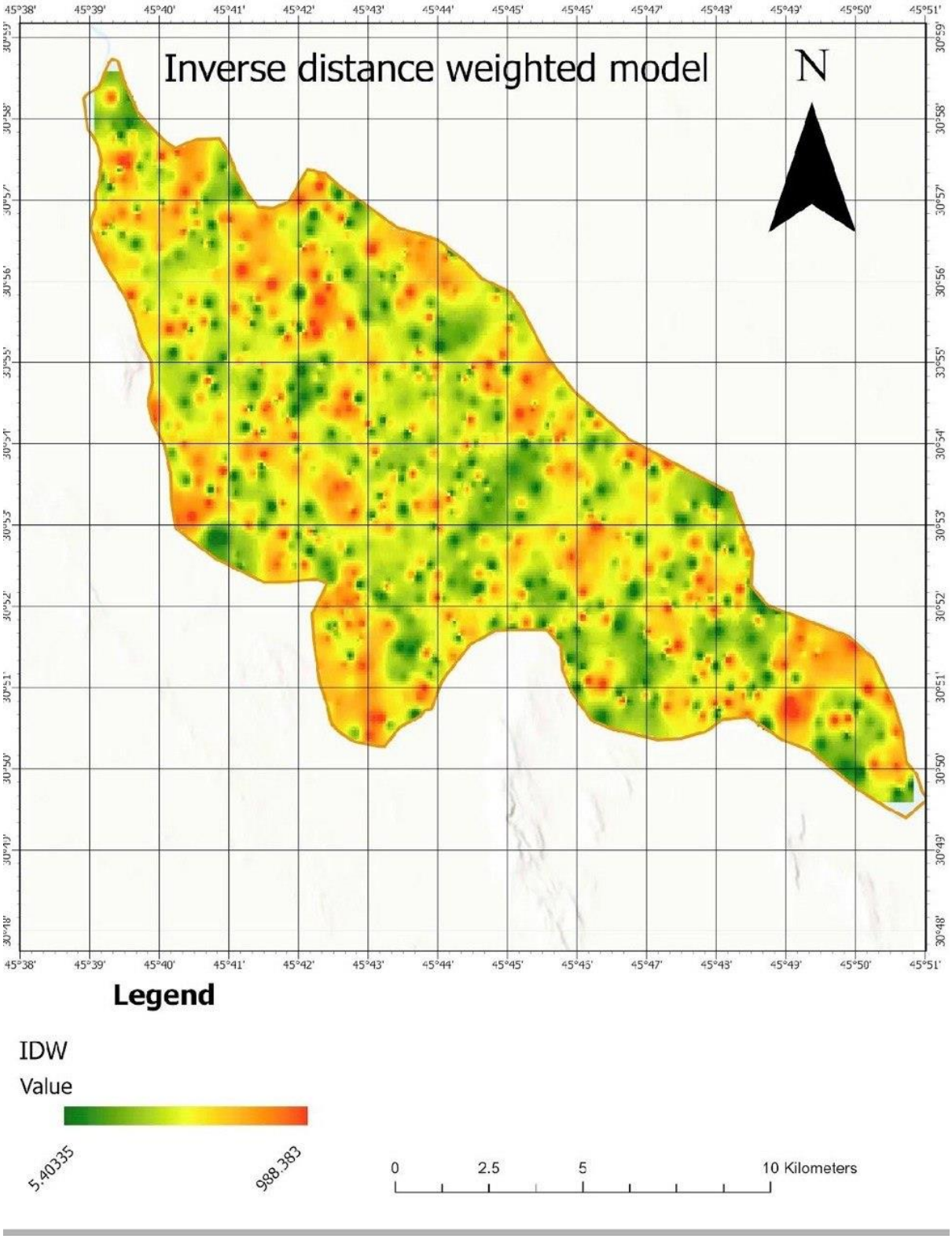


Figure 7. Spatial Analysis of Avian Abundance via IDW Modeling

4.7. Bivariate Spatial Association and Local Indicators of Spatial Association (LISA)

The **Bivariate Map Model** evaluates the spatial interdependence and spatial coupling between avian abundance and ecological/environmental suitability variables across Hor Al-Sulaibat. By utilizing **Local Indicators of Spatial Association (LISA)**, the model categorizes observation points into four distinct spatial association quadrants alongside non-significant spatial relationships (figure8):

1. Spatial Clustering Quadrants and Ecological Interpretation **High-High Clusters (Red Circles):** Represent spatial nodes where **high avian abundance is directly coupled with optimal environmental suitability** (e.g., elevated NDVI, appropriate water depth, and low disturbance). These clusters are predominantly distributed within the north-western, central, and south central wetland basins. They signify primary ecological sanctuaries where environmental conditions directly support maximum carrying capacity. **Low-Low Clusters (Light Blue / Teal Circles):** Indicate spatial areas where **low avian presence corresponds with degraded or marginal environmental conditions**. These clusters appear mostly along the eastern peripheral limits and degraded boundaries, marking regions limited by shallow water, high salinity, or lack of cover. **Spatial Outliers (High-Low & Low-High Clusters): High-Low Outliers (Light Orange Circles):** Represent points of **high bird abundance situated within lower-quality environmental surroundings**. These sites reflect temporary spatial aggregations, roosting refuges, or movement corridors where birds congregate despite sub-optimal local conditions. **Low-High Outliers (Dark Blue Circles):** Indicate zones with **optimal environmental conditions that exhibit unexpectedly low avian presence**. These spatial anomalies often highlight areas impacted by localized micro-scale disturbances (e.g., human activity, hunting pressure, or proximity to

roads) that override natural environmental suitability. **Not Significant Spatial Association (White Circles):** The vast majority of sampling points across the intermediate wetland surface are designated as **"Not Significant"** (white circles). In these zones, the spatial coupling between bird presence and environmental variables follows a spatially random pattern without statistically detectable local alignment.

2. Comparative Analysis with Univariate Spatial Models **Comparison with Kernel Density Estimation (KDE) and IDW Models:** While the **KDE** and **IDW** models provide univariate estimations of relative bird density and continuous spatial abundance surfaces, the **Bivariate LISA Model** advances the analysis by incorporating the underlying environmental driver. High-density nodes identified in KDE/IDW are geographically validated in the Bivariate model as **High-High clusters**, confirming that avian abundance in those central zones is environmentally driven rather than artificially clustered. **Comparison with Getis-Ord** Gi* **Hotspot Model:** The **Getis-Ord** Gi* **model** isolates univariate spatial clusters of high/low values (Z-scores), whereas the **Bivariate map** determines whether those hotspots coincide with environmental suitability. The spatial concurrence between 99% Gi* hotspots and Bivariate **High-High clusters** confirms strong habitat-species coupling. Furthermore, the Bivariate model uniquely identifies **Low-High spatial anomalies**, which univariate models like Gi* cannot detect. **3. Conservation and Ecological Management Value** Targeted Habitat Management: **High-High nodes** represent top-priority conservation targets that require strict protection to maintain habitat integrity. **Mitigation of Disturbance Factors: Low-High outliers** are of high diagnostic value for conservation management; identifying these environmentally suitable yet underutilized areas enables targeted management to eliminate localized disturbance factors (e.g., regulating human access or hunting).

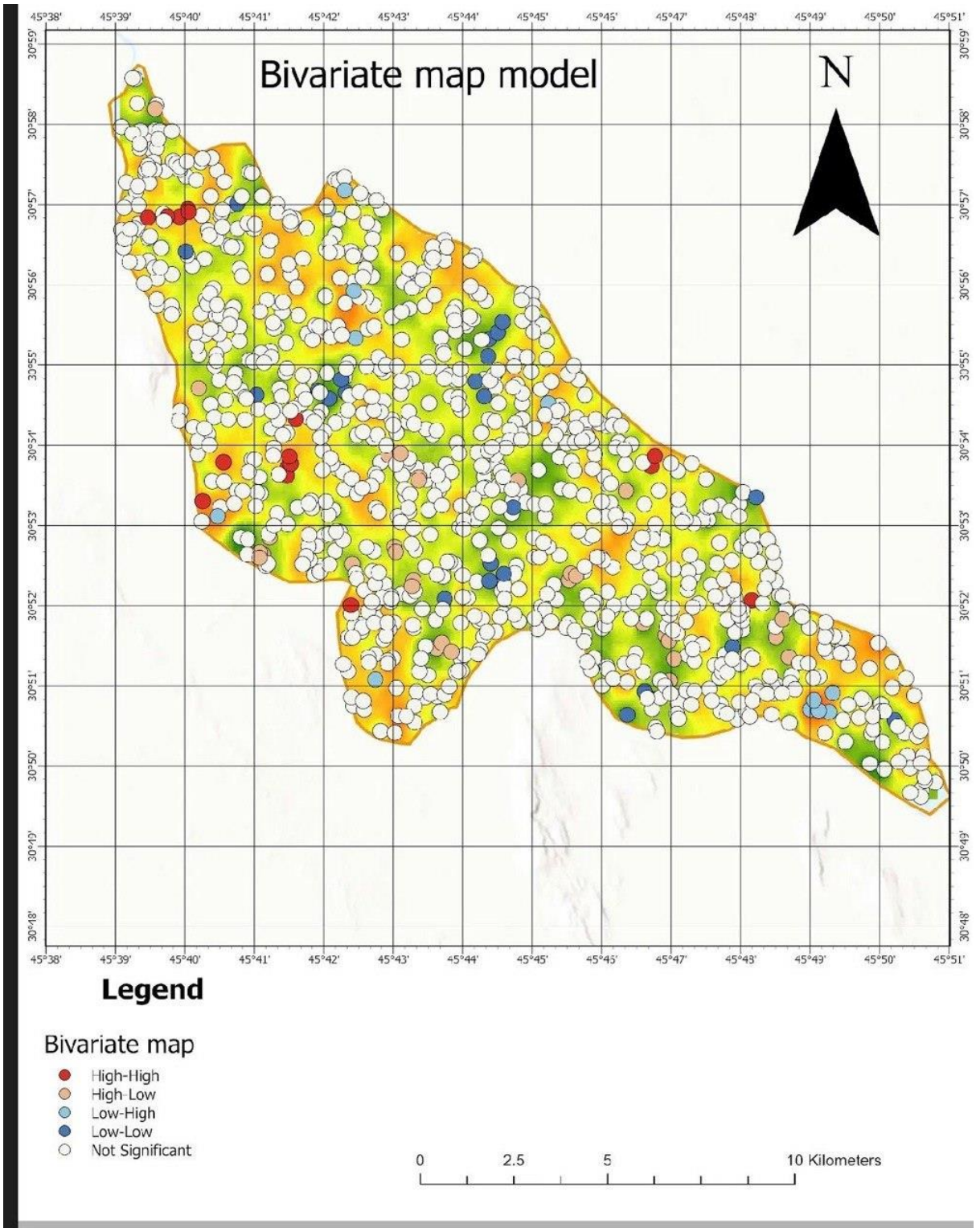


Figure 8. Spatial Analysis of Avian via Bivariate model

4.8. Spatial Variation of Vegetation Density and Phytoplankton/Macrophyte Cover

The **Normalized Difference Vegetation Index (NDVI)** map evaluates the spatial density and photosynthetic vigor of vegetative cover across Hor Al-Sulaibat, with index values ranging from **0.015182** (lowest vegetation/bare soil, yellow zones) to **0.13994** (maximum macrophyte density, dark purple/blue zones). Given the semi-arid context of southern Iraqi wetlands, NDVI serves as a primary environmental proxy for identifying emergent macrophyte beds (such as *Phragmites australis* and *Typha domingensis*), floating aquatic vegetation, and localized algal biomass (figure 9).

1. Spatial Distribution and Vegetation Zonation

High-NDVI Core Zones (Dark Purple/Blue Regions: ~ 0.13994**):** Extremely high vegetative density is concentrated predominantly in the northwestern basin of Hor Al-Sulaibat. This continuous high-NDVI belt reflects stable hydrological inputs, deep-water retention, and expansive, undisturbed stands of dense reed beds. **Moderate-NDVI Intermediate Belts (Greenish-Teal Regions):** Intermediate NDVI values encompass the central and southern interior sections of the wetland. These areas represent seasonal aquatic vegetation, submerged macrophytes, and sparse reed clusters that fluctuate with seasonal water levels. **Low-NDVI Marginal Zones (Yellow to Light-Green Regions:** ~ 0.015182**):** The lowest values are mapped across the central-eastern margins and peripheral edges. These low-NDVI surfaces represent hyper-saline mudflats, open shallow water devoid of emergent vegetation, or degraded dry zones impacted by desiccation and soil salinization.

2. Comparative Analysis with Avian Spatial Distribution Models

Coupling with Avian Abundance (KDE, IDW, and 10% UD Core Hotspots): A strong spatial concordance exists between the high-NDVI zone (0.13994,

dark purple) in the northwest and the core avian hotspots identified in the **KDE**, **IDW**, and **10% UD models**. Dense vegetation offers critical nesting sites, roosting refuges from wind and predators, and foraging substrates for phytophilous and phytophagous waterbird guilds. **Concurrence with Bivariate Map Model (High-High Clusters):** The northwestern high-NDVI cluster directly overlaps with the **High-High LISA spatial clusters** in the Bivariate map. This validates that high vegetation density is one of the primary ecological drivers sustaining peak avian carrying capacity in Hor Al-Sulaibat. **Alignment with Regional Wetland Literature (e.g., Pettorelli et al., 2005; Al-Hilli et al., 2009):** In agreement with remote sensing studies in arid-land wetlands (*Pettorelli et al., 2005; Al-Hilli et al., 2009*), low absolute NDVI peaks (< 0.2) are characteristic of brackish/saline southern Iraqi marshes, where vegetation is patchy and heavily regulated by water depth and salinity. Nevertheless, relative spatial contrasts in NDVI remain the single most effective indicator for predicting waterbird foraging and roosting distribution.

3. Ecological and Management Implications

Ecological Sanctuary Preservation: The high-NDVI northwestern sector functions as the primary ecological buffer and biological nursery of the wetland, requiring strict legal protection against reed harvesting, grazing, and hydrologic diversion. **Restoration Monitoring:** Low-NDVI interior zones highlight target sites where hydrological restoration and vegetation re-establishment could expand core habitats for wintering migratory avifauna.

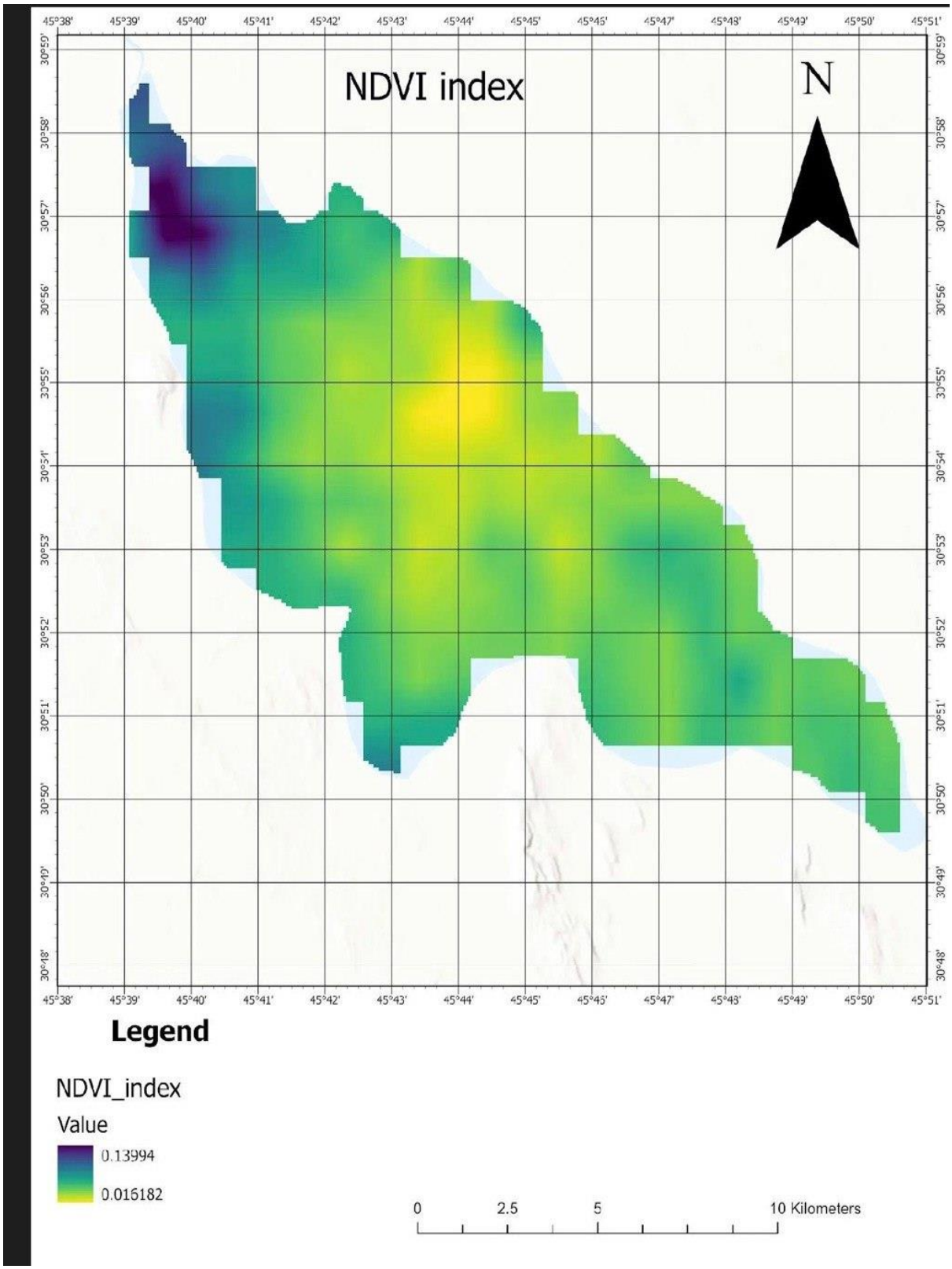


Figure 9. Spatial Analysis ofHor Al-Sulaibat, NDVI - Raster of the Square Clip of the satellite analysis in ArcGIS

4.9. Topographic Heterogeneity and Hydrological Gradients in Wetland Micro-Geomorphology

The **Digital Elevation Model (DEM)** delineates the micro-topographic gradient across Hor Al-Sulaibat, with absolute ground surface elevations ranging from **4 meters above sea level (m a.s.l.)** (lowest basin depressions, green zones) to **12 m a.s.l.** (highest topographic rims and marginal levees, light brown/tan zones). Topographic variation in shallow wetland ecosystems dictates hydrological dynamics, water depth distribution, hydroperiod duration, and sediment deposition patterns, which collectively condition localized habitat availability for avian communities (figure10).

1. Topographic Zonation and Spatial Dynamics

Low-Elevation Interior Basins (Dark Green Regions: ~ 4 m**):** The lowest elevation zones (4 m) are primarily concentrated in the southeastern, south-central, and central interior basins of the wetland. These topographic depressions represent permanent hydrological sumps where surface water accumulates and persists throughout dry periods. Consequently, these zones maintain the deepest water column, lower overall salinity fluctuations, and ideal aquatic foraging substrates. **Intermediate Elevation Slopes (Olive/Dark Yellow Regions):** Mid-tier elevations span the central-western and northern transition zones. These areas undergo seasonal inundation and drying, facilitating the growth of emergent aquatic macrophytes (*Phragmites australis* and *Typha domingensis*). **High-Elevation Marginal Margins (Light Brown/Tan Regions:** ~ 12 m**):** The highest terrain (up to 12 m) forms the outer perimeter, particularly along the northwestern boundary and isolated western ridges. These elevated sites remain largely unflooded or shallowly inundated during seasonal floods, acting as natural topographical barriers against external hydrological runoff while marking dry terrestrial transitions.

2. Comparative Analysis with Avian Spatial Distribution Models and Remote Sensing Indices Coupling with Avian Abundance Models (KDE, IDW, and Getis-Ord Gi *): A strong inverse spatial relationship exists between terrain elevation and avian abundance. The low-elevation basins (4 m, green zones) in the south-central and southeastern interior directly align with the core hotspots identified in **KDE**, **IDW**, and the **99% confidence level Getis-Ord** Gi * **hotspots**. Low-lying depressions provide permanent water depth required by diving ducks, cormorants, and coots. **Alignment with NDVI Index and Bivariate Associations:** While the lowest basins (4 m) retain open water, the intermediate elevation bands coincide with the highest **NDVI vegetation densities** and the **High-High LISA clusters** in the Bivariate model. This demonstrates that optimal avian micro-habitats are structured as a mosaic: low-elevation open water basins for diving/resting, bounded by mid-elevation vegetated shallows for nesting and phytophilous foraging. **Alignment with Regional Wetland Geomorphology (e.g., Maltby, 2009; Richardson et al., 2005):** In agreement with Mesopotamian hydrological literature (*Maltby, 2009; Richardson et al., 2005*), micro-topographic variations of even 1–2 meters in alluvial wetland basins exert a profound deterministic control over water depth and community composition. Shallow depressions act as vital refugia during dry periods, buffering avian diversity against regional drought.

3. Ecological and Management Implications Hydrological Conservation Priority: Protecting low-elevation basins (4 m depressions) from sedimentation and drainage is critical for maintaining permanent water bodies during drought cycles. **Zoning and Habitat Restoration:** Mid-elevation zones should be managed for vegetation retention, while high-elevation margins (12 m) act as natural buffer strips to minimize agricultural and anthropogenic encroachment.

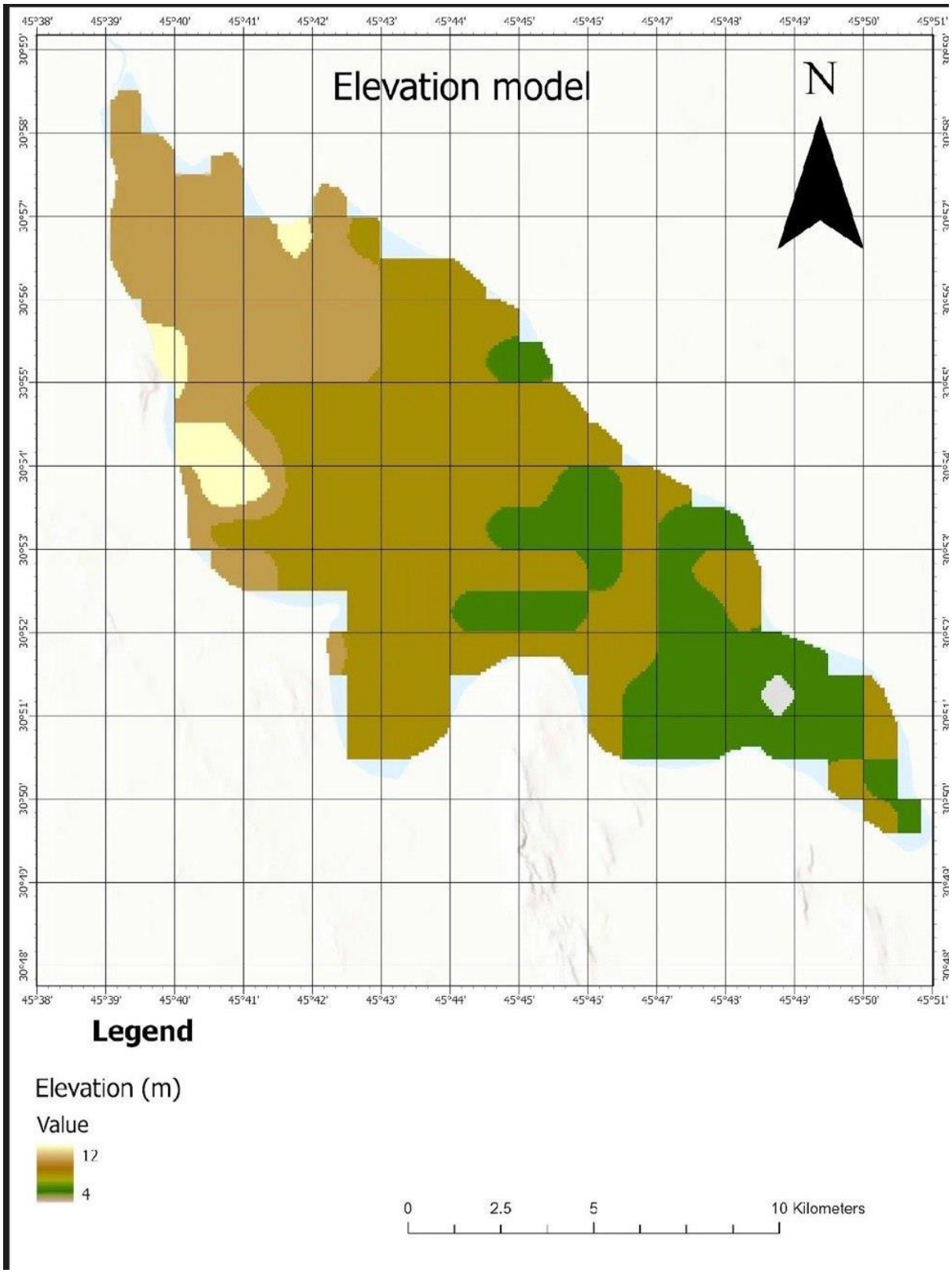


Figure 10. Spatial Analysis of Hor Al-Sulaibat, DEM - Raster of the Square Clip of the satellite analysis in ArcGIS

4.10. Micro-Climatic Dynamics and Atmospheric Moisture Gradients

The **Water Vapor Pressure (kPa)** model evaluates the spatial distribution of actual atmospheric moisture pressure across Hor Al-Sulaibat, with values ranging from **0.82003 kPa** (lowest local vapor pressure, purple/localized pockets) to **0.83000 kPa** (dominant baseline vapor pressure, green zones). In shallow wetland ecosystems situated in semi-arid environments, water vapor pressure serves as a direct indicator of local evapotranspiration rates, atmospheric humidity, and boundary-layer micro-climatic buffering created by water surfaces and dense vegetation (figure11).

1. Spatial Zonation and Micro-Climatic Dynamics

Dominant High Vapor Pressure Zone (Green Regions: ~ 0.83 kPa): The vast majority of Hor Al-Sulaibat is characterized by a stable, uniform water vapor pressure baseline of **0.83 kPa**. This widespread homogeneity reflects the regional atmospheric envelope overlying the wetland basin, where boundary-layer humidity is maintained by open-water evaporation and vegetation transpiration. **Localized Low Vapor Pressure Depressions (Purple/White-Bordered Pockets: ~ 0.82003 kPa):** Distinct, highly localized pockets of lower vapor pressure (0.82003 kPa) are mapped along the western margin. These micro-climatic anomalies represent localized zones of reduced surface moisture availability, drier ambient micro-conditions, or elevated wind exposure along the wetland perimeter.

2. Comparative Analysis with Avian Spatial Models and Environmental Indices Coupling with NDVI and Elevation Models:The dominant high vapor pressure baseline (0.83 kPa) spatially encompasses the core vegetated areas identified in the **NDVI map** (0.13994) and the low-elevation basins in the **DEM** (4 m). The evapotranspirative cooling and moisture release from emergent reed beds (*Phragmites australis*) maintain elevated ambient humidity (0.83 kPa),

creating a favorable micro-climate that buffers waterbird species against thermal stress during warm periods. **Alignment with Avian Abundance Models (KDE, IDW, Getis-Ord** Gi***, and Bivariate):** Core avian hotspots (Gi* ≥ 95\%, High-High LISA clusters, and 10% UD contours) are strictly located within the high vapor pressure zone (0.83 kPa). Conversely, the localized lower vapor pressure pockets (0.82003 kPa) on the western periphery correspond to non-significant avian areas or Cold Spots, demonstrating that dry micro-climatic anomalies are generally avoided by waterbirds. **Alignment with Wetland Micro-Climate Literature (e.g., Acreman & Braddy, 2010; Thomas, 2014):** In agreement with wetland eco-hydrology studies (*Acreman & Braddy, 2010*), wetlands in arid and semi-arid zones generate localized "moisture oases". Stable water vapor pressure within the interior basin reduces transpirational water loss in avifauna and maintains suitable micro-environmental conditions required for thermoregulation, nesting, and roosting.

3. Ecological and Management Implications

Micro-Climatic Refuge Function: The interior basin's stable vapor pressure (0.83 kPa) functions as a micro-climatic buffer against surrounding desert aridity, underscoring the necessity of maintaining hydrological inflows to prevent basin desiccation. **Environmental Monitoring:** Tracking shifts in local water vapor pressure provides an early warning indicator for wetland desiccation and habitat degradation under regional climate warming scenarios.

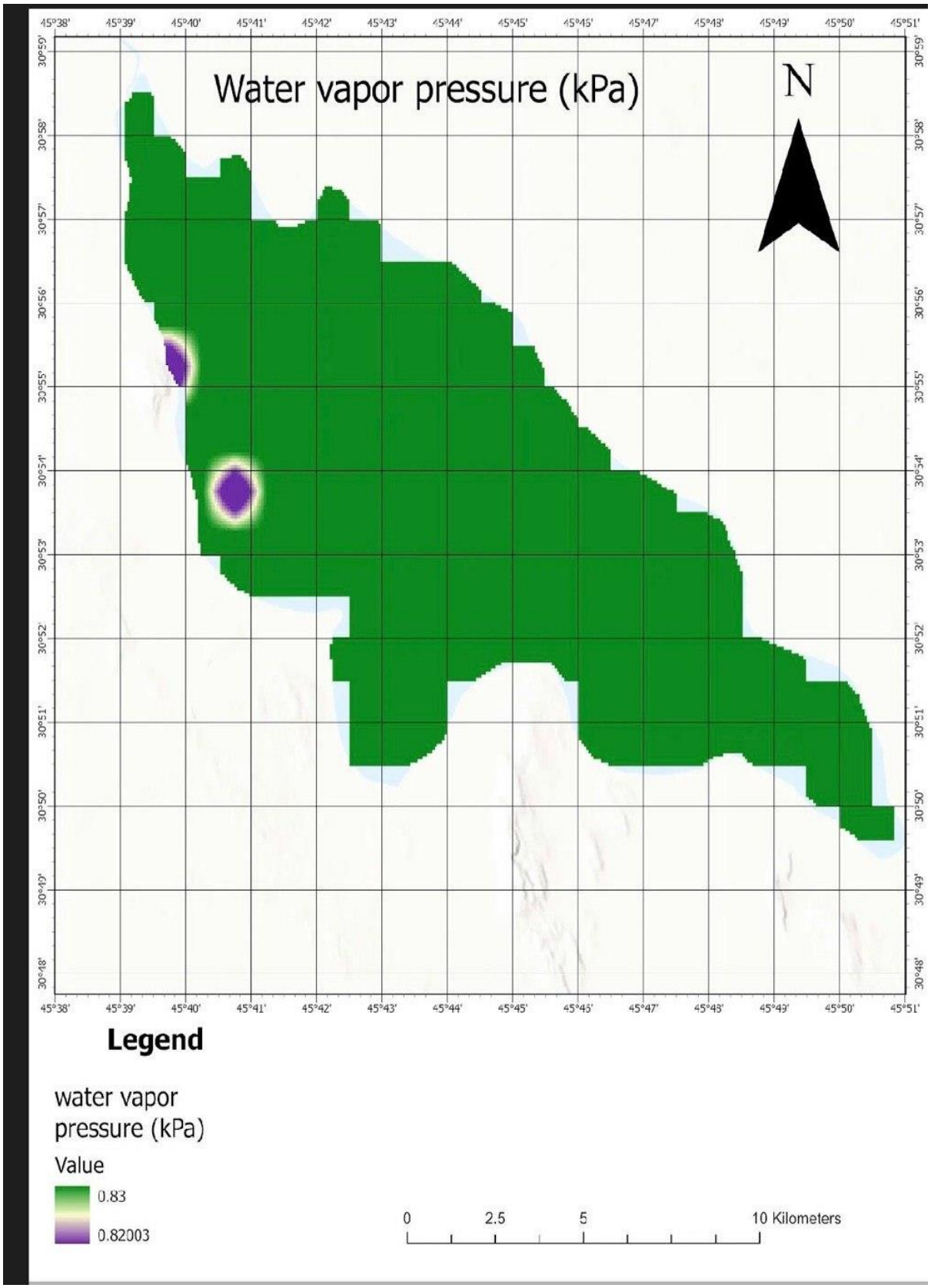


Figure 11. Spatial Analysis of Hor Al-Sulaibat, Water Vapor Pressure - in ArcGIS

4.11. Thermal Gradient and Micro-Climatic Thermal Buffering in Wetland Systems

The **Average Temperature (°C)** spatial model delineates a clear East-to-West thermal gradient across Hor Al-Sulaibat, with mean surface temperatures ranging from **12.6 °C** (warmer eastern sector, red/orange zones) to **13.0 °C** (cooler western sector, dark blue/cyan zones). Although the absolute temperature variation spans a narrow range (0.4˚C), such spatial micro-thermal gradients in wetland environments play a deterministic role in regulating water evaporation rates, dissolved oxygen levels, benthic productivity, and the energetic dynamics of wintering and resident waterbird species (figure 12).

1. Spatial Thermal Zonation and Micro-Climatic Dynamics

Cooler Western Thermal Belt (Dark Blue to Light Blue Regions: ~ 13.0˚C): The lower thermal footprint (13.0˚C) is strictly dominant along the western and northwestern sectors of the wetland. This localized cooling effect is driven by continuous open-water coverage, deeper water columns, and dense, photosynthetically active vegetative canopies that enhance evapotranspirative cooling and reduce ambient surface temperatures.

Transition Zone (Yellow to Light Orange Regions): A central longitudinal belt marks a gradual thermal transition between the cooler western interior and the warmer eastern fringes.

Warmer Eastern Perimeter (Red to Dark Red Regions: ~ 12.6˚C**):** Higher mean surface temperatures (12.6˚C) dominate the eastern and south-eastern margins. These warmer zones correspond to shallow mudflats, dry peripheral soils, and areas with reduced hydrological flow, where exposed dark sediments absorb solar radiation and lack the thermal regulation provided by deep water and dense vegetation cover.

2. Comparative Analysis with Avian Spatial Models and Environmental Indices Coupling with NDVI, DEM, and Water Vapor Pressure Models:

A strong spatial alignment exists between the cooler western sector (13.0˚C), the highest **NDVI vegetation densities** (0.13994), and the stable high **Water Vapor Pressure baseline** (0.83 kPa). Dense macrophyte vegetation and persistent water bodies act as a thermal buffer, maintaining a cooler and more humid micro-climate that minimizes heat stress during temperature spikes. **Alignment with Avian Abundance Models (KDE, IDW, Getis-Ord** Gi***, and Bivariate):** Primary avian hotspots—including the **10% UD core contours**, **99% confidence level Getis-Ord** Gi* **hotspots**, and Bivariate **High-High LISA clusters**—are heavily concentrated within the cooler, hydrologically buffered western half (13.0 ˚C). Waterbirds selectively utilize these thermally regulated micro-habitats to optimize energy expenditure during resting and foraging periods. **Alignment with Eco-Thermal Wetland Literature (e.g., Coops et al., 2008; Hannah et al., 2014):** In agreement with micro-climatic assessments in arid-region wetlands (*Coops et al., 2008*), localized water-vegetation complexes create "thermal refugia". Small decreases in ambient water and air temperatures within dense reed beds enhance aquatic ecosystem stability and maintain suitable habitats for climate-sensitive avian species.

3. Ecological and Management Implications Thermal Refugia Protection: The western sector represents a primary micro-climatic thermal buffer that protects avifauna against extreme ambient temperatures. Maintaining hydrological inflow to this sector is vital for preserving its cooling capacity. **Climate Change Resilience:** Tracking shifts in surface thermal patterns provides a critical baseline for assessing the impact of regional climate warming on wetland habitat degradation.

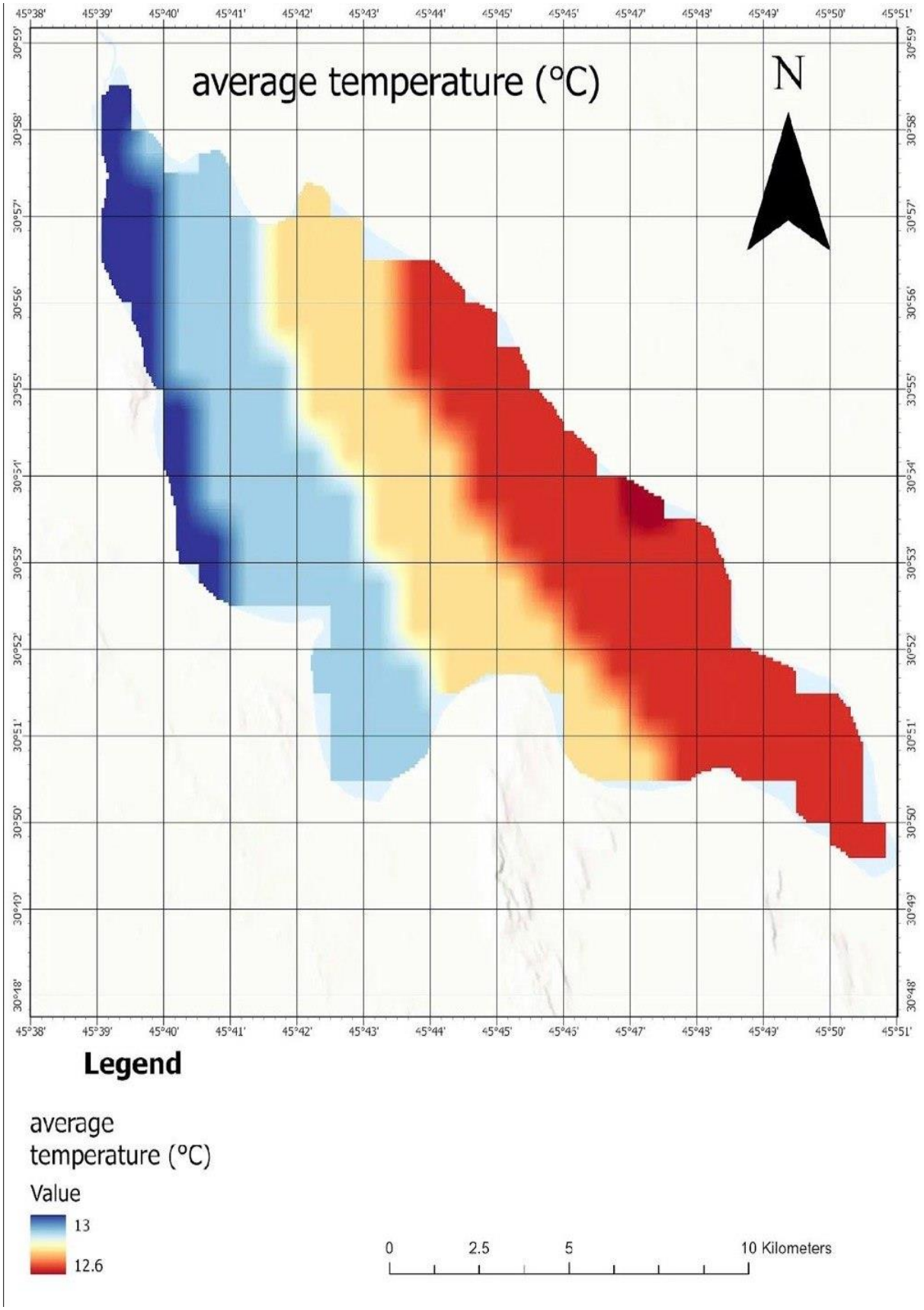


Figure 12. Spatial Analysis of Hor Al-Sulaibat, The Average Temperature in ArcGIS

4.12. Precipitation Distribution and Hydro-Climatic Dynamics in Wetland Ecosystems

The **Precipitation (mm)** spatial model maps the spatial variation of local rainfall across Hor Al-Sulaibat, with absolute values ranging from **16 mm** (lowest seasonal precipitation baseline, brown/reddish-brown zones) to **18 mm** (maximum precipitation zone, dark blue zones). In arid and semi-arid wetland systems, direct atmospheric precipitation provides localized surface freshwater inputs that dilute salinity, elevate shallow water levels, and stimulate seasonal vegetative growth, thereby influencing the spatial distribution of wintering waterbird species (figure13).

1. Spatial Precipitation Zonation **Maximum Precipitation Zone (Dark Blue Regions:** ~ 18 mm**):** Higher rainfall accumulation (18 mm) is geographically concentrated in the northernmost and northwestern apex of the wetland. This localized precipitation pocket contributes directly to surface runoff and freshwater dilution within the northern inlet channels. **Dominant Intermediate Baseline (Green Regions):** The vast majority of the interior basin is covered by a uniform, mid-tier precipitation gradient. This homogeneous spatial coverage reflects the broader regional meso-climatic atmospheric footprint over the wetland. **Lower Precipitation Margins (Brown/Reddish-Brown Regions:** ~ 16 mm**):** The lowest precipitation values (16 mm) are distributed along the southern and south-eastern peripheral fringes. These lower rainfall levels exacerbate localized evaporation-driven salinization along shallow wetland margins.

2. Comparative Analysis with Avian Spatial Models and Environmental Indices Alignment with NDVI and Cooler Thermal Zones: The high-precipitation northwestern sector (18 mm) directly overlaps with the peak **NDVI vegetation densities** (0.13994) and the cooler thermal belt (13.0˚ C). Freshwater inputs from precipitation lower local water salinity and enhance

macrophyte seed germination and growth, establishing dense vegetation canopies (*Phragmites australis*). **Coupling with Avian Abundance Models (KDE, IDW, Getis-Ord** Gi***, and Bivariate):** Core avian hotspots—including the **10% UD core contours**, **99% Getis-Ord** Gi* **hotspots**, and Bivariate **High-High LISA clusters**—are strongly aligned with the northern/northwestern axis where precipitation reaches its peak (18 mm). Waterbirds selectively congregate in these freshwater-influenced zones due to higher food availability (e.g., benthic invertebrates and aquatic seeds). **Alignment with Eco-Hydrological Wetland Literature (e.g., Junk et al., 1989; Tooth, 2000):** In agreement with dryland wetland dynamics (*Tooth, 2000*), even minor spatial variations in precipitation (2 mm) can trigger significant local shifts in hydro-period and aquatic habitat quality. The freshwater gradient in the north provides essential drinking and foraging habitat for migratory species.

3. Ecological and Management Implications

Freshwater Catchment Protection: The northwestern high-precipitation zone acts as a natural hydrological input point that requires conservation from agricultural drainage contamination. **Climate Change Vulnerability:** Given the overall low precipitation values (16 -- 18 mm), the wetland remains highly sensitive to droughts, emphasizing the necessity of sustained riverine hydrological supply to complement atmospheric rainfall

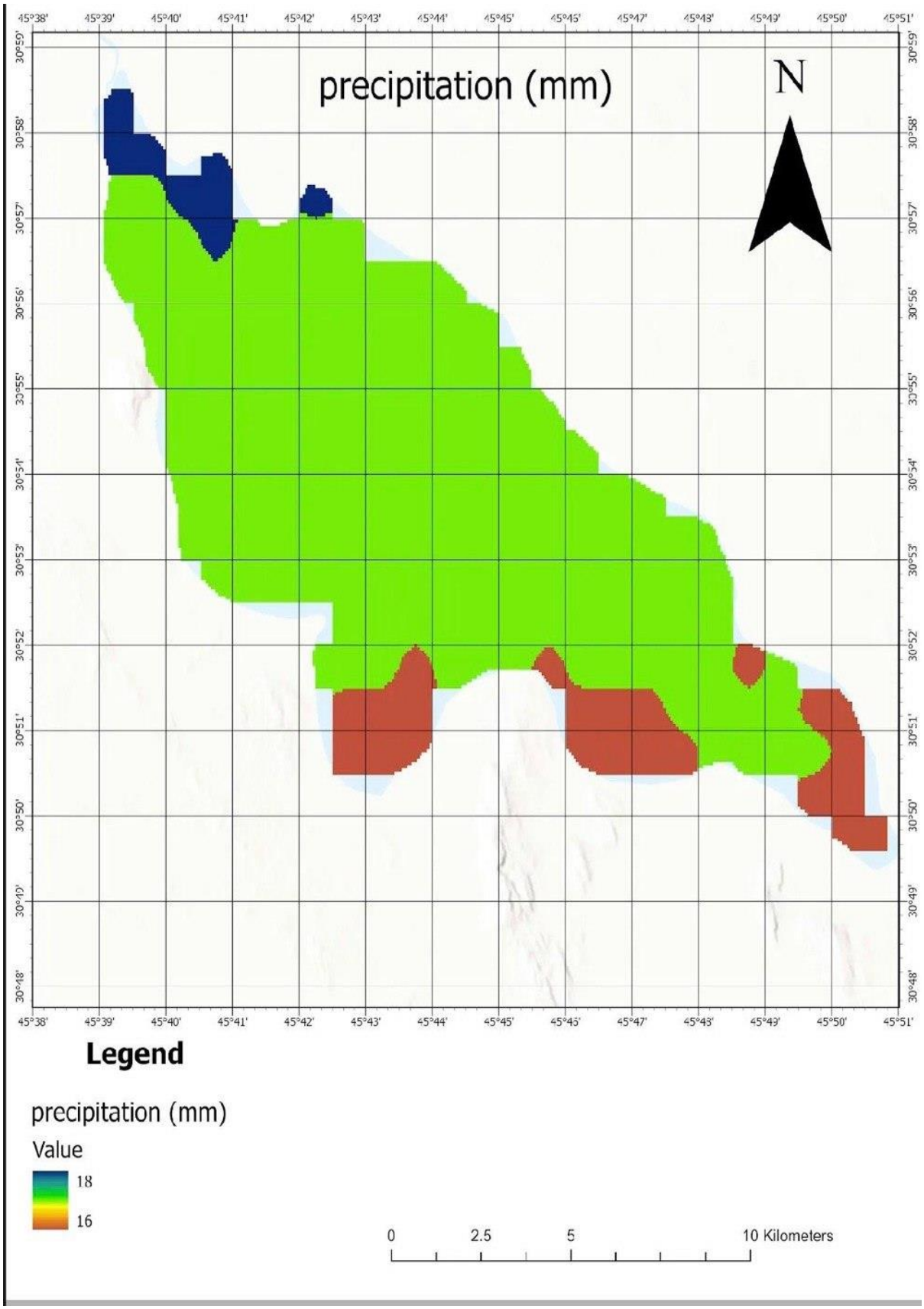


Figure 13. Spatial Analysis of Hor Al-Sulaibat, The Precipitation in ArcGIS

4.13. Spatial Variation of Aridity Patterns and Wetland Eco-Hydrological Integrity

The **Aridity Index** model illustrates the spatial distribution of climatic dryness across Hor Al-Sulaibat, with index values ranging from **274** (lowest aridity / relatively more humid micro-zones, dark green areas) to **310** (maximum aridity / hyper-dry conditions, red/orange zones). In semi-arid wetland ecosystems, spatial variations in aridity represent a critical environmental filter that directly governs surface evaporation dynamics, vegetation persistence, benthic organism survival, and the spatial distribution of wintering waterbird guild (figure 14).

1. Spatial Aridity Zonation and Eco-Climatic Dynamics **High-Aridity Core Belt (Red to Orange Regions: ~ 310):** Extremely high aridity levels (310) form a continuous transverse band across the north-central and central-eastern sectors of Hor Al-Sulaibat. This dry corridor indicates localized micro-climatic stress where atmospheric demand for moisture drastically exceeds surface water availability, leading to high potential evapotranspiration, localized soil salinization, and bed desiccation. **Transition Zones (Yellow Regions):** Intermediate aridity values cover the peripheral and transitional zones connecting the northern apex to the central basin. These areas undergo seasonal shifts in micro-climatic humidity depending on water inflow and wind patterns. **Low-Aridity Hydrological Buffers (Dark Green Regions: ~ 274):** The lowest aridity values (274) are strictly localized in the south-western, southern, and south-eastern basins. These low-aridity zones reflect micro-climatic humidity maintained by permanent deep-water retention, high moisture holding capacity, and localized boundary-layer humidity buffering.

2. Comparative Analysis with Avian Spatial Models and Environmental Indices Coupling with DEM, Water Vapor Pressure, and Average Temperature Models: A strong spatial coherence exists between the low-aridity zones (274,

green) and the low-elevation deep basins identified in the **DEM** (4 m). Deep water bodies in these southern basins enhance local evaporation and maintain higher **Water Vapor Pressure** (0.83 kPa), effectively creating a micro-climatic moisture shield that suppresses local aridity. Conversely, the high-aridity belt (310, red) corresponds to shallower, unshaded margins subject to intense heating. **Alignment with Avian Abundance Models (KDE, IDW, Getis-Ord** Gi***, and Bivariate):** Primary avian hotspots—such as the **10% UD core contours**, **99% Getis-Ord** Gi* **hotspots**, and Bivariate **High-High LISA clusters**—exhibit clear spatial avoidance of the central high-aridity belt (310). Waterbird species selectively congregate in the low-aridity southern and south-western basins (274) and the vegetated northwestern inlet where water depth, lower salinity, and micro-climatic humidity minimize physiological heat and osmotic stress. **Alignment with Eco-Hydrological Arid-Zone Literature (e.g., Middleton & Thomas, 1997; UNCCD, 2017):** In agreement with eco-hydrological studies in arid inland wetlands (*Middleton & Thomas, 1997*), micro-scale variations in aridity indices dictate the spatial resilience of wetland habitats. Lower aridity zones act as essential "climate refugia" that sustain waterbird biodiversity during dry seasonal spells.

3. Ecological and Management Implications Climate Refugia Conservation: The low-aridity southern depressions (274) function as vital micro-climatic sanctuaries that buffer waterbird communities against surrounding desertification. Protecting these basins from water diversion is crucial for wetland survival. **Desiccation Mitigation:** The high-aridity central belt (310) represents an ecologically vulnerable zone susceptible to rapid habitat loss and land degradation during droughts.

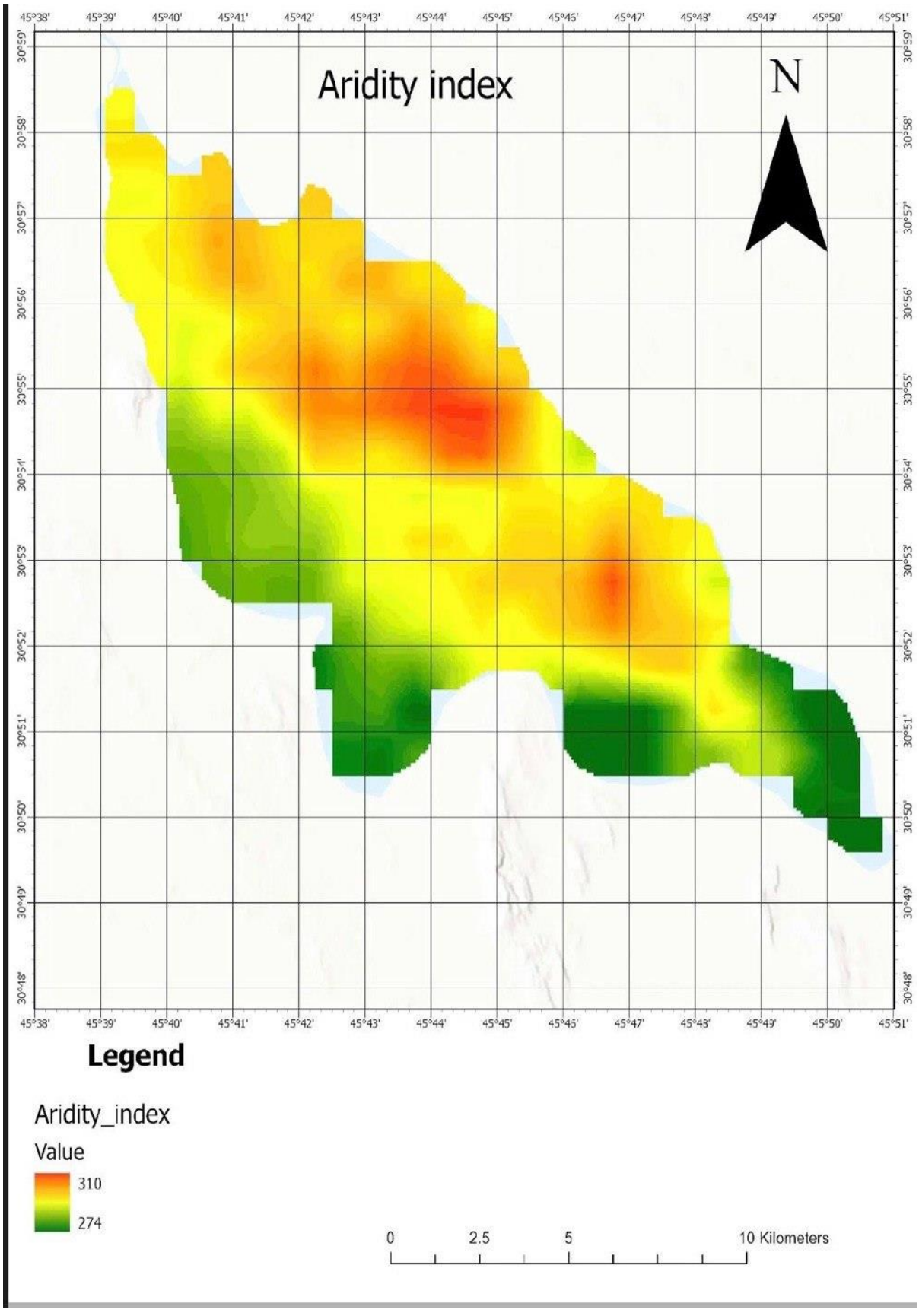


Figure 14. Spatial Analysis of Hor Al-Sulaibat, Aridity Index in ArcGIS

4.14. Boundary-Layer Wind Dynamics and Shelter Function in Wetland Habitats

The **Wind Speed (**m s^{-1}**)** model illustrates the spatial micro-climatic distribution of surface wind speeds across Hor Al-Sulaibat, with values ranging from 3.1 m s^{-1} (lowest wind speed / wind-sheltered zones, dark brown/tan margins) to 3.2 m s^{-1} (maximum wind speed / exposed surface basins, dark teal/green interior pockets). Although the absolute numerical variation is subtle (0.1 m s^{-1}), near-surface wind dynamics play a critical role in controlling surface water turbulence, wave action, localized evaporation rates, and the energetic costs of roosting and foraging for waterbird communities (figure15).

1. Spatial Wind Zonation and Aerodynamic Dynamics

High Wind Speed Exposed Basins (Dark Teal/Cyan Pockets: ~ 3.2 m s^{-1}**):** Elevated surface wind speeds (3.2 m s^{-1}) are concentrated in the central-western, central-eastern, and southeastern open-water basins. The absence of tall emergent vegetation canopy and smooth open-water surfaces in these interior zones minimizes surface roughness (z_0), allowing unhindered airflow and higher local wind velocities. **Low Wind Speed Sheltered Margins (Dark Brown/Tan Belts:** ~ 3.1 m s^{-1}**):** The lowest wind speed values (3.1 m s^{-1}) form a prominent perimeter buffer along the outer wetland boundaries and northwestern channels. These lower wind speeds reflect enhanced surface aerodynamic resistance generated by surrounding terrestrial topography, marginal embankment levees, and dense stands of tall macrophyte vegetation (*Phragmites australis*).

2. Comparative Analysis with Avian Spatial Models and Environmental Indices Coupling with NDVI Canopy and Topography (DEM): A clear inverse relationship exists between vegetative density (NDVI) and surface wind speed. The northwestern sector, characterized by peak **NDVI** values (0.13994) and intermediate terrain elevation, aligns with the low-wind

sheltered zone (3.1 m s^{-1}). The tall reed canopy acts as a biological windbreak, significantly damping micro-scale turbulence and creating sheltered micro-habitats.

Coupling with Water Vapor Pressure, Temperature, and Aridity: The high-wind interior pockets (3.2 m s^{-1}) correspond to regions with increased potential evaporation rates, which interact with local **Aridity Index** dynamics and **Water Vapor Pressure**. Wind exposure accelerates surface mixing, influencing local surface water temperature gradients.

Alignment with Avian Abundance Models (KDE, IDW, Getis-Ord Gi***, and Bivariate):** Primary avian hotspots—including the **10% UD core contours**, **99% Getis-Ord** Gi* **hotspots**, and Bivariate **High-High LISA clusters**—are predominantly positioned within or immediately adjacent to the sheltered, low-wind zones (3.1 m s^{-1}). Waterbirds actively select wind-protected micro-sites to reduce aerodynamic drag during roosting, minimize heat loss through forced convection, and avoid turbulent open water during foraging.

3. Ecological and Management Implications

Windbreak Habitat Conservation: Preserving tall emergent vegetation belts along the northwestern and central margins is essential for maintaining natural wind-shelter zones for waterbirds. Structural Buffer Management: Protecting peripheral topographical boundaries prevents wind-driven wave erosion and habitat degradation in shallow nesting areas.

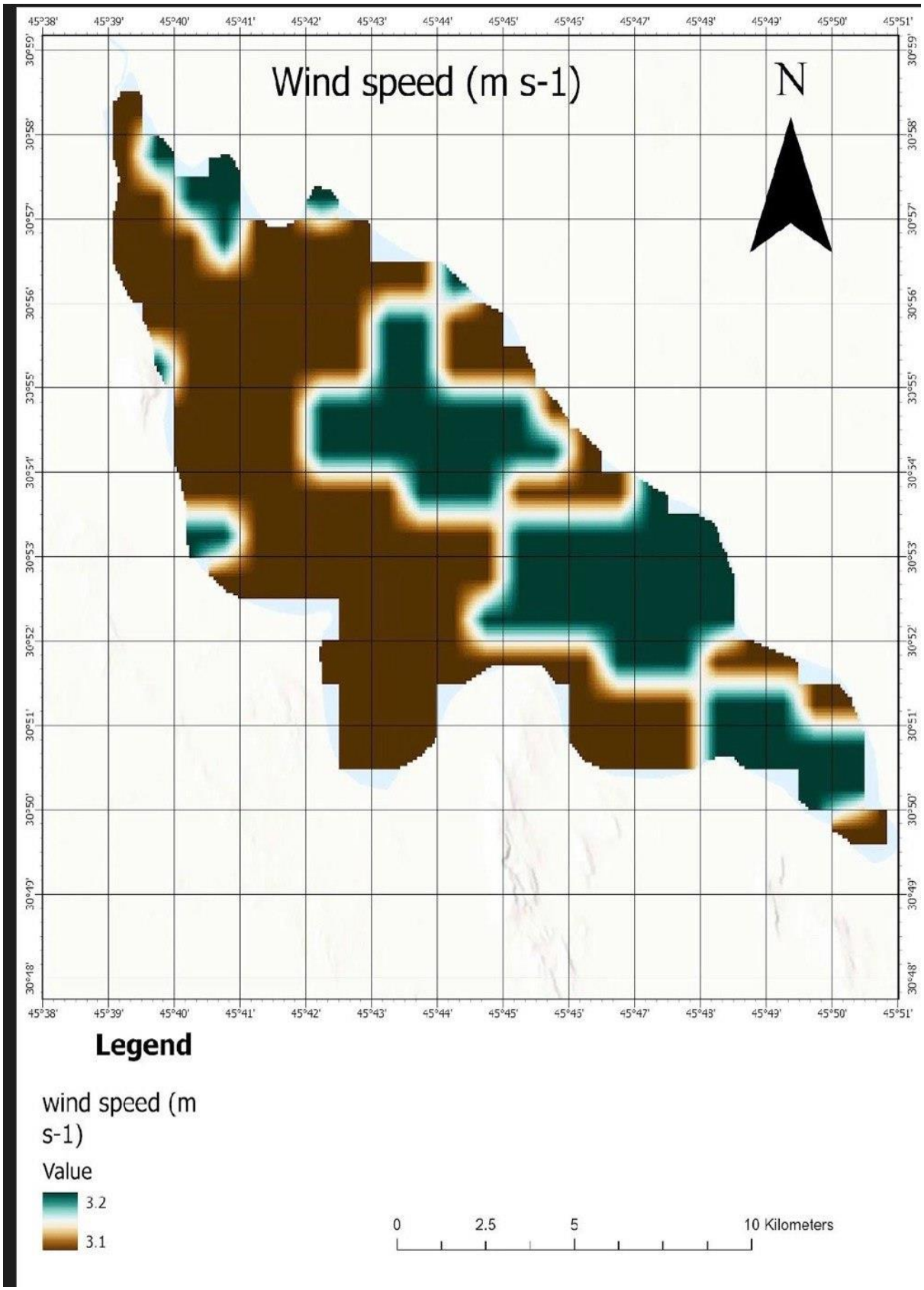


Figure 15. Spatial Analysis of Hor Al-Sulaibat, The Wind Speed - in ArcGIS

4.15. Annotated Fauna Check-List for Hor Sulibat, Southern Iraq, Systematic List (Terminology &Abbreviation)

4.15.1. Steppe Eagle

A huge raptor in the Accipitridae family, the Steppe Eagle (*Aquila nipalensis*) is well-known for its striking wingspan and characteristic dark brown feathers (BirdLife International, 2021). This migratory bird, which is native to the wide dry habitats, steppes, and semi-deserts that stretch from Eastern Europe to East Asia, travels great distances in the winter to parts of Africa, the Middle East, and South Asia (Ferguson-Lees & Christie, 2001). Small mammals, especially ground squirrels, carrion, and other small vertebrates make up the majority of its diet (Mebs & Schmidt, 2006). Due to habitat degradation, agricultural expansion, secondary poisoning, and electrocution on power lines, the Steppe Eagle's global population has declined to such an extent that the IUCN has designated the species as Endangered (BirdLife International, 2021).



Plate 6 : The Steppe Eagle (*Aquila nipalensis*), Hor Al-Sulaibat, Iraq

4.15.2. Long-legged Buzzard

A medium-to-large member of the Accipitridae family, the Long-legged Buzzard (Buteo rufinus) is distinguished by its broad wings, long legs, and changeable plumage that ranges from pale rufous to dark brown (Ferguson-Lees & Christie, 2001). It is adapted to hunting in arid habitats and is native to mountainous areas, semi-deserts, open landscapes, and dry

steppes in Southeastern Europe, North Africa, the Middle East, and Central Asia (Forsman, 2016). Its main food sources are large insects, reptiles, tiny birds, and small mammals, especially rodents like ground squirrels and voles (Orta et al., 2020). Although habitat loss, illegal shooting, and secondary chemical poisoning pose dangers to local populations, the Long-legged Buzzard is now classified as Least Concern by the IUCN (BirdLife International, 2021).



Plate 7 : The Long-legged Buzzard (*Buteo rufinus*), Hor Al-Sulaibat, Iraq

4.15.3. Short-toed Snake Eagle

The Short-toed Snake Eagle (*Circaetus gallicus*) is a medium-to-large bird belonging to the Accipitridae family. It may be identified by its round, owl-like head, brilliant yellow eyes, and mostly white underparts with light brown striping (Ferguson-Lees & Christie, 2001). It is a migratory species that spends the winter in sub-Saharan Africa and the Indian subcontinent. It is native to wide spaces, sunny shrublands, arid steppes, and semi-deserts throughout the Mediterranean basin, Eastern Europe, the Middle East, and portions of Central Asia (Forsman, 2016). Its food is almost exclusively made up of reptiles, especially snakes and lizards, which it hunts by skilfully hovering in midair before diving to catch prey with its thick, scaly legs, which are meant to defend against poisonous bites (Mebs & Schmidt, 2006). The Short-toed Snake Eagle is now listed by the IUCN as Least Concern worldwide, despite localised

decreases in European populations brought on by habitat destruction, decreased prey availability, and disruptions at nesting sites (BirdLife International, 2021).



Plate 8 : The Short-toed Snake Eagle (*Circaetus gallicus*), Hor Al-Sulaibat, Iraq

4.15.4. Egyptian Nightjar

The Egyptian Nightjar (*Caprimulgus aegyptius*) is a medium-sized, nocturnal, crepuscular bird belonging to the Caprimulgidae family. Its pale, sandy-buff plumage, which is beautifully vermiculated with grey and brown, makes it extremely well-suited to desert habitats (Cleere, 2010). When it roosts motionless during the day on barren desert soils, dunes, and salt flats, its extremely cryptic colouration makes it nearly invisible (Cramp, 1985). It is native to dry regions in areas of Southwestern Asia, the Middle East, and North Africa. After mating, it migrates regionally southward toward the Sahel zone of sub-Saharan Africa (Holyoak, 2001). The Egyptian Nightjar is a strictly insectivorous bird that hunts at nite and dusk by using its broad gape, which is fringed with rictal hairs, to catch flying insects, primarily moths, beetles, and

winged ants (Jackson, 2000; Kirwan et al., 2020). The species has a wide geographic distribution and is classified as Least Concern by the IUCN, despite possible localised concerns from habitat degradation and desertification (BirdLife International, 2021).



Plate 9 : The Egyptian Nightjar (*Caprimulgus aegyptius*), Hor Al-Sulaibat, Iraq

4.15.5. Northern Wheatear

The Northern Wheatear (*Oenanthe oenanthe*) is a small, extremely migratory passerine bird that belongs to the Muscicapidae family of Old World flycatchers. Its characteristic white rump and inverted black "T" pattern on its tail feathers make it easy to identify (Panov, 2005). One of the most amazing long-distance transoceanic migrations of any small songbird, it breeds across open, stony, and tundra habitats in Northern Europe, Asia, Greenland, and Northwestern North America. Almost all global populations winter in sub-Saharan Africa (Bairlein et al., 2012). While females have a milder, sandy-brown colouration, adult males have a striking blue-grey mantle, white supercilium, and a dramatic black eye-mask during the breeding season

(Shirihai & Svensson, 2018). It mostly eats insects, primarily ground-dwelling invertebrates like ants, beetles, spiders, and caterpillars, which it captures via quick ground pouncing or fleeting aerial sallies (Cramp, 1988; Collar et al., 2020). The IUCN now classifies the species as Least Concern due to its enormous worldwide population and wide breeding distribution (BirdLife International, 2021).



Plate 10 : The Northern Wheatear (*Oenanthe oenanthe*), Hor Al-Sulaibat, Iraq

4.15.6. Crested Lark

The Crested Lark (*Galerida cristata*) is a common passerine bird that belongs to the Alaudidae family of larks. It may be easily identified by its high, spiky crest held erect on its crown and its mysteriously patterned, streaked greyish-brown plumage (Cramp, 1988). It is found throughout mainland Europe, North Africa, the Middle East, and portions of Central Asia in dry steppes, semi-deserts, agricultural field margins, roadsides, and urban wasteland due to its exceptional adaptability to open and arid environments (de Juana et al., 2020). Foraging

mostly on the ground for a mixed diet of weed seeds, grains, and small invertebrates like beetles and ants, it maintains a terrestrial existence as a non-migratory resident species over the majority of its range (Donald, 2004; Guillaumet et al., 2005). Both from low ground perches and during short, hovering aerial song flights, the male is renowned for its lovely, melodious singing (Shirihai & Svensson, 2018). The IUCN now classifies the species as Least Concern due to its wide geographic distribution and big worldwide population, notwithstanding localised population decreases in northwestern Europe brought on by extensive agricultural mechanisation and land-use changes (BirdLife International, 2021).



Plate 11 : The Crested Lark (*Galerida cristata*), Hor Al-Sulaibat, Iraq

4.15.7. Desert Wheatear

The Desert Wheatear (*Oenanthe deserti*) is a small passerine bird belonging to the Muscicapidae family of Old World flycatchers. It is uniquely adapted to extremely dry conditions and can be clearly identified by its entirely black tail, which sets it apart from the majority of other wheatears (Panov, 2005). While females have a considerably milder, homogeneous sandy colouration with a dark brown or greyish-black tail, adult males during the breeding season display a stunning buff-sandy mantle, a warm buffish breast, and a conspicuous black neck reaching to the ear-coverts (Collar et al., 2020). Northern breeding populations move south to spend the winter in the Sahel area and the Arabian Peninsula. They are native to dry steppes, gravel plains, salt flats, and sandy deserts that stretch from North Africa across the Middle East to Central Asia (Shirihai & Svensson, 2018). Ants, beetles, grasshoppers, and small larvae make up its nearly exclusively insectivorous diet, which it obtains by falling to the ground from low perches or by making quick aerial sallies (Cramp, 1988; Yosef et al., 2002). The Desert Wheatear is categorised as Least Concern by the IUCN because of its wide range over dry regions and steady population trends (BirdLife International, 2021).



Plate 12 : The Desert Wheatear (*Oenanthe deserti*), Hor Al-Sulaibat, Iraq

4.15.8 European Stonechat

The European Stonechat (Saxicola rubicola) is a small insectivorous passerine bird belonging to the Muscicapidae family of Old World flycatchers. The male's glossy black head, vivid white half-collar, and warm orange-chestnut breast make it easy to identify (Urquhart, 2002). It is widely dispersed over Western, Southern, and Central Europe, as well as portions of North Africa and the Middle East, and inhabits open habitats like heathlands, rough pastures, coastal scrub, and agricultural field margins (Collar et al., 2020). The species' sharp, clicking alarm call, which sounds like two pebbles being knocked together, is the source of its common name (Cramp, 1988). As an ambush predator, it usually hunts from conspicuous perches, like tall plant stems or fence posts, and then drops to the ground to capture invertebrates, such as flies, beetles, caterpillars, and spiders (Greig-Smith, 1982; Shirihai & Svensson, 2018). Northern and eastern breeders travel to Mediterranean regions and North Africa

for the winter, while populations in western and southern Europe are primarily resident (Fiedler, 2005). The IUCN has classified the species as Least Concern due to its huge population size and broad geographic distribution (BirdLife International, 2021).



Plate 13 : The European Stonechat (*Saxicola rubicola*), Hor Al-Sulaibat, Iraq

4.15.9. Commen Chiffchaff

The Commen Chiffchaff (*Phylloscopus collybita*), Often referred to simply as the Common Chiffchaff, this little, energetic leaf warbler belongs to the Phylloscopidae family and is distinguished by its dark legs, dull greenish-brown upperparts, off-white underparts, and a faint yellowish supercilium (Cramp, 1992). It is a migratory passerine that winters in the Mediterranean basin, North Africa, the Middle East, and portions of the Indian subcontinent. It is widely spread across open woodlands, parks, scrublands, and reedbeds throughout Europe and Northern Asia (Clement, 2020; Shirihai & Svensson, 2018). The male's straightforward, repeating, and recognisable "chiff-chaff" territorial song,

which he constantly sings from high tree perches in the spring, is the source of the species' common name (Rodrigues, 1996). Its food is nearly completely composed of small insects, spiders, and insect larvae, with the odd addition of small berries during fall migration. It is an extremely active and foliage-gleaning animal by nature (Marchetti et al., 1995). The IUCN has classified the Eurasian Chiffchaff as Least Concern due to its large worldwide population, wide geographic distribution, and flexible breeding practices (BirdLife International, 2021).



Plate 14 : The European Chiffchaff (*Phylloscopus collybita*), Hor Al-Sulaibat, Iraq

4.15.10. White Wagtail

is a small, thin passerine bird belonging to the Motacillidae family that is easily identified by its striking black, white, and grey feathers as well as its distinctive long tail that wags continuously (Cramp, 1988). It inhabits a wide range of open settings, from riverbanks, lake sides, and agricultural fields to urban parks and

paved city surfaces, and it has a large breeding range throughout Eurasia, parts of North Africa, and Western Alaska (Tyler, 2020; Shirihai & Svensson, 2018). Northern and eastern breeders travel great distances to spend the winter in the Mediterranean basin, Africa, the Middle East, and South Asia, while southern populations are primarily resident (Davies, 1976). It is an energetic insectivorous species that forages on the ground. Its main food sources are adult flies, beetles, small caterpillars, and aquatic invertebrates, which it obtains with quick sprints or short aerial chase flights (Burtini & Davies, 1990). The IUCN has designated the White Wagtail as Least Concern due to its extensive worldwide range, strong ecological tolerance, and steady population trends (BirdLife International, 2021).



Plate 15 : The White Wagtail (*Motacilla alba*), Hor Al-Sulaibat, Iraq

4.15.11. Blue-cheeked Bee Eater

The Blue-cheeked Bee-eater (Merops persicus) is a thin, vividly coloured near-passerine bird that belongs to the Meropidae family of bee eaters. It may be identified by its long central tail streamers, blue face stripes, chestnut neck patch, and bright green plumage (Fry, 1984). It migrates south to tropical sub-

Saharan Africa for the winter after breeding in open dry habitats, agricultural landscapes, canal banks, and semi-deserts throughout North Africa, the Middle East, Iraq, and Central Asia (Cramp, 1985; Fry & Fry, 1992). It is a highly specialised aerial insectivore that feeds mostly on flying hymenopterans, especially wasps, dragonflies, and honeybees, which it captures during swift, gliding hawking flights and repeatedly strikes against perches to extract venom and stingers before consuming (Krebs & Avery, 1985; Kirwan et al., 2020). The species nests in colonies, digging deep tunnels to deposit its eggs in flat dirt mounds, earthen cliffs, or sandy riverbanks (Skead, 1997). The IUCN presently classifies the Blue-cheeked Bee-eater as Least Concern due to its wide geographic range, high local abundance, and steady population trends (BirdLife International, 2021).



Plate 16 : The Blue-cheeked Bee-eater (*Merops persicus*), Hor Al-Sulaibat, Iraq

4.15.12. Rufous-tailed Scrub Robin

The Rufous-tailed Scrub Robin (*Cercotrichas galactotes*), Often called the Rufous Bush Robin, this medium-sized passerine bird belongs to the Old World flycatcher family Muscicapidae. Its warm chestnut-rufous mantle, prominent whitish supercilium, and characteristic long, rounded tail with bold black-and-white terminal spots make it easy to identify (Cramp, 1988). It is a migratory species that winters in sub-Saharan Africa and the Sahel region and breeds in dry scrublands, Mediterranean olive groves, palm plantations, and arid river valleys from Southern Europe and North Africa through the Middle East to Central Asia (Collar et al., 2020; Shirihai & Svensson, 2018). According to Lopez-Iborra et al. (2004), the bird is well-known for its terrestrial foraging habit and distinctive behavioural display, which often involves dipping its wings while cocking and fanning its broad tail to highlight its striking tail markings. It eats only insects, mainly searching for ants, beetles, grasshoppers, caterpillars, and spiders on bare soil or low vegetation (Perez-Contreras et al., 2003). The species has a wide global distribution and is categorised as Least Concern by the IUCN, despite localised reductions brought on by agricultural intensification and the destruction of traditional hedgerows (BirdLife International, 2021).



Plate 17 : The Rufous-tailed Scrub Robin (*Cercotrichas galactotes*), Hor Al-Sulaibat, Iraq

4.15.13. Kentish Plover

The Kentish Plover (Charadrius alexandrinus) is a small, international shorebird belonging to the Charadriidae family. It is distinguished by its dark legs, dazzling white underparts, pale sandy-brown upperparts, and characteristic dark lateral breast patches rather than a whole breast band (Hayman et al., 1986). It typically lives in sandy beaches, saline mudflats, salt pans, and transient desert lakes in open coastal and interior wetland habitats throughout Eurasia, North Africa, and the Middle East (Cramp & Simmons, 1983; Wiersma et al., 2020). The species builds its nests in shallow ground scrapes adorned with tiny pebbles or shell fragments close to water borders, and it has a flexible mating system that ranges from monogamy to sequential polygamy (Szňely & Lessells, 1993). Its food is primarily composed of small coastal and aquatic invertebrates, such as polychaete worms, molluscs, crabs, and beetles, which it takes employing a distinctive "run-and-stop" foraging technique. It is a visually guided visual predator (Küpper et al., 2006). Despite its overall IUCN

classification as Least Concern, localised populations experience significant pressure from coastal tourism development, wetland drainage, and human disturbance at nesting sites, resulting in localised declines (BirdLife International, 2021).



Plate 18 : The Kentish Plover (*Charadrius alexandrinus*), Hor Al-Sulaibat, Iraq

4.15.14. Red-wattled Lapwing

The Red-wattled Lapwing (*Vanellus indicus*) is a noticeable, medium-sized wader belonging to the plover family. Charadriidae is easily identified by its eye-catching black head and breast, white cheeks, long yellow legs, and fleshy red wattles that protrude in front of its crimson-based bill (Hayman et al., 1986). It is a non-migratory species that inhabits riverbanks, marshlands, wetland borders, and agricultural fields throughout the Middle East, South Asia, and Southeast Asia (Ali & Ripley, 1987; Piersma & Wiersma, 1996). The species, which is highly noisy and territorial, is well-known for its loud, piercing alarm sounds, which are sometimes phonetically transcribed as "did-he-do-it" and are

continuously uttered when disturbed or when protecting its ground nest from possible predators (Cramp & Simmons, 1983; Sethi et al., 2010). Beetles, ants, grasshoppers, molluscs, and tiny earthworms collected from moist soil or shallow water edges make up the majority of its opportunistic, terrestrial diet (Kalsi & Khera, 1990). The IUCN has designated the Red-wattled Lapwing as Least Concern because to its wide range throughout tropical and subtropical Asia, remarkable resilience to habitats disturbed by humans, and stable population trends (BirdLife International, 2021).



Plate 19 : The Red-wattled Lapwing (*Vanellus indicus*), Hor Al-Sulaibat, Iraq

4.15.15. Black-crowned Night Heron

The Black-crowned Night Heron (Nycticorax nycticorax) is a medium-sized, stocky wading bird that belongs to the Ardeidae family of herons. It is distinguished by its remarkable ruby-red eyes, pale grey wings, glossy black crown and back, and thick black beak (Kushlan & Hancock, 2005). It has a practically global range, living in fresh, brackish, and saltwater wetlands in

Europe, Asia, Africa, and the Americas. It is very adaptable to reedbeds, riverbanks, marshlands, and urban estuaries (Cramp & Simmons, 1977; Martínez-Vilalta & Motis, 1992). It is mostly nocturnal and crepuscular, as its name implies. During the day, it roosts in dense vegetation, and at twilight, it emerges to visually hunt in shallow water employing a method known as "stand-and-wait" or slow stalking (Davis, 1993). Fish, crustaceans, amphibians, aquatic insects, small animals, and occasionally the eggs or chicks of other waterbirds make up its extremely opportunistic diet (Riegner, 1982). The species constructs large stick platforms in trees, shrubs, or dense reed beds while nesting colonially with other ardeids in traditional heronries (Fasola et al., 2002). The IUCN has designated the Black-crowned Nite Heron as Least Concern because to its extensive worldwide range, sizable population, and adaptability to a variety of aquatic environments (BirdLife International, 2021).



Plate 20 : The Black-crowned Night Heron (*Nycticorax nycticorax*), Hor Al-Sulaibat, Iraq

CHAPTER FIVE

5. Conclusion & Recommendation

5.1 Conclusion

Based on the integrated spatial, environmental, and taxonomic analyses conducted over Hor Al-Sulaibat wetland, which included GIS mapping layers (13 spatial parameter maps) and field census data, the following key results were drawn :

1. High avian taxonomic and structural diversity: Hor Al-Sulaibat hosts a diversified avifauna community of 72 species from 11 orders and 29 families. The community is dominated by Passeriformes (27 species) and Charadriiformes (18 species), indicating a diverse habitat mosaic that includes aquatic, wading, and terrestrial guilds.
2. Spatial Hotspots and Density Distribution (Kernel Density Analysis) GIS-based density modelling over 13 geographical layers identifies different hotspot zones for avian aggregation. High-density core clusters are located in center water bodies and shallow inundation zones, whereas peripheral mudflats and shrub borders act as distributed foraging corridors.
3. Ecological and hydrological coupling (NDVI and topography): Overlay analyses of the Digital Elevation Model (DEM: 4-12 m a.s.l.) and Normalised Difference Vegetation Index (NDVI) show that water depth retention and thick aquatic macrophyte cover (Phragmites australis and Typha domingensis) strongly influence geographical distribution. The hydrological spatial pattern directly influences species composition in open water, emergent vegetation, and peripheral dry edges.
4. Microclimatic Impacts on Avian Dynamics: The spatial surfaces of temperature, precipitation, wind speed, water vapour pressure, and aridity index (274-310) confirm the ecosystem's hyper-aridity. Despite severe

climatic stress, the wetland serves as an important microclimatic buffer and shelter for resident and migratory bird species.

5. Conservation Value at the Global and Regional Level: The presence of IUCN Red List species—including the Endangered Steppe Eagle (Aquila nipalensis), Vulnerable European Turtle Dove (Streptopelia turtur), and Near Threatened Marbled Teal (Marmaronetta angustirostris)—alongside regional specialities (Hypocolius ampelinus) confirms that Hor Al-Sulaibat meets the criteria for an Important Bird Area (IBA) requiring formal protected-area status.

5.2 Recommendation

1. Formal Protected Area Designation and Zoning :Formally designate Hor Al-Sulaibat as a Protected Area / Important Bird and Biodiversity Area (IBA) under national environmental laws.
2. Sustainable Ecohydrological Management and Environmental Flow Allocation Create guarantyd seasonal minimum environmental water flows (E-flows) to ensure hydrological connection and surface water depth.
3. Targeted conservation protocols for globally threatened avifauna: Create species-specific conservation action plans for IUCN Red List species Enforce stringent anti-poaching measures and reduce habitat loss during peak breeding and migration seasons.
4. Implementing Long-term Multi-Temporal Avian Monitoring: Implement a continuous, long-term avifauna monitoring program based on the standardised Whole-Wetland Area Search Protocol. Future surveys should combine high-resolution multi-temporal satellite remote sensing (e.g., Sentinel-2, PlanetScope) with GPS telemetry to monitor inter-

annual population dynamics, migratory stopover lengths, and flyway connectivity.

5. Interdisciplinary Ecological and Ecotoxicological study: Promote additional multidisciplinary academic study into the eco-hydrological dynamics of Hor Al-Sulaibat under climate change scenarios.

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الخلاصة

يُعد "هور الصليبات" واحداً من أهم النظم البيئية للأراضي الرطبة من الناحية البيولوجية في جنوب العراق. وتُشكل هذه المنطقة الرطبة -الواقعة ضمن سهل بلاد الرافدين شديد الجفاف- واحةً هيدرولوجيةً حيوية، فضلاً عن كونها محطة توقف وملاذاً شتوياً بالغ الأهمية لأنواع الطيور المهاجرة التي تسلك مسار الهجرة الممتد من غرب آسيا إلى شرق أفريقيا. وسعياً لسد الفجوة في البيانات الميدانية المتعلقة بالتنوع البيولوجي، أجرت هذه الدراسة تقييماً شاملاً - من النواحي التصنيفية والجغرافية والبيئية- لمجتمع الطيور في هور الصليبات خلال الفترة الممتدة من سبتمبر 2024 إلى مارس 2026. وقد أُجريت عمليات المسح الميداني للطيور وفقاً للبروتوكول القياسي الموحد لمسح كامل مساحة الأراضي الرطبة، مع الاستعانة بأدوات نظم المعلومات الجغرافية (GIS)، وتقنيات الاستشعار عن بُعد عبر الأقمار الصناعية، و13 طبقة بيئية مكانية للسطح. وقد تم توثيق ما مجموعه 72 نوعاً من الطيور تنتمي إلى 11 رتبة و 29 عائلة ؛ حيث شكلت رتبتا العصفوريات (27 - *Passeriformes* نوعاً) والزقزاقيات (18 - *Charadriiformes* نوعاً) المجموعات السائدة في هذا المجتمع. وتضمن مجتمع الطيور: الطيور المائية الشتوية -وفي مقدمتها البط الشتوي/الحذف الشتوي (**Anas crecca**) بأعداد بلغت 1160 فرداً-، وطيور الخواضات والنوارس (مثل النورس أسود الرأس **Chroicocephalus ridibundus** بعدد 350 فرداً، والدريجة الصغيرة **Calidris minuta** بعدد 140 فرداً)، وطيور البلشون المرتبطة بالمستنقعات (مثل البلشون الأبيض الصغير **Egretta garzetta** والبلشون الرمادي **Ardea cinerea**)، وأنواعاً متخصصة من العصفوريات (مثل نقشارة الشيفشاف **Phylloscopus collybita** والهيبوكوليوس * *Hypocolius ampelinus**)، وجوارح رئيسية (مثل مرزة المستنقعات الغربية **Circus aeruginosus**). وكشفت نمذجة الكثافة المكانية -باستخدام طريقة تقدير كثافة النواة (*Kernel Density Estimation*)- عن بؤر تجمع متميزة تتركز في أحواض المياه المفتوحة وسط الهور ومناطق الغمر الضحلة؛ وتتأثر هذه التجمعات بتدرجات الارتفاع الطبوغرافي (4-12 متراً فوق مستوى سطح البحر) والكثافة العالية للنباتات المائية البارزة (مثل القصب **Phragmites australis** والبردي **Typha domingensis**)، وذلك وفقاً لما أظهرته طبقات مؤشر الغطاء النباتي (NDVI). كما كشفت نمذجة المناخ المحلي (الميكرو-مناخ) أنه على الرغم من الجفاف الشديد للمنطقة (حيث تراوح مؤشر الجفاف بين 274 و310)، فإن هذه الأراضي الرطبة تعمل كعامل تخفيف مناخي محلي هام. أظهر تقييم الحفاظ على البيئة وجود أنواع مهددة عالميًا مدرجة على القائمة الحمراء للاتحاد الدولي لحفظ الطبيعة، مثل نسر السهوب المهدد بالانقراض (*Aquila nipalensis*)، واليمامة الأوروبية المعرضة للخطر (*Streptopelia turtur*)، والبط الرخامي القريب من التهديد (*Marmaronetta angustirostris*). تؤكد هذه

النتائج العملية الأهمية الحيوية للحفاظ على بيئة هور السليبات، وتدعم بقوة تصنيفها رسميًا كمنطقة مهمة للطيور (IBA) مع إدارة بيئية مائية مستدامة.

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وهي جزء من متطلبات نيل شهادة الدكتوراه فلسفة في علوم البيئة

إعداد

زينب وسام ناجي

بكالوريوس في علوم البيئة (2018)

ماجستير في علوم البيئة (2022)

بإشراف

الأستاذ الدكتور سلوان علي عبيد

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