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Reconstructing Lost Urban Wetland: A Spectral and Topographic Remote Sensing Framework

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Abstract- Wetlands are crucial ecosystems that regulate floods, store carbon, and support a wide range of biodiversity. Their loss negatively impacts the surrounding areas; in flood-prone regions, this increases vulnerability to floods and endangers lives. The conversion of natural wetlands to agricultural lands is common in Punjab; this process often involves intentionally draining wetlands for agricultural use. In Lahore, natural wetlands are often overlooked and vanish without documentation due to encroachment, leaving gaps in our existing knowledge of the city's natural wetlands. The study verifies and retraces a lost natural wetland in the current Barkat colony to address this gap. Multi-temporal Landsat imagery (1990–2024) was analyzed with Modified Normalized Difference Water Index (MNDWI) and Normalized Difference Water Index (NDWI) to delineate wetland extent, while historical Google Earth imagery and Digital Elevation Models (DEMs) were employed to understand site-specific changes and flood vulnerability. Results reveal that in 2001, there existed at least 150 acres of a natural wetland, identified as an oxbow lake in the area now known as Barkat Colony. This wetland's existence was never officially documented. The site is highly vulnerable to floods and is 10 meters lower in elevation than the surrounding areas, leading to stagnant floodwaters that persisted for an entire year in 2013. Such findings highlight the use of remote sensing techniques in reconstructing the history of undocumented wetlands, filling critical local data gaps, and providing insights for flood risk mitigation, ecological conservation, and urban planning in Lahore. This paper provides a framework that can be employed to delineate and document other wetlands in Lahore.

Keywords- Natural Wetlands, Remote Sensing Indices, Land Use Change, Lost Wetlands, Flood Vulnerability.

I. INTRODUCTION

Only 6% of the global land area consists of wetlands[1], yet 42% of the animal and plant species depend on wetland ecosystems to thrive. [2] Wetlands are the most productive ecosystems in terms of their ecological value. Wetlands play an important role in flood mitigation. They can store floodwater [3] and their plants play a key role in slowing down the speed of floods [4]. The extent of their flood reduction services depends on their location. Wetlands located in floodplains have far more potential in reducing the area's flood vulnerability, acting as a shield against erosion. [5-6] They reduce the LST (Land Surface Temperature) through evaporation as they are bodies of water[7]. They absorb carbon from the atmosphere and store it, acting as a natural buffer against climate change. [8] Approximately 12% of the global carbon is stored in wetland ecosystems. [9]

Despite the extensive amount of ecosystem services provided by wetlands, they are disappearing 3 times faster than forests, making them globally the most degraded ecosystems. [2] Depending on the location, the world has experienced 30% - 90% loss of wetland ecosystems. [1] Their loss negatively impacts the surrounding areas; in flood-prone regions, this increases vulnerability to floods and endangers lives. When disturbed, these ecosystems, instead of being a carbon sink, release the stored carbon along with Greenhouse Gases (GHGs) like Carbon Dioxide (CO_2), Methane (CH_4), and Nitrous Oxide into the atmosphere.[8]

In Pakistan, wetlands cover an area of 700,000 ha, which equates to 9.7% of the total land area. Pakistan has a diverse range of wetlands, including marshes, alpine lakes, floodplain wetlands, lowland natural lakes, coastal wetlands, peat swamps, springs, and streams. 225 wetlands have been identified as wetlands of international importance, with 19 designated as Ramsar sites. [10] Punjab comprises many natural wetlands in its river's floodplains. [11] These are often overlooked and ignored, leading to their decline and eventual demise. Conversion of wetlands into agricultural lands in Punjab is a common practice. This is mostly done by deliberately draining the wetlands, making the land suitable for agriculture [11]. This case is very true for Lahore, and unfortunately, many

natural wetlands have already been lost without a trace.

Remote sensing is the most effective method for wetland mapping and study, especially when field surveys aren't feasible, using indices like NDVI and NDWI alongside freely available Landsat TM/ETM+/OLI satellite data. [12].

The Paper first employs the remote sensing index MNDWI (Modified Normalized Difference Water Index) to map the wetlands of Lahore in 1990 and compares it with 2024, highlighting the long-term changes in their extent. Based on GIS screening and regional satellite data limitations, Barkat Colony was selected as the study area. Google Earth imagery showed blurred resolution before the year 2001, and spectral satellite data before 1990 are unavailable, limiting access to the wetland ecosystems lost before that time. Within these constraints, the selected area exhibited significant wetland ecosystem loss and clear patterns of urban encroachment over time. For detailed analysis, MNDWI, NDWI, historical Google Earth imagery, and DEM contour models were applied to verify and retrace the existence of a lost wetland and assess the impacts of its disappearance. This approach provides both an overall perspective on wetland loss in Lahore and a detailed site-specific exploration of a lost wetland story.

Research Question:

"How can remote sensing techniques (MNDWI, NDWI, DEM, and historical Google Earth imagery) be used to retrace undocumented wetlands in Lahore, address the existing data gaps, and assess the impacts of their loss?"

Objectives:

- To delineate and verify a lost natural wetland using MNDWI and NDWI analysis, addressing the gap of no prior documentation of lost natural wetlands of Lahore.
- To assess land use changes and flood vulnerability following the disappearance of the lost natural wetland, highlighting some implications for solving site-specific issues.

II. Literature Review

Globally, many wetland studies have employed remote sensing techniques for wetland delineation and change analysis. In partnership with the Ramsar Convention, the project consists of many individual local studies to develop a global inventory of wetlands. It utilizes satellite data and GIS to delineate and study the wetlands, improving local understanding. [13]. This research analyzes the land use/ land cover change of Uttarakhand, India, using supervised classification, NDWI, NDVI, and NDBI with Landsat TM imagery [14]. Other global wetland studies include [15-17] These have employed satellite data, spectral indices to study the wetland area.

Regionally, this study provides an inventory of lost natural wetlands of Indian Punjab, in the floodplains of its rivers. It uses old topographical maps of India from 1911 and satellite imagery to delineate natural wetlands, and addresses the contextual data gaps [11].

In Pakistan, a few researchers have utilized remote sensing techniques to study wetlands. This research uses multiple remote sensing techniques, including NDTI, supervised classification, and DEM, to study the effects on neglected wetlands of Borith, Phander, Upper Kachura, Satpara, and Rama Lakes [18]. This study analyzes land use changes of Uchhali and Khabeki wetland lakes using Landsat images through supervised classification [19]. This research analyzes the changing dynamics of Haleji & Kinjhar wetland lake by processing Landsat imagery with spectral Indices [20]. Many wetland studies on its transformations, changes and trends have employed spectral water indices to study its extent over the years. In these studies, MNDWI have been the most successful index in terms of clarity and results obtained [21-23]. Landsat is the most used dataset in wetland studies because of its long-term records with reasonable spatial resolution [24]. This study has investigated the impact of land use change on the urban wetlands by using NDWI, MNDWI, and other built-area indices [25]. This study assessed the loss and gain of wetland area in Chhattisgarh between 2002 and 2023 using Landsat 5 TM, Landsat 8, and Sentinel-1 data. It uses MNDWI to map wetland areas, hence studying wetland dynamics over time [26]. This study employed multiple spectral indices to access wetland health, it uses 13 different indicators for this purpose including MNDWI for water extent, NDVI for vegetation health assessment [27]. Current wetland studies in Pakistan are primarily focused on the more significant wetlands. While this study employed Landsat classification and normalized difference vegetation and built-up indices (NDVI, NDBI) to analyze the change in Land Surface Temperature LST of Lahore from 1996 to 2016. The results revealed that the decrease in surface water has the biggest impact on the increase in LST of Lahore [7].

Despite all these advancements and techniques available, nothing is known about the natural wetlands of Lahore, Pakistan. Locally, they are often dismissed as "wastelands." This has resulted in an extensive loss of many natural wetland ecosystems. This loss needs to be quantified.

III. Study Area

Initially, the site of Lahore was analyzed by preparing MNDWI maps. In these maps, the site of the Barkat colony was highlighted as the area of significant change. After further study using Google Earth Maps, as shown in "Fig. 1" and "Fig. 7", it was

found that this site has exhibited the characteristics needed for this study over the years, indicating significant land-use changes and the presence of a natural wetland in 2001.

Barkat Colony is located at Latitude: *31.4198° N,* Longitude: *74.1483° E* in the southwestern part of Lahore, Pakistan, within the floodplains of the River Ravi. It's now an unauthorized housing settlement that has been expanding rapidly since 2020. The area also consists of a natural riparian forest near the river, which frequently gets washed away by floods from the Ravi River[28]. The study area is located in a rapidly urbanizing context, resulting in numerous new housing developments, including DHA Eme and Izmir town. The Average Temperature of the region varies from 46°F to 103°F, and the climate is semi-arid.



(a)



(b)

Figure 1 a) Barkat Colony, Lahore 2024 Google Earth Imagery. b) Barkat Colony, Lahore 2001 Google Earth Imagery.

It indicates the presence of a possible natural wetland among the agricultural lands. Due to the limited resolution of Google Earth Imagery before 2001, it was selected as the baseline. The green area in 2001 could be just dense vegetation and not a natural wetland. Hence, it needs to be tested through remote sensing.

IV. METHODOLOGY

The methodology adopted for this study includes preparing and analyzing MNDWI and NDWI maps for the verification and delineation of the natural wetland. Then, historical Google Earth Imagery was analyzed for land-use changes over the years (2001, 2005, 2011, 2013, 2018, 2020, 2024). Contour maps were prepared using DEM data to study the site's flood vulnerability. For this entire process, free GIS software, QGIS, was used.

MNDWI was used to delineate the wetland instead of NDWI because of the lack of clarity in the NDWI map. The NDWI often mixes the enhanced water data with the build-up land noise. On the other hand, MNDWI can efficiently suppress or even remove the built-up noise, making MNDWI more suitable for areas that are mostly dominated by built-up features like Lahore.[29] These maps were validated based on visual interpretation from Google Earth imagery, except for the year 1990, as the satellite image of that time is way too blurry for any interpretation.

4.1. Data Collection:

The Landsat Thematic Mapper (TM) imagery was used as the primary dataset for the Spectral indices. USGS Earth Explorer provides Landsat data for the current year as well as past years. Depending on the launch year of the specific satellite, Landsat data from the following years can be sourced from that particular satellite. For 2024 mapping, the data were sourced from the Landsat 8-9 Thematic Mapper (TM) sensor. However, for years 2000 or below, Landsat 7 Thematic Mapper (TM) sensor data would normally be used. In the case of this project, Landsat 7 was under-maintenance due to overheating issues, so instead, Landsat 5 Thematic Mapper (TM) sensor data was used.

While selecting the suitable Landsat imagery, it was ensured that the cloud cover was at a minimum, as it could affect the results. Depending on the specific satellite imagery, spatial resolution varies. Landsat 5, launched in 1984, offered a maximum resolution of 30m (98ft). However, Landsat 8-9, launched in respective years 2013 and 2021, offered a spatial resolution of 30-15m (98-50ft). It is to be noted that the oldest imagery one could obtain of this given context is the year 1990. For Lahore, Google Earth provides historical imagery that could go back as far as 1980. However, due to the very limited resolution, the site can't be studied before the year 2001. The study employs Local Ecological Knowledge (LEK) for the confirmation of the events that happened in the study area.

The Digital Elevation Models STRM were also sourced from USGS Earth Explorer; for this specific region, only 2005 and 2014 DEM models were available. There wasn't a significant difference in topography between the years 2005 and 2014,

suggesting no drastic difference in elevation over the years.

4.2. Spectral Indices:
Different materials on Earth's surface interact differently with electromagnetic radiation, creating their own characteristic spectral signatures. To obtain the desired information, specific spectral bands are combined to enhance the feature under study. [30] These indices are extensively used methods. This study employs two of these indices, namely, MNDWI (Modified Normalized Difference Water Index) for the extraction of water, and NDVI (Normalized Difference Vegetation Index) for understanding unique characteristics of the wetland.

4.2.1. Modified Normalized Difference Water Index (MNDWI) Analysis:
The Modified Normalized Difference Water Index (MNDWI) improves the identification of open water features by using the green and shortwave infrared (SWIR) bands. This index is effective at removing built-up areas, often confused with water in remote sensing analyses, while preserving the water information more effectively than some other indices. [31-32] For MNDWI map preparation, the following formula was used in the raster calculator tool of QGIS to process Landsat (8, 5) Thematic Mapper (TM) Bands 3 (Green) and 6 (SWIR, Short-Wave Infrared) imagery.
MNDWI = (Green - SWIR) / (Green + SWIR)

4.2.2. Normalized Difference Vegetation Index (NDVI) Analysis:
Spectral vegetation extraction indices enhance the enrichment of vegetation. This analysis was done to understand the characteristics of the wetland as shown in the 2001 MNDWI map. To prepare this map, the following formula was used to process Landsat 5,8 Thematic Mapper (TM) bands 4 (NIR, Near Infrared) and 3 (Red) in the raster calculator tool of QGIS.
NDVI = (NIR - R) / (NIR + R)

4.3. DEM Digital Elevation Model Analysis:
Digital Elevation models carry the data of Earth's topography. The sourced DEM models were processed in QGIS to generate contour maps with a contour interval of 2 meters.

V. Results & Discussion

The results obtained through the analysis of Landsat Thematic Mapper imageries are shown in "Fig. 5" and "Fig. 6". The detailed discussion of results is below.

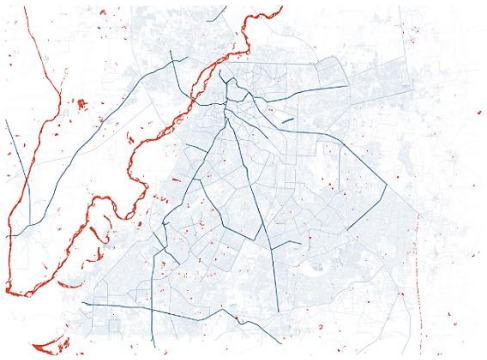


Figure 2 MNDWI, Lahore 1990. The Color Red Indicates the Presence of Water.

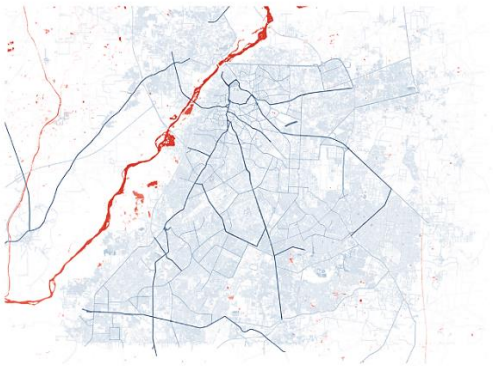


Figure 3 MNDWI Lahore Map, 2024. The Color Red Indicates the Presence of Water.

Comparing "Fig. 3" and "Fig. 4", it's evident that Lahore has lost many wetlands since 1990. Agriculture, followed by urban expansion and its collective pressure on wetland ecosystems, is the core reason for this loss of wetlands. Wetlands are termed wastelands among the locals, and their ecosystem services are unfortunately not recognized by the people. The loss of wetlands has resulted in increased LST of Lahore [7]
For the detailed study of the chosen site,

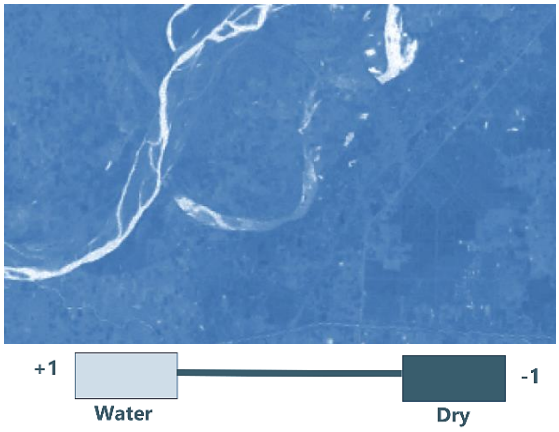


Figure 4 MNDWI 2001, Verification of Google Earth Imagery. +1 = Pure Water, -1 = Dry Land, Values > 0 Indicate Varying Levels of Water Content.

"Fig. 4" verifies the presence of water in the wetland area. Values are represented between +1 (water) and -1 (Dryland). The value of 0.2 represents the presence of an open water feature. While all the values above 0 represent water content. One could see the varying levels of water content throughout the wetland area. Another MNDWI image was made for 1990 to understand these changes in water content.

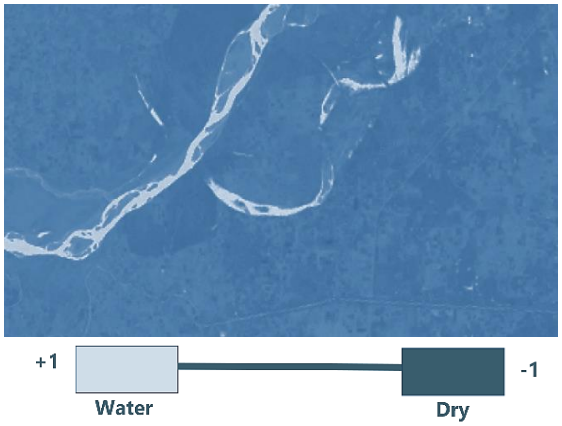


Figure 5 MNDWI 1990, Showing More Water Than 2001. +1 = Pure Water, -1 = Dry Land, Values > 0 Indicate Varying Levels of Water Feature.

As seen in "Fig. 5", the water content is the same throughout the wetland area. To find the reason why MNDWI represented the values differently, another index was used, namely NDVI.

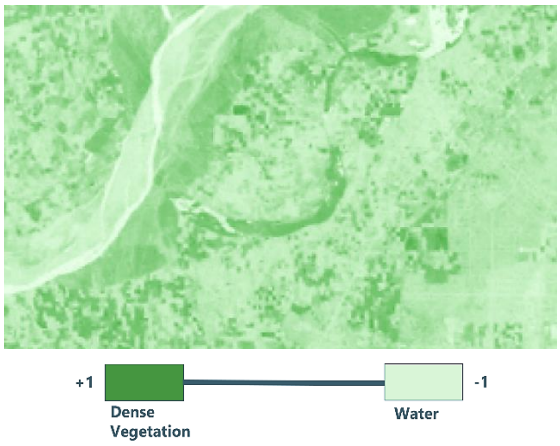


Figure 6 NDVI 2001 Showing Enrichment of Vegetation in the Wetland Area. +1 = Denser Vegetation, -1 = Water Content.

The wetland area showed the presence of dense vegetation, as indicated in "Fig. 6". Wetlands are characterized by the presence of healthy vegetation. It could also be a phenomenon called eutrophication. It mostly happens when wetlands are surrounded by agricultural lands, which results in nutrient overflow in wetlands, causing green surface growth on the surface of the wetlands. Eutrophication also affects the MNDWI results. As natural wetlands are unique ecosystems, either of these two could be true.

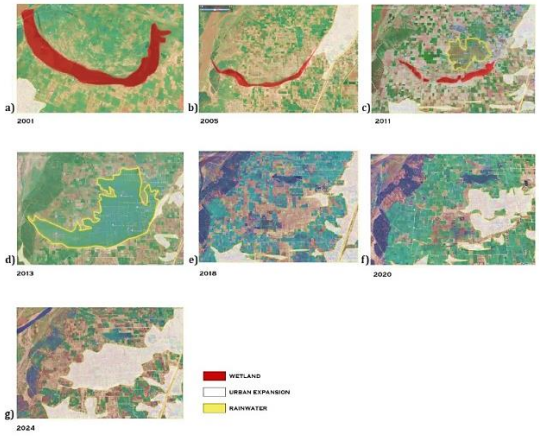


Figure 7 Historical Google Earth Imagery a) 2001 b)2005 c)2011 d) 2013 e)2018 f)2020 g)2024.

This wetland went through a series of anthropogenic events. "Fig. 7a) 2001" is marked by the presence of either wetland plants or eutrophication. "Fig. 7b) 2005" suggests that there was land pressure on the wetland area, resulting in the drying and filling out of the area by the farmers. As Punjab is an agricultural region, these kinds of events are common here. It's one of the main reasons for wetland loss in Pakistan.[10] "Fig. 7c) 2011" is marked by further drying and filling out of the wetland ecosystem by the farmers. In "Fig. 7d) 2013", a flood event occurred and resulted in flood water stagnation in the entire area. As the wetland can store water from floods within itself, after its disappearance, this destruction was inevitable. According to local knowledge (LEK), since 2005, farmers began to sell soil from their agricultural lands as it was in demand by the construction sites nearby, which resulted in a drastic decrease in the elevation of the study area. Consequently, during the flood of 2013, floodwater filled this depression, and as there was no other way for the water to go, it stood there for more than a year. The locals reported that they used to come here every day to see how much water had been lowered. "Fig. 7e) 2018" is marked by the beginning of encroachments by the housing society developers. As Lahore is a rapidly developing city, over the years, many new housing societies, including DHA EME, Izmir Town, have emerged near the study area. This region is a hotspot for urban expansion in Lahore. As a result, some farmers sold their agricultural lands, while some are actively selling housing plots of this illegal development. This site's history aligns with the land pressure hierarchy of Lahore, where wetlands are under pressure from agricultural lands, and agricultural lands are under pressure from housing developments. "Fig. 7g) 2024" shows the current extent of the rapidly expanding Barkat colony.

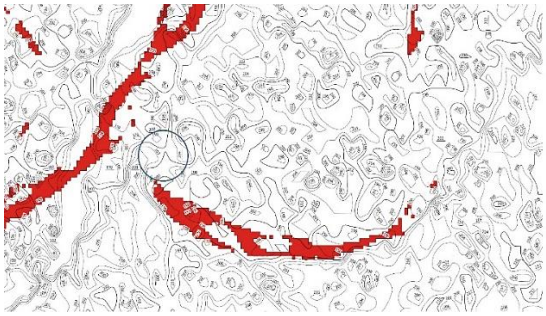


Figure 8 Contour Maps 2005, Made from the DEM Model.

Contour maps of 2005 and 2014 were analyzed; however, there was no significant difference in elevation over these years. The study area is at an elevation of 200m, while its surroundings are at 210m, which corresponds to almost 30 feet. The slope is 1:6 at the south; however, it gets gradual as it continues to the west. One critical area was highlighted; it serves as the main pathway for Ravi floods to enter this area. It can be identified clearly in "Fig. 7d) 2013" and "Fig. 8". LEK confirmed that they used to put their money together and spend it on blocking this channel. It's the same channel that used to connect the wetland with the river. The disappearance of the natural wetland has increased the site's flood vulnerability. Bioswales or detention wetlands connected to this channel can solve the area's current flooding issues, taking in floodwater and storing it. For future urban planners, the connecting pathway is the critical point to solve this issue.

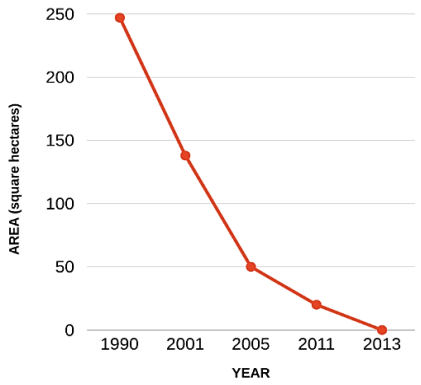


Figure 9 Approximate Wetland Area Decline from 1990 to 2013

Fig. 9 elaborates on the wetland's area decline from 1990 to 2013. In 1990, the total wetland coverage was around 250 square hectares; it drastically decreased over the years until it vanished in 2013.

5.1 Wetland Type Identification and Hydrology:
Based on the unique features of the wetland and its hydrological location, it was identified as an oxbow lake. These are formed in the floodplains of the main river. As this wetland is in the Ravi flood plain, it's a riverine wetland. Oxbow lakes are formed naturally when a river changes its course.[33] This wetland exhibits the characteristic U-shape of typical oxbow lakes, as shown in "Fig. 7a) 2001". Their hydrology depends on the river that supports it; usually, it's maintained through floods or tie channels connecting it to the main river. Natural shrinking of oxbow lakes through evaporation and drainage-based losses causes fluctuations in water content. The extent of shrinkage also depends on their hydrological connectivity with the main river. This specific wetland's hydrology is connected to the main river through a channel, as indicated in "Fig. 8". The presence of this channel has increased the study area's flood vulnerability concerns. The evolution from 1990 to 2001 likely made it from an oxbow lake to a swamp, indicated by the presence of healthy vegetation in NDVI.

VI. Conclusion

These findings suggest the utilization of remote sensing techniques to fill critical local data gaps and are significant to establish a data set of lost natural wetlands of Lahore. Documenting these ecosystems is the first step in their conservation. The government should develop and implement policies for its protection, conservation, and restoration. Making it illegal to drain it and declaring it as a no-use land, especially in urban areas with severe pressure of urban expansion. Protecting the wetland area from its neighboring activities is crucial. Establishing required buffer zones around the wetland area protects it from the impacts they may cause. Furthermore, policies should restrict activities allowed in neighboring areas, as they directly impact wetland ecology. In case of agricultural lands nearby, the excess nitrogen run-off from the agricultural lands should be managed before it enters the wetland.
The current Barkat Colony is highly vulnerable to stagnant floodwaters; these past traces can serve as insights to solve this issue. The construction of a flood-dependent constructed wetland, as it used to exist in the past, can be a possible solution for urban planners. Future research on this subject should focus on possible restoration strategies that can be implemented, although it's impossible to restore a natural wetland ecosystem completely, even if some percentage of its ecosystem is restored can have a profoundly positive impact on the environment.

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