

AHP-Based Multi-Criteria Assessment of Vegetation Health in Bhawal National Park

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Abstract: The Bhawal National Park (BNP) is an ecologically important area which has a rich biological diversity that helps maintain equilibrium in ecology. It experienced urban expansion, agricultural encroachment, land degradation, and other issues that affected the health of vegetation. The purpose of this study was to use a multi-criterion decision-making (MCDM) framework, specifically Analytic Hierarchy Process (AHP), to study BNP vegetation health from 2000 to 2025. The research used various vegetation indices such as NDVI, EVI, SAVI, NDMI, PVI, SI, NDBI, NDBal, EBBI, and GI and integrated through AHP technique; where weights are assigned, normalized, combined and finally Consistency Ratio (CR) score is calculated. The final CR score of 0.09428 indicates moderate vegetation health, balancing healthy areas with those impacted by urbanization and degradation. Notable results were an improvement of 14.94% with 1,437.39 ha moving from moderate to high. In addition, 215.59 ha (2.24%) shifted from low to high while 43.66 ha (0.46%) switched from low to very high vegetation health. Conversely, the rest of the area that is 79.65 hectares (0.83%) went from moderate vegetation health to very low vegetation health. This indicates that the area is always experiencing stress particularly the southern portion of the area. According to the findings, growth in the vegetation recovery is intensifying, especially in the areas of northern and central belts. This study highlights the importance of ongoing management of the land and demonstrates the usefulness of AHP for ecological assessment and conservation planning.

Keywords: Bhawal National Park (BNP), Vegetation Health (VH), Analytic Hierarchy Process (AHP), Multi-Criteria Decision Making (MCDM), GIS

1. Introduction

Increasing environmental problems focus on the sustainability of land management and conservation of biodiversity. Forest ecosystems contribute towards ecological balance. Forests contribute in a multitude of ways as they are responsible for a wide variety of services including carbon sequestration, water regulation, and supply of habitat to various species (WWF, 2021). These ecosystems are essential for maintaining ecological balance but are being threatened by increasing human activities like deforestation, urbanization and climate change which is degrading important natural resources (FAO 2021). The loss

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of forest cover and the degrading of ecological health is posing increasing threat to management and conservation practices. Similarly, Malczewski (2004) mentions that monitoring and assessment of forest health and land suitability can be capably done using modern geospatial technologies like GIS and remote sensing. By combining essential criteria and multi-criteria decision-making procedures such as the AHP, these are useful for assessing land-use transformations, environmental deterioration, and ranking conservation priorities (Saaty, 1980; Dutta et al., 2020).

The main goal of this study is to evaluate the vegetation health of Bhawal National Park by utilization of multi-criteria decision-making, especially AHP Method. The research is focused on Bhawal National Park (BNP), Bangladesh located in Central Bangladesh, an eco-sensitive area known for its rich biodiversity and important environmental functions. Despite its status as a national park, human influence causes habitat fragmentation, illegal encroachments, and deforestation. This study assesses vegetation health of the park by using AHP. At the same time, it makes recommendations for managing the park's ecosystems, including future ecotourism development.

The methodology of GIS and AHP in land evaluation is widely used by researchers to verify the environmental sustainability of landscapes. Basically, AHP in forestry management helps identify the most significant impacts on soil, vegetation, climate and human's disturbances that affect the quality of forests (Sarai et al. 2024). According to Dutta et al (2020) & Chaudhary et al (2021), the use of analytic hierarchy process (AHP) has been done in South Asia, particularly in West Bengal and Himalayan foothills, by incorporating remote sensing data, vegetation indices (NDVI, EVI) and other important indicators, to assess forest health.

Additionally, AHP has frequently used for assessing land suitability as sustainable tourism based on site factors like naturalness of the landscape, vegetative cover and richness of biodiversity. The geographic information system (GIS) and Analytic Hierarchy Process (AHP) were used by Chaudhary et al. to assess the potential of ecotourism in Garhwal region in India. The factors of slope, elevation, vegetation kinds and distance from protected areas is taken into consideration. Their research determined the best places for ecotourism while maintaining the natural habitat despite the occurrence of tourism. According to Roshani et al., (2022) and Li et al., (2018), fuzzy AHP is an effective measure for handling uncertainties and subjectivity in the decision-making that concerns forest health and land suitability for conservation and ecotourism.

AHP has been effectively used to balance ecological conservation and economic development in land-use planning and ecotourism development. While ecotourism can bring substantial economic benefits to communities, unregulated tourism can cause overexploitation and degradation of natural resources (Goodwin, 1996). In this way, the relationship between human activity, biodiversity conservation and ecotourism development is very important to ensure sustainability of nature and people in the long run (Sati, 2020).

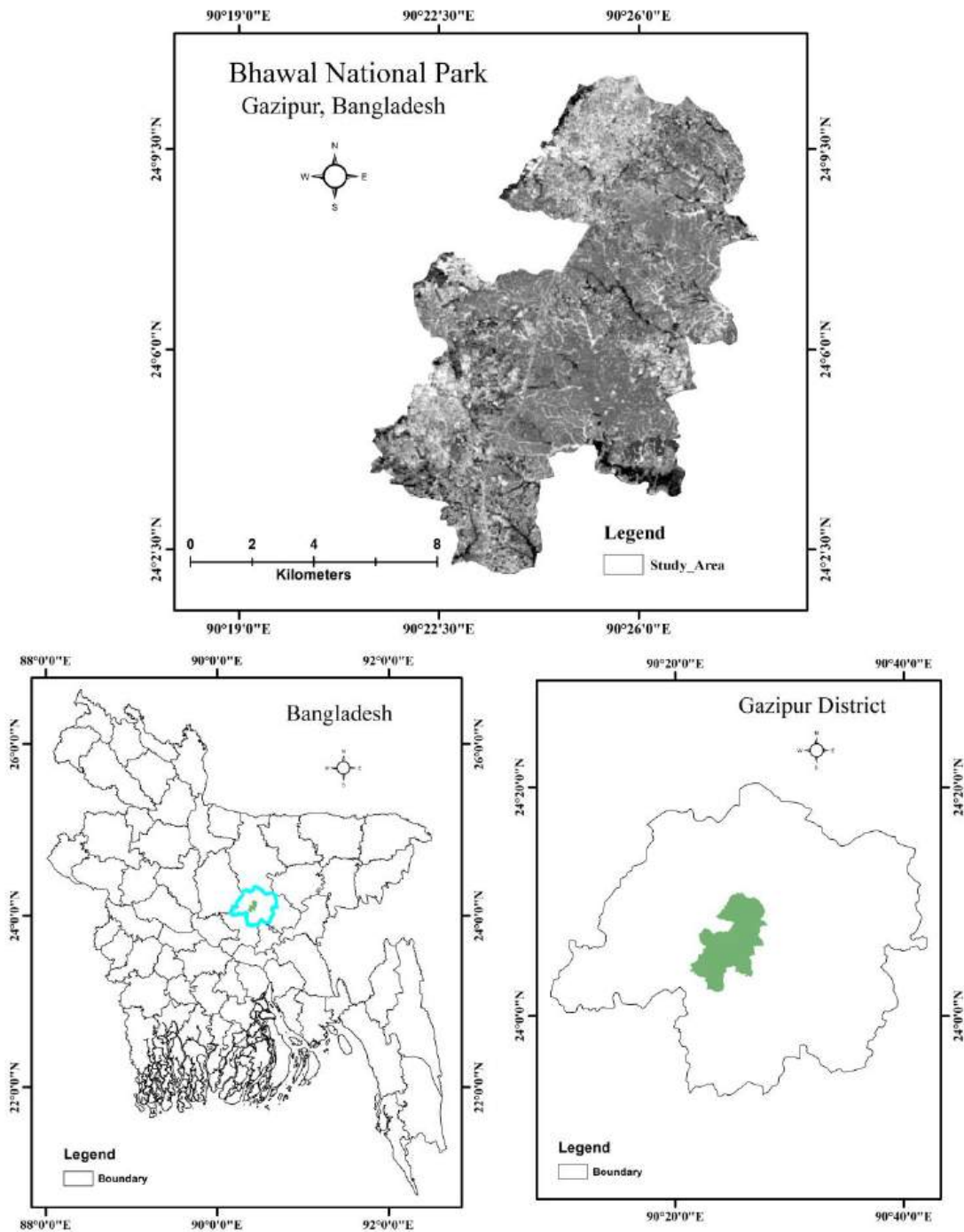


Figure 1.1 Study area map of Bhawal National Park

Source: Compiled by author, 2025

Bhawal National Park, situated at 23.8833° N and 90.5167° E (fig. 1.1), is located in Gazipur District, Central Bangladesh. It has an area of about 5000 hectares and is located 35 km north of Dhaka. The park experiences a tropical monsoon climate, with hot summers, heavy rainfall during the monsoon season, and cooler winters (FAO, 2021). The surrounding area is predominantly rural, with local populations relying on the park for resources such as wood and agriculture (Chaudhary et al., 2022). The majority of the Bhawal National Park is covered with moisture deciduous and semi-evergreen trees. These creatures are a suitable habitat for various flora and fauna. According to Malczewski, 2004 Shrub species, grass species, like *Shorea robusta*, *Terminalia belerica*, *Acacia catechu* species are the different vegetation which are distributed in the soil of such forest. The park's rolling hills, formed by seasonal floods, house all sorts of plants and animals. Though, the park is facing much human pressure in terms of encroachment and extraction of resources which adds to the degradation (WWF, 2021).

2. Data and Method

This study on the vegetation health of Bhawal National Park has utilized Landsat 5 (2000) and Landsat 8 (2025) images that have 30m resolution and <5% cloud cover (Table. 2.1). The AHP model (fig. 2.1) enabled by GIS computes several vegetation indices (NDVI, EVI, SAVI, etc.) by assigning weights, normalizing and calculating to arrive at a vegetation health (VH) score. The use of GIS illustration helps in the understanding of the spatial patterns of changes in vegetation quality and degradation.

2.1 Data

Table 2.1 The utilization of images in this research

Satellite	Sensor Type	Acquisition Date	Resolution	Cloud Cover	Source
Landsat 8	OLI	10/2/2025	30m	<05	<i>Earthexplorer.usgs.gov</i>
Landsat 5	TM	08/2/2000	30m	<05	

2.2 Methodology

The method used in this research initiates with the acquisition of satellite images at two different times 2000 and 2025 (table 2.1, fig. 2.1). Satellite data from Landsat 5 TM 2000 and Landsat 8 OLI 2025 is specifically used to assess changes in vegetation health over a period of 25 years. The satellite images form the basis for developing diverse vegetation and land-use indices that are essential for assessing various aspects of vegetation cover and ecological health in the study area. The two main indices are NDVI that measures overall vegetation health and EVI (enhanced vegetation index), which is better for more densely forested areas.

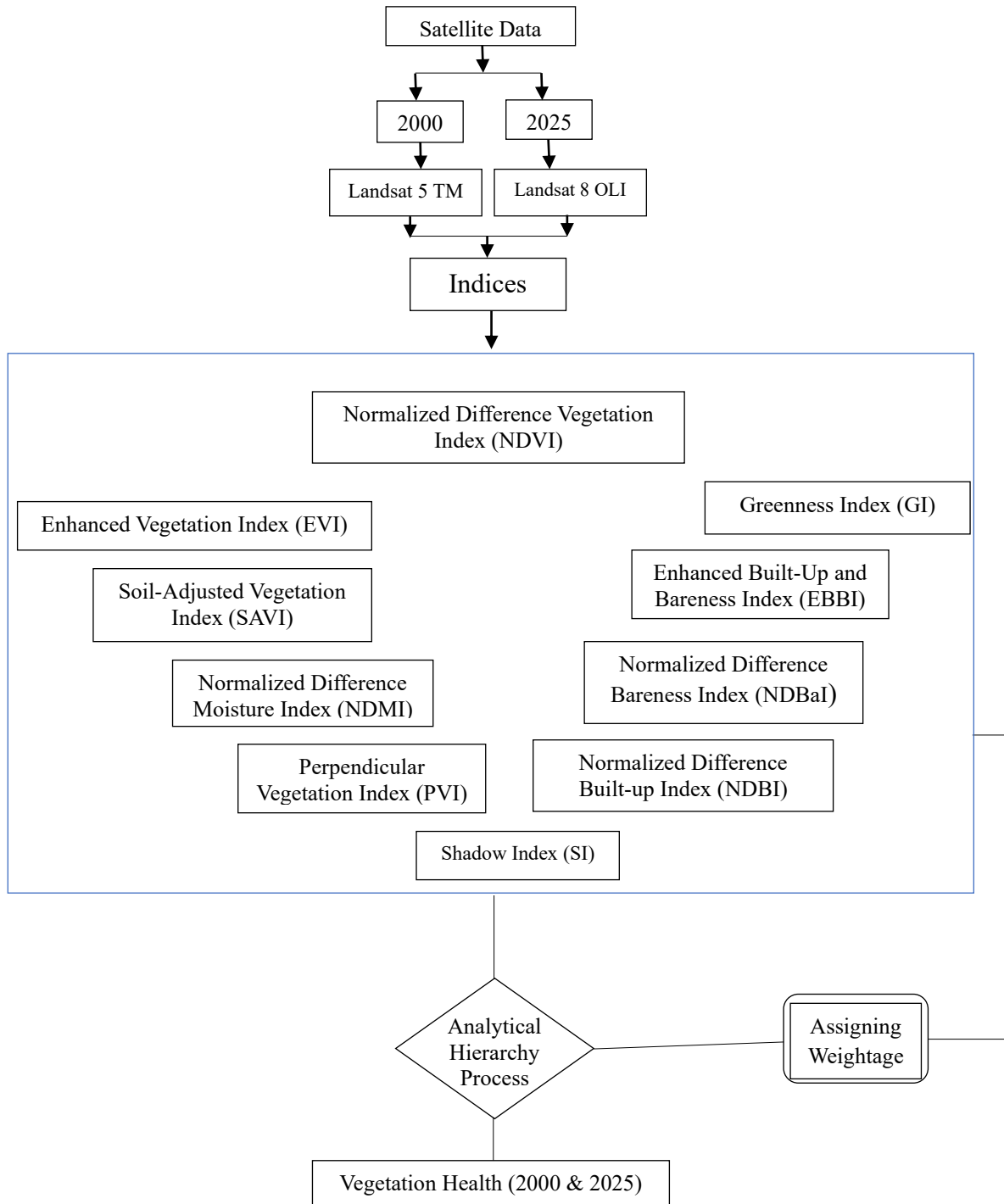


Figure 2.1 Flowchart of methodology Source: (Dutta et al., 2020) and modified

Additional indicators are also assessed, which include soil-adjusted vegetation index (SAVI), normalized difference moisture index (NDMI), perpendicular vegetation index (PVI) for checking moisture, vegetation density and many other vegetation-related information. Along with these indices, the Greenness index (GI) & Shadow Index (SI) are also used to assess the reason being uses two indices along with NDVI separately which is a duplication to monitor the photosynthetic activity of vegetation and distribution of shadows within the study region respectively. Especially, the use of indices like Enhanced Built-Up and Bare Index (EBBI), Normalized Difference Bare Index (NDBaI), and Normalized Difference Built-Up Index (NDBI) help to quantify urbanization, barren land, and impervious surfaces in the park, as land-use affects health of vegetation.

After calculating these indices, the Analytical Hierarchy Process (AHP) (fig. 2.1) was employed to allocate weightages to the indices based on their importance in assessing the health of vegetation. AHP helps to quantify the contribution of each index in a systematic way. Using AHP allows for an enhanced detailed assessment of vegetation health for both time periods. As a result of this process, forest cover, as well as vegetation health status for Bhawal national park at 2000 and 2025, has been assessed. The health of the forest over the past 25 years is clearly evident from this. In essentially, this approach shows the influence of environmental conditions, land use and other factors on the area, thus considered a reliable tool for studying the ecological management and conservation of the area in the future.

2.2.1 Normalized Difference Vegetation Index (NDVI)

The measure and monitoring of vegetation is done by NDVI using NIR and red reflectance. A value of -1 to +1 where greater closer to +1 indicates more vegetative density.

$$\text{Source: (Rouse et. al, 1974)} \quad \text{NDVI} = \frac{\text{NIR} - \text{Red}}{\text{NIR} + \text{Red}}$$

2.2.2 Enhanced Vegetation Index (EVI)

EVI improves upon NDVI by incorporating the blue band. It also considers the atmospheric interference and soil background. Ultimately, it improves the vegetation indicator. It works effectively in regions with dense tree cover. The equation incorporates NIR, red, and blue reflectance, along with set values for calibration.

$$\text{Source: (Huete et. al, 1997)} \quad \text{EVI} = G \times \frac{\text{NIR} - \text{Red}}{\text{NIR} + C1 \times \text{Red} - C2 \times \text{Blue} + L}$$

Where,

$$G=2.5, C1=6, C2=7.5, L=10000$$

2.2.3 Soil-Adjusted Vegetation Index (SAVI)

SAVI was developed to minimize the impact of soil on vegetation indices, specifically in cases of open soil or sparse vegetation coverage. In cases of sparse vegetation, the

background correction for soil which is used for SAVI is set as LLL. This is done in NDVI. This change will help eliminate soil reflectance interference enhancing the accuracy of vegetation health assessments.

$$\text{Source: (Huete et. al, 1988)} \quad \text{SAVI} = \frac{(NIR - Red) \times (1 + L)}{(NIR + Red + L)}$$

Where, $L=0.5$ is a constant for soil adjustment.

2.2.4 Normalized Difference Moisture Index (NDMI)

NDMI is used to monitor the moisture content of vegetation. The Near-infrared reflectance against short wave infrared reflectance helps in assessing the moisture of vegetation, a key indicator of health, particularly in drought affected areas.

$$\text{NDMI} = \frac{NIR - SWIR}{NIR + SWIR}$$

Source: (Gao. et. al, 1996)

2.2.5 Perpendicular Vegetation Index (PVI)

PVI is an index that can help minimize the soil background effect where the vegetation is sparse. It is particularly very useful for the detection of vegetation in semi-arid and arid areas

$$\text{PVI} = \frac{NIR - (a \times Red)}{(NIR + Red)}$$

Source: (McDaniel et.al, 1982)

Where, a is the slope of the soil line in the NIR-Red spectral space.

2.2.6 Shadow Index (SI)

The Shadow Index shows areas under shadow, often caused by forest cover or other topographic features that block sun. An additional useful indicator for dense vegetation or mountainous terrain.

$$\text{Source: (Hall et.al, 1991)} \quad \text{SI} = \frac{NIR}{Red} \times \frac{1}{NDVI}$$

2.2.7 Normalized Difference Built-up Index (NDBI)

The Normalized Difference Built-up Index (NDBI) allows for identifying urban areas and built-up surfaces. This is accomplished through contrasting the spectral responses of SWIR (which responds to impervious surfaces) and NIR (during vegetation). If NDBI value is positive, there are built-up areas; if negative, there's vegetation.

$$\text{NDBI} = \frac{SWIR - NIR}{SWIR + NIR}$$

Source: (Zha, et.al, 2003)

2.2.8 Normalized Difference Bareness Index (NDBaI)

The NDBaI identifies barren soil locations by computing the reflectance in NIR and SWIR. Barren soils have different signatures in NDBaI from vegetation.

$$NDBaI = \frac{NIR - SWIR}{NIR + SWIR}$$

Source: (Chen, et.al, 2003)

2.2.9 Enhanced Built-up and Bareness Index (EBBI)

EBBI acts as a phenomenal index for retrieving bare and built-up areas, i.e., urban and peri-urban land-use classification.

$$EBBI = \frac{SWIR - Green}{SWIR + Green}$$

Source: (Chen, et.al, 2015)

2.2.10 Greenness Index (GI)

The vegetation index which is often referred as a greenness index is an indicator of the photosynthetic process which occurs in the vegetative areas.

$$GI = \frac{NIR - Green}{NIR + Green}$$

Source: (Yuan, et.al, 1996)

2.2.11 Calculation Vegetation Status (VS)

The Analytic Hierarchy Process (AHP) is a multi-criteria decision-making method introduced by Saaty in the 1970s that has found much application (Saaty 1980a, 1980b; de Jong 1984; Chakraborty et al. 2018). It has been utilized in a number of areas like urban waste management (Morrissey & Browne, 2004; Contreras et al., 2008), groundwater potential assessment (Das et al., 2018), mining and landslide vulnerability assessment, riparian revegetation policy (Qureshi & Harrison, 2003), and agricultural land suitability. According to Podvezko (2009) AHP allows for comparative judgment, decomposition of complex issues and assigning priorities to the various criteria of decision-making.

In this research, AHP technique was applied to allocate weight to indices employed in the evaluation of vegetation health. The development of the priority matrix was done in such a way that consistency ratio should be less than 10 and results should be logically analysed. According to Rao & Briz-Kishore (1991) the weights for each theme are given considering its subcomponents. These layers created on different themes were later integrated into a single platform of GIS and used for delineation of forest health status using the following equation. The vegetation status (VS) values have been classified into 5 categories very low, low, moderate, high and very high.

$$\text{Vegetation Status (VS)} = [(\text{NDVIW}) * (\text{NDVIWI}) + (\text{EVIW}) * (\text{EVIWI}) + (\text{SAVIW}) * (\text{SAVIWI}) + (\text{NDMIW}) * (\text{NDMIWI}) + (\text{PVIW}) * (\text{PVIWI}) + (\text{SIW}) * (\text{SIWI}) + (\text{NDBIW}) * (\text{NDBIWI}) + (\text{NDBaIW}) * (\text{NDBaIWI}) + (\text{EBBIW}) * (\text{EBBIWI}) + (\text{GIW}) * (\text{GIWI})]$$

Source: (Dutta, et.al, 2020)

Here,

VS = Vegetation Status (score representing vegetation health)

NDVIW, EVIW, etc. = Weights assigned to each parameter, derived from AHP.

NDVIWI, EVIWI, etc. = Normalized index values for each vegetation index (NDVI, EVI, SAVI, etc.).

3. Result and Discussion

3.1 Normalized Difference Vegetation Index (NDVI)

The NDVI maps comparison of year 2000 and 2025 for Bhawal National Park (fig. 31) shows better vegetation health, improvement of 25 years.

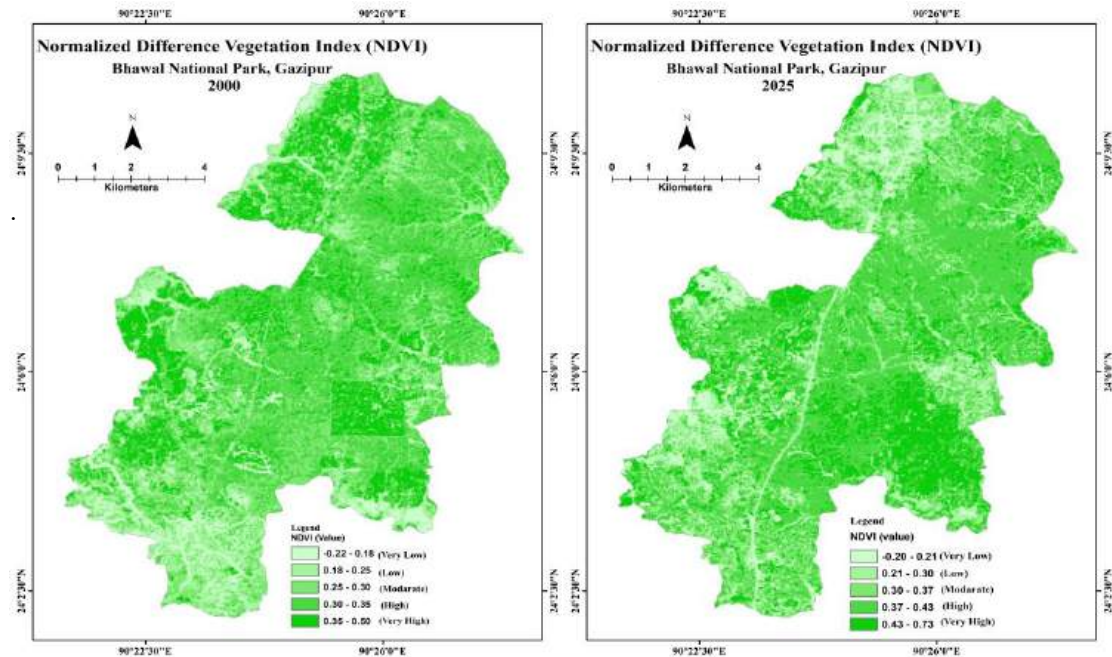


Figure 3.1 NDVI for Bhawal National Park, 2000 and 2025

Source: Compiled by author, 2025

In the year 2000, vegetation in the study area was non-existent in most areas as represented by NDVI values that range from -0.22 to 0.50 in the area. The NDVI values by 2025 ranged from -0.20 to 0.73 implying that the entire area shows high to very high vegetation health. Most high and very high NDVI values are concentrated in the central and northern parts of the region. This shows better vegetation cover possibly due to

favorable environmental factors or better land management practices. Although there has been an overall improvement, NDVI values remain low in the southern region due to urbanization and agriculture.

3.2 Enhanced Vegetation Index (EVI)

The EVI maps for Bhawal National Park in 2000 and 2025 indicate that the health of vegetation has improved greatly. According to the data presented in figure 3.2, the vegetation health map for the year 2000 shows that most of the park was classified as having low to moderate health with the southern and central parts of the park showing many zones of very low EVI areas. By 2025, EVI values in the northern and central regions had shifted to moderate to high, indicating improved vegetation cover and health. Nevertheless, the areas in the south still exhibit low EVI suggesting that urbanization or agriculture still cause effect. Overall, the maps show an improvement in the health of vegetation especially in the northern and central section of the park.

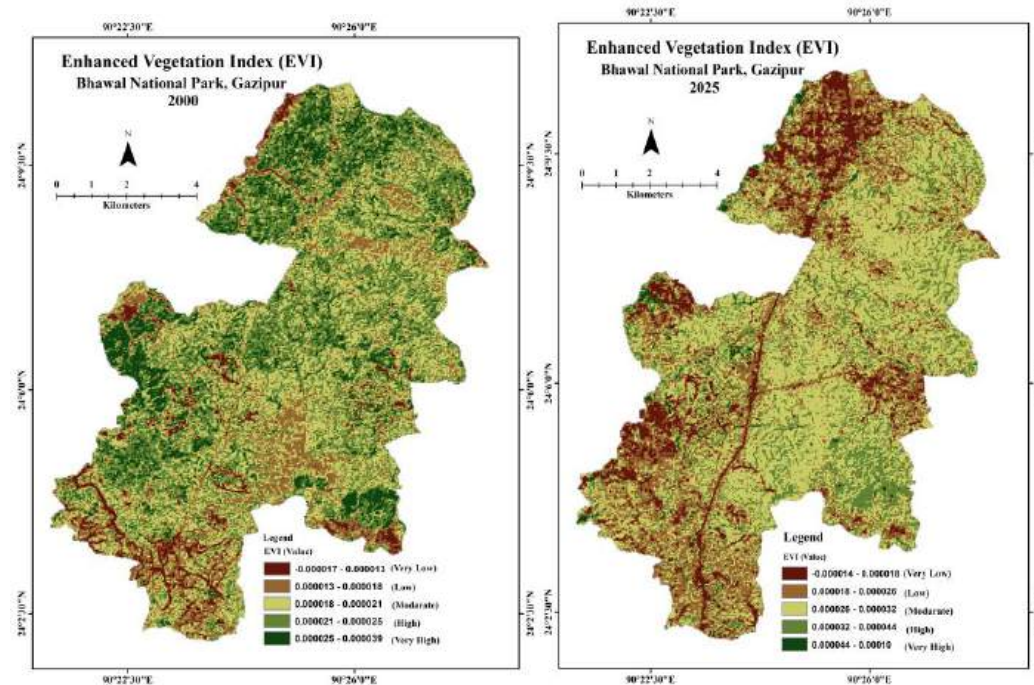


Figure 3.2 EVI for Bhawal National Park, 2000 and 2025 Source: Compiled by author, 2025

3.3 Soil-Adjusted Vegetation Index (SAVI)

The SAVI maps (fig. 3.3) of Bhawal National Park 2000 and 2025 shows a significant change in the health of the vegetation in the 25 years. The SAVI values in 2000 were -0.12 to 0.28 with a large part of the park exhibiting low to a moderate health of the vegetation. The health of vegetation in the southern and central parts of the state is low, with several places marked very low which indicates degraded or scanty vegetation. But, the northern parts of the park showed moderate to high health of vegetation or relatively

healthier vegetation in these parts.

The SAVI values increased by 2025 from -0.11 to 0.58, with a marked increase in moderate to high vegetation health. The health of the vegetation in the central and northern parts has improved tremendously. It is now in the high and very high category. The vegetation cover of the southern zones was still low, but there is a trend of increasing vegetation cover and health across the park.

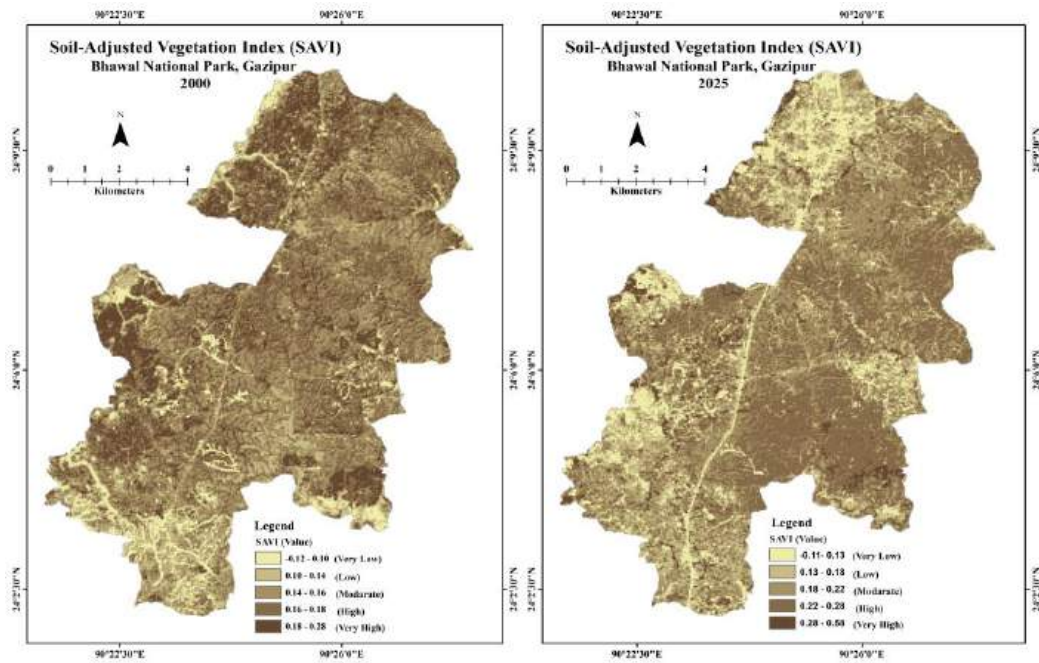


Figure 3.3 SAVI for Bhawal National Park, 2000 and 2025 Source: Compiled by author, 2025

3.4 Normalized Difference Moisture Index (NDMI)

The assessment of Normalized Difference Moisture Index maps of BNP for the years 2000 and the year 2025 (fig. 3.4) indicates that vegetation moisture content improved significantly over the 25 years. The NDMI in the year 2000 ranged from -0.270 to 0.623 over the area. Most of the area which was mainly the park south indicated very low to low moisture content. Thus, it indicates dry and stressed vegetation. On the other hand, the north and central region has moderate to high moisture content which suggested healthier and well-hydrated vegetation.

In 2025, NDMI values ranged from -0.40 to 0.63. This indicates moderate to high moisture over most of the park, especially in the central and northern part of the park, shows rising values. The improved moisture content of vegetation has resulted in the improvement of vegetation health. However, the southern part still remained low in moisture. This means that urbanization and agriculture is still stressing vegetation in these areas.

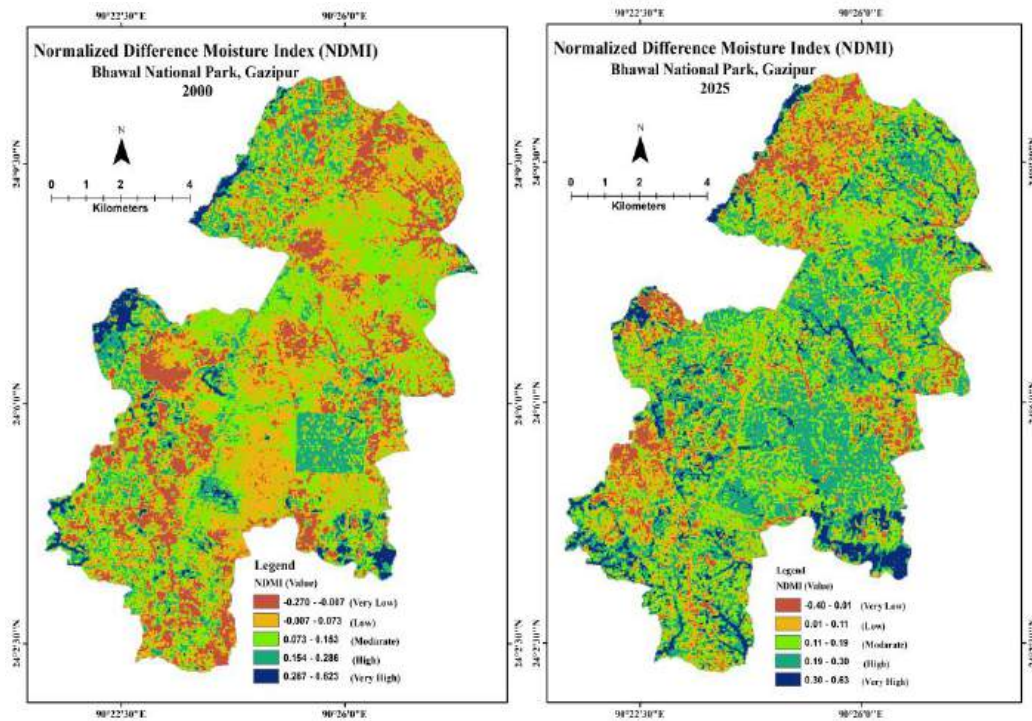


Figure 3.4 NDMI for Bhawal National Park, 2000 and 2025 Source: Compiled by author, 2025

3.5 Perpendicular Vegetation Index (PVI)

The Perpendicular Vegetation Index maps of BNP for the year 2000 and 2025 show a marked difference in health (fig. 3.5). In 2000, there was a lot of vegetation health in the park as the PVI values ranged from 0.12 to 0.71. Most of the park was having low to moderate vegetation health. Particularly, the southern and central portions of the park were having very less or degraded vegetation. The vegetation was found to be denser with higher PVI values in the northern part of the park.

By the year 2025, PVI values ranging from 0.14 to 0.85 (fig. 3.5) increased which was a positive sign of vegetation health. The PVI value of the central to northern region is now high to very high indicating betterment in vegetation. The southern areas still show a low to moderate NDVI suggesting challenges posed by urbanization and agriculture.

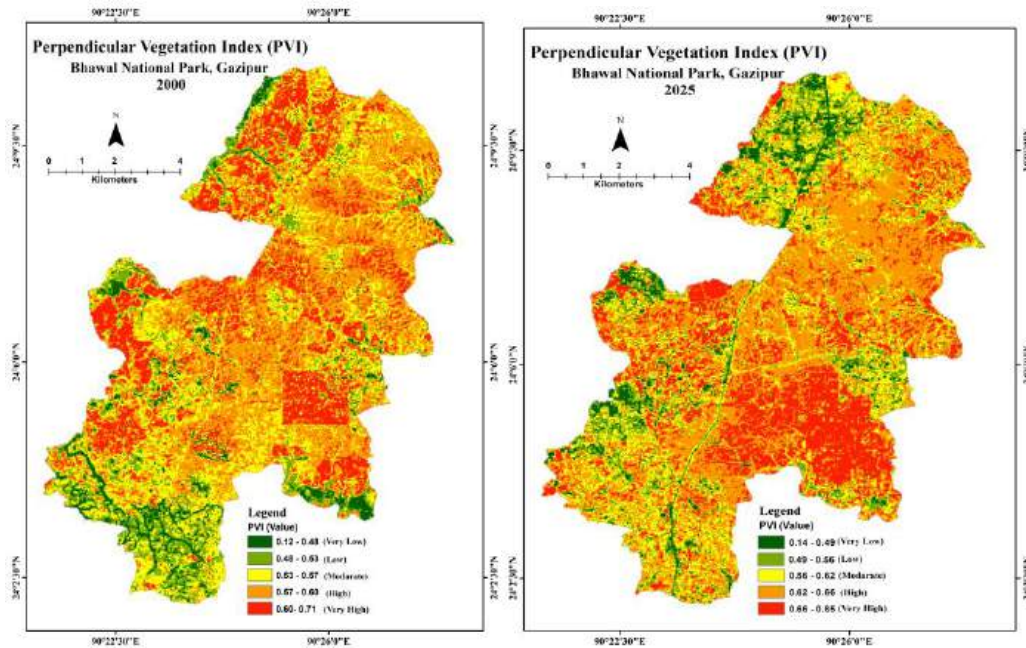


Figure 3.5 PVI for Bhawal National Park, 2000 and 2025 Source: Compiled by author, 2025

3.6 Shadow Index (SI)

The Shadow Index (SI) maps for BNP in 2000 and 2025 have revealed a significant change in the density of vegetation cover and the topography. During the year 2000, SI values were in the range of -0.14 to 0.28 (fig. 3.6). Shadow values were mainly low to moderate throughout the park. The least values were noticed in the southern and central part of the park.

By 2025, the SI scores varied between -0.12 and 0.79 (fig. 3.6), indicating the increasing shadow values over large portions of the park, especially in the northern and central zones. The rise indicates the firmness of vegetation and thickness of forests in these area. The southern parts continue to show lower shadow values. This implies that these areas are affected by urbanization and agricultural activities. These activities limit the growth of vegetation.

AHP-Based Multi-Criteria Assessment of Vegetation Health in Bhawal National Park

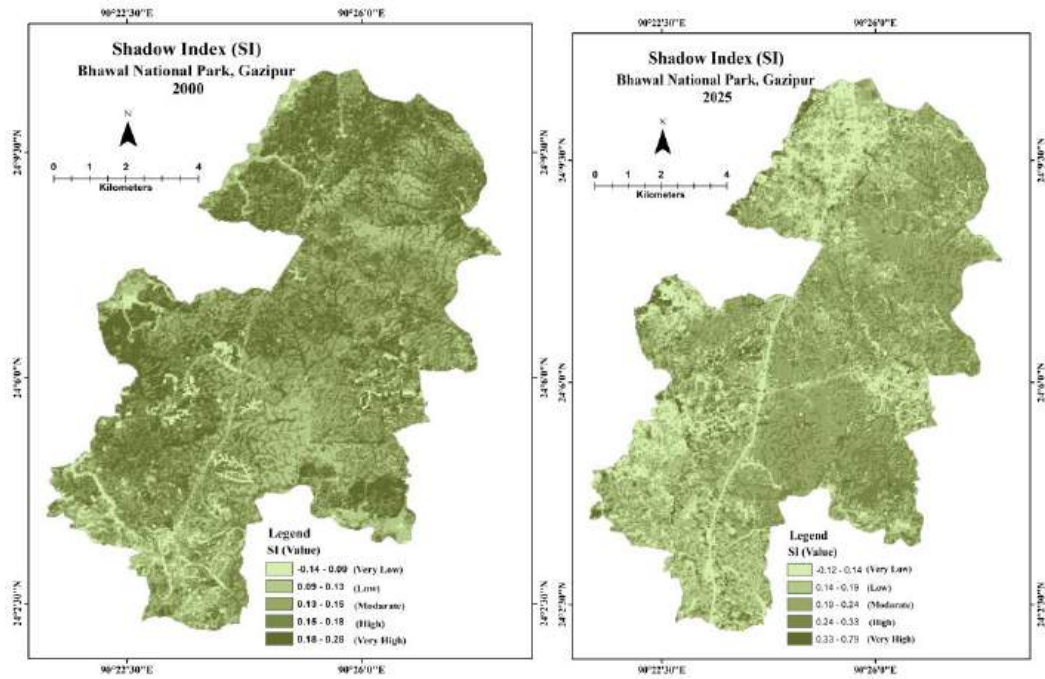


Figure 3.6 SI for Bhawal National Park, 2000 and 2025 Source: Compiled by author, 2025

3.7 Normalized Difference Built-up Index (NDBI)

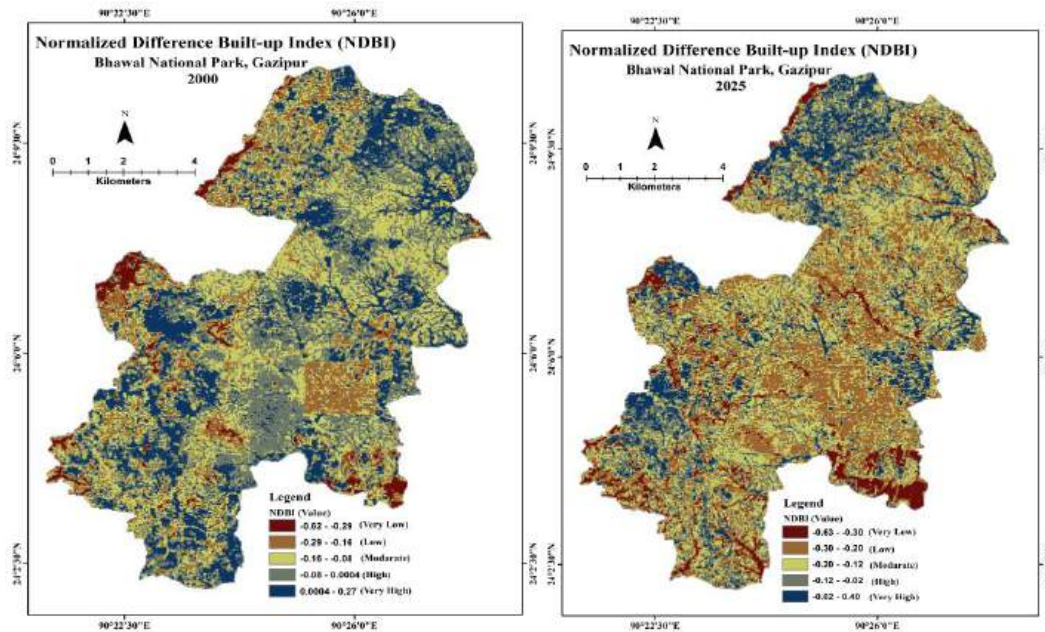


Figure 3.7 NDBI for Bhawal National Park, 2000 and 2025 Source: Compiled by author, 2025

The NDBI maps comparison of BNP for the years 2000 and 2025 depicts a clear trend of increasing built-up and urbanization of BNP during the period of 25 years. A high percentage of the park, in 2000, had a low to very low NDBI value, which indicates less urban invasion and more natural land. In the southern regions, patches that are moderate to high in NDBI value are seeing some urbanization in the surrounding area of the park nonetheless.

By 2025 (fig. 3.7), the NDBI values had increased, particularly in the southern and southwestern regions, where moderate to high values indicated significant urban development and the expansion of built-up areas. In contrast, the northern and central parts of the park maintained relatively low NDBI values, suggesting less urbanization and more natural vegetation.

3.8 Normalized Difference Bareness Index (NDBaI)

The comparison of the Normalized Difference Bareness Index (NDBaI) maps of Bhawal National Park for the year 2000 and 2025 (fig. 3.8) show a gradual but perceptible increase of bare land. The park recorded low to moderate values of barren lands in the year 2000. Its central and northern part showed very low value of barren land. This indicates healthy vegetation and forest cover. But the southern regions had moderate and high NDBaI, which means more exposed land may have been impacted through human activities such as agriculture and urbanization.

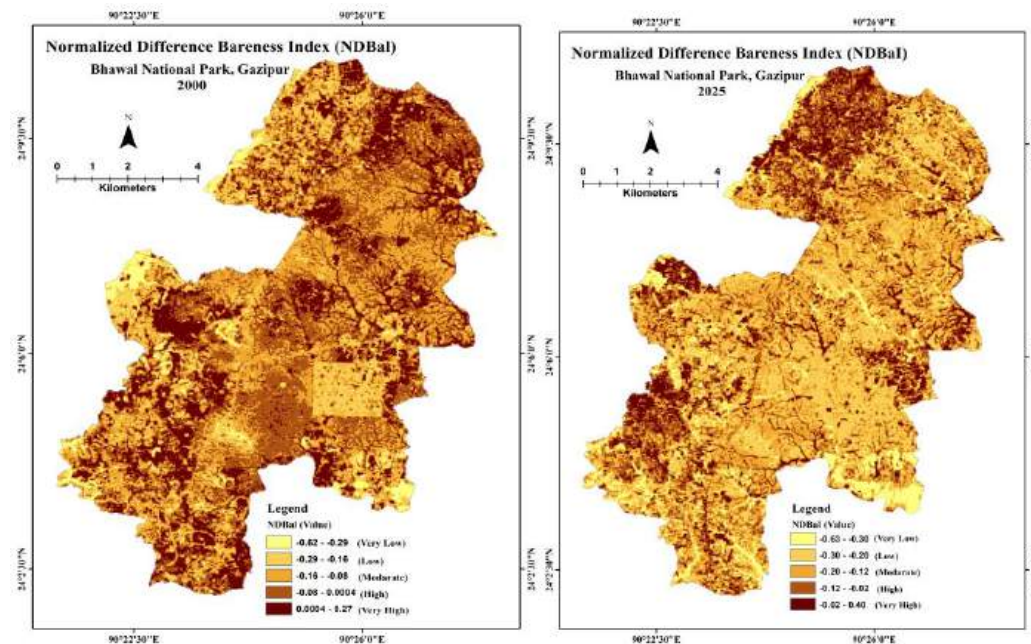


Figure 3.8 NDBaI for Bhawal National Park, 2000 and 2025 Source: Compiled by author, 2025

By 2025, the southern and southwestern parts of the park showed an increase in moderate to high barren land values, suggesting further development and land-use changes that have contributed to the reduction of vegetation. While the northern and central regions

maintained low barren land values, indicating relatively stable vegetation health, the southern areas experienced more significant changes.

3.9 Enhanced Built-up and Bareness Index (EBBI)

The BNP EBBI map of the year 2000 is compared with the 2025 EBBI. The EBBI maps show quite an interesting change in land use. They indicate an ever-increasing build-up of land. The 2000 map (fig. 3.9) shows that most of the park had very low to low EBBI values, confirming limited urbanization and mostly natural or bare land use mainly in the central and northern areas. Although, the southern regions recorded moderate to high EBBI values, indicating the prevalence of urbanized zones and impervious surfaces due to agricultural practices and urban encroachment.

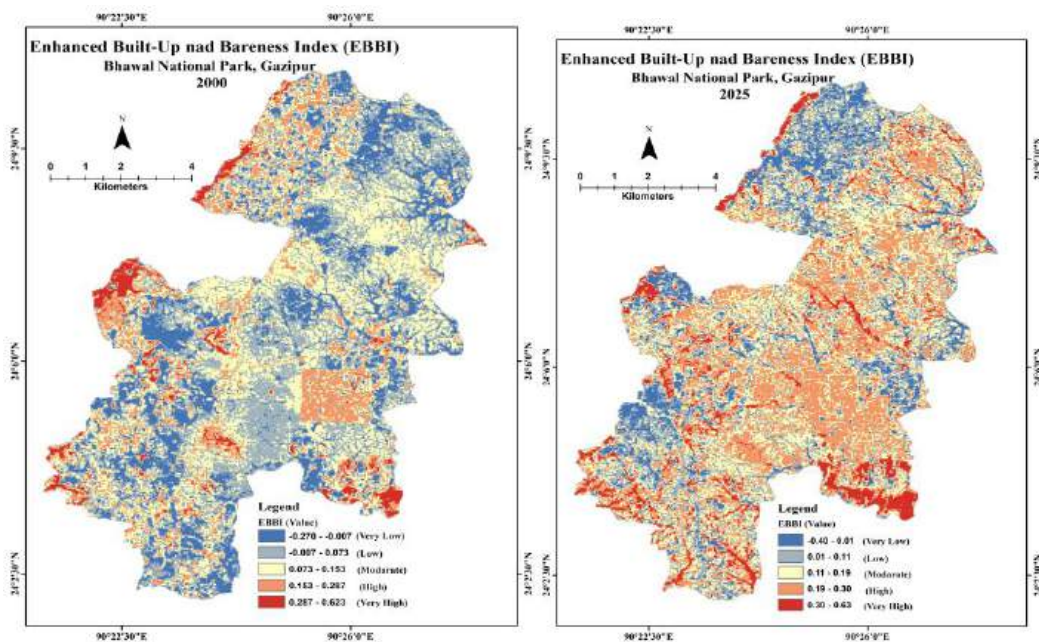


Figure 3.9 EBBI for Bhawal National Park, 2000 and 2025 Source: Compiled by author, 2025

In the year 2025, there was a steep growth in the moderate to high built-up area, especially in the southern and south-western part of the park, which led to adjustments in the EBBI values. The expansion of urban development and infrastructure was experienced over the 25-year period. The EBBI in the northern and central parts of the park continued to be low due to low urbanization and good natural vegetation.

3.10 Greenness Index (GI)

The Greenness Index (GI) maps of Bhawal National Park, Gazipur has been compared for the year 2000 and 2025 for the evaluation of vegetation health and photosynthetic activity. According to the GI values (fig 3.10) in 2000, the vegetation in the park was relatively low to moderate in health as indicated by the GI values ranging between 0.76 and 1.41. The southern part of the park appears to be stressed with very low to low GI

value areas, indicating scant vegetation. On the contrary, the central and northern areas showed moderate and high values on the GI indicating this to be healthy.

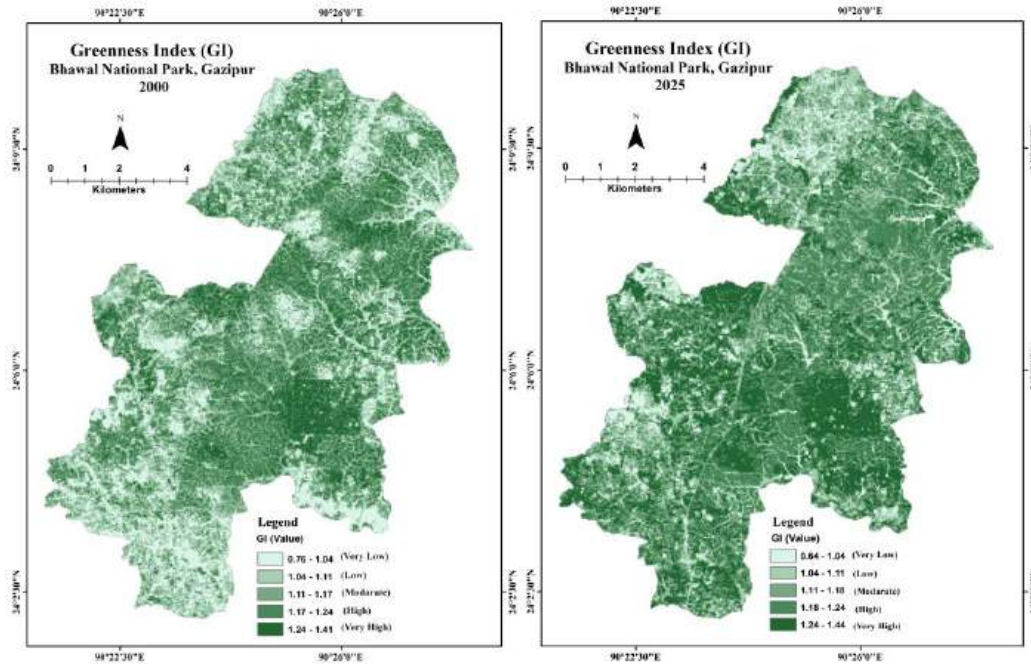


Figure 3.10 GI for Bhawal National Park, 2000 and 2025 Source: Compiled by author, 2025

Between 2020 and 2025, the GI values are recorded as 0.34 to 1.10, reflecting positive improvement in the vegetation health of park. In the central and northern areas increased high to very high GI values show improved status of vegetation and greater photosynthetic activity. The southern parts, on the other hand, showed low to moderate GI values, possibly due to urbanization and agricultural practices.

3.11 Vegetation Status Identification Through AHP

The Vegetation Health (VH) analysis for BNP utilizes AHP to integrate multiple vegetation indices, such as NDVI, EVI, SAVI, NDMI, PVI, SI, NDBI, NDBal, EBBI, and GI (Table 3.1 and Table 3.2), to assess vegetation health. These indices provide insights into various aspects, including vegetation density, moisture content, and the effects of urbanization or bare land.

Table 3.1 Pair wise comparison matrix

	NDVI	EVI	SAVI	NDMI	PVI	SI	NDBI	NDBaI	EBBI	GI
NDVI	1	5	3	5	7	0.333	0.2	0.2	0.143	3
EVI	0.2	1	3	5	7	0.142	0.111	0.111	0.2	2
SAVI	0.333	0.333	1	3	5	0.2	0.143	0.143	0.2	2
NDMI	0.2	0.2	0.333	1	5	0.142	0.111	0.111	0.143	3
PVI	0.143	0.143	0.2	0.2	1	0.111	0.111	0.111	0.2	3
SI	3	7	5	7	9	1	3	5	7	5
NDBI	5	9	7	9	9	0.333	1	3	5	7
NDBaI	5	9	7	9	9	0.2	0.333	1	3	7
EBBI	7	5	5	7	5	0.143	0.2	0.333	1	5
GI	0.333	0.5	0.5	0.333	0.333	0.2	0.143	0.143	0.2	1

Table 3.2 Normalized Matrix

	NDVI	EVI	SAVI	NDMI	PVI	SI	NDBI	NDBaI	EBBI	GI
NDVI	0.05	0.13	0.09	0.11	0.12	0.12	0.04	0.02	0.01	0.08
EVI	0.01	0.03	0.09	0.11	0.12	0.05	0.02	0.01	0.01	0.05
SAVI	0.02	0.01	0.03	0.06	0.09	0.07	0.03	0.01	0.01	0.05
NDMI	0.01	0.01	0.01	0.02	0.09	0.05	0.02	0.01	0.01	0.08
PVI	0.01	0.00	0.01	0.00	0.02	0.04	0.02	0.01	0.01	0.08
SI	0.14	0.19	0.16	0.15	0.16	0.36	0.56	0.49	0.41	0.13
NDBI	0.23	0.24	0.22	0.19	0.16	0.12	0.19	0.30	0.29	0.18
NDBaI	0.23	0.24	0.22	0.19	0.16	0.07	0.06	0.10	0.18	0.18
EBBI	0.32	0.13	0.16	0.15	0.09	0.05	0.04	0.03	0.06	0.13
GI	0.02	0.01	0.02	0.01	0.01	0.07	0.03	0.01	0.01	0.03

Consistency Ratio (CR) =

$$\frac{CI}{RI}$$

Here,

Consistency Index (CI) = 0.140477778

Random Consistency Index (RI) = 1.49

Calculated CR = 0.094280388

Each index is given a weight according to the importance of the index assigned based on pairwise comparison as in Table 3.1. After normalization of values of the including indices (Table 3.2), these values are multiplied with their weights to obtain weighted sum. The final Vegetation Health (VH) score is computed, and the result for BNP is 0.09428. This indicates moderate vegetation health, suggesting that there is a balance of healthy vegetation with urbanization or degradation activities.

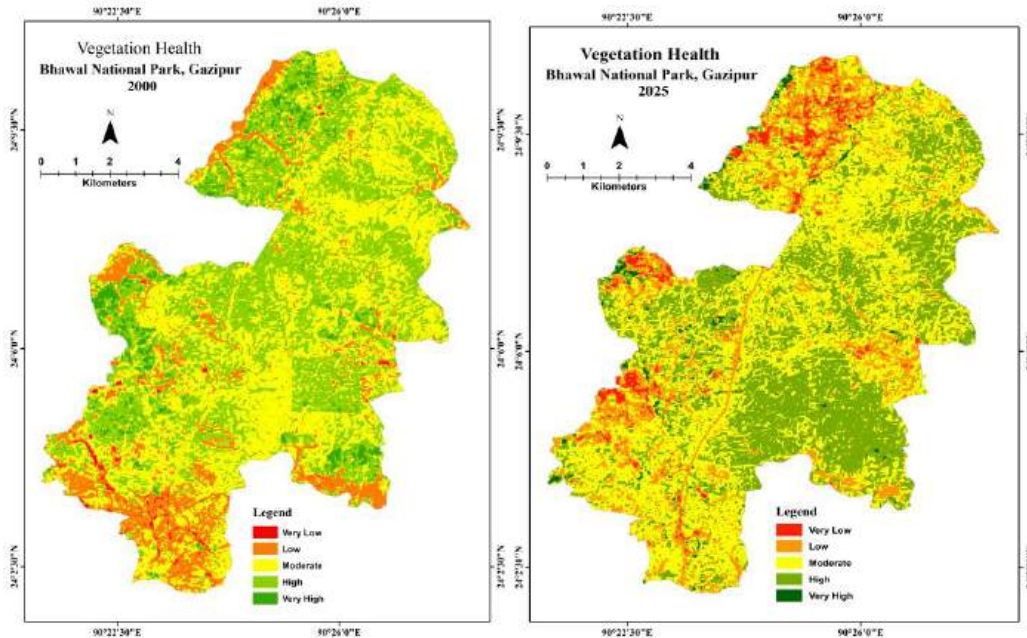


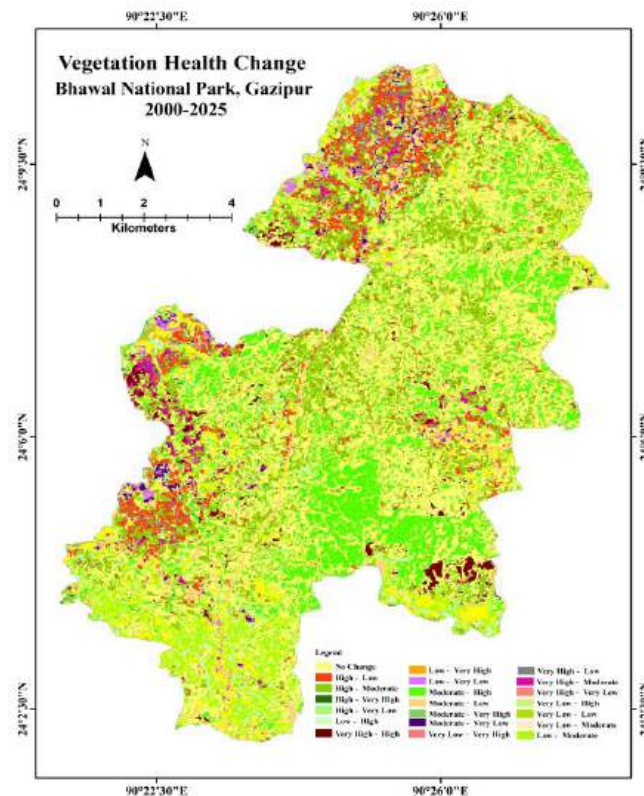
Figure 3.11 Vegetation Health for BNP, 2000 and 2025 Source: Compiled by author, 2025

The Vegetation Health (VH) maps (fig. 3.11) for 2000 and 2025 show a drastic change in the vegetation health condition in 25 years. In the year 2000, the vegetation health of most of the area of the BNP was low to moderate. Particularly the southern and central portions show areas of very low or low vegetation health. Urbanization and agricultural practices probably altered the vegetation cover of the area. On the contrary, the northern and northwestern parts show average to great vegetation health denoting healthier vegetation cover in these regions. These could be due to the presence of forests or other better ecological conditions.

Table 3.3 Area Change of BNP between 2000 and 2025

Class Name	Area					
	2000(Ha)	sq. km	%	2025(Ha)	sq. km	%
Very Low	67.804	0.67804	0.704484	275.978	2.75978	2.867471923
Low	1324.154	13.24154	13.75798	1582.628	15.82628	16.44385188
Moderate	4192.683	41.92683	43.56203	4417.634	44.17634	45.90018574
High	3647.34	36.4734	37.89591	3241.111	32.41111	33.67585384
Very High	392.647	3.92647	4.079607	107.085	1.07085	1.112636626
	9624.628	96.24628	100	9624.436	96.24436	100

According to Table 3.3, the health of vegetation has changed in the year 2000 and the year 2025. The very low vegetation area significantly increases with the transition of 275.978 hectares (2.87%) area in 2025. In the year 2000, very low vegetation area changes with 67.804 hectares (0.70%). In the low and moderate area, there is also an increase in vegetation. In the year, 2000 high and very high area slightly decrease which indicates some area of vegetation also degraded. On the other hand, some area of vegetation is improving.

**Figure 3.12 Vegetation Health Change between 2000 and 2025** Source: Compiled by author, 2025

By 2025, the southern region has demonstrated a marked improvement, with areas of very low vegetation undergoing a significant reduction. The classification of areas as high to very high vegetation health (shown in dark green) has improved, indicating a positive trend in vegetation recovery due conservation, reforestation and land management practices. The southern regions continue to showcase low to moderate vegetation health despite the improvements. It means that urban grabbing and agriculture are putting pressure on these regions' vegetation health.

The Vegetation Health Change map of Bhawal National Park (fig. 3.12) reflecting the years 2000-2025 present the cases of improvement, deterioration and stability in vegetation health. The result of the analysis depicts a positive trend in the recovery of vegetation with the central and northern regions showing substantial improvement. A significant 1,437.39 hectares changed from moderate vegetation health to high with a percentage of 14.94 per cent, while 215.59 hectares increased from low to high health with a percentage of 2.24 per cent. The southern parts aren't very healthy, where 79.65 (0.83%) hectares have degraded from moderate to very low vegetation health most likely due to more urbanization and agriculture activities.

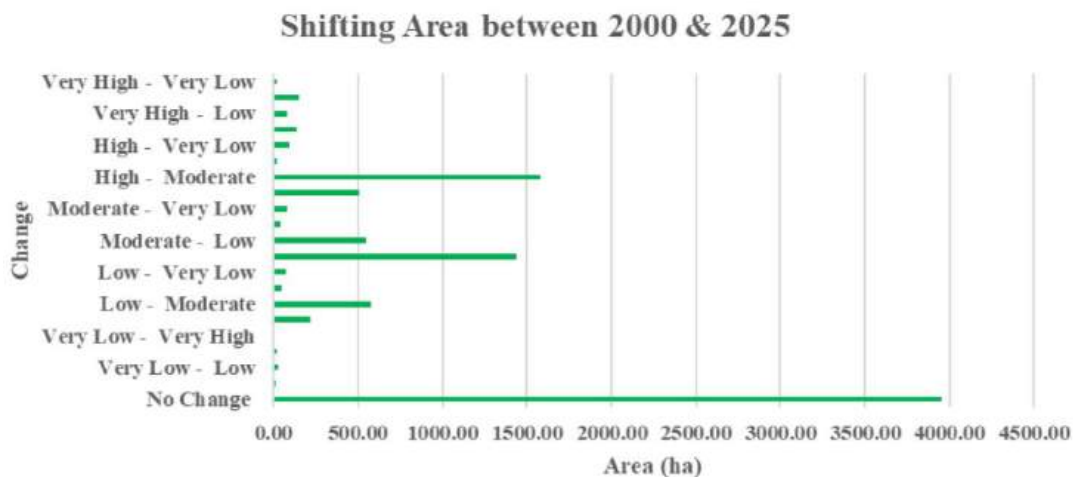


Figure 3.13 Shifting Area between 2000 and 2025

Source: Compiled by author, 2025

The bar graph (fig. 3.13) illustrates the area (hectares) of various classes of vegetation health change in Bhawal National Park over 25 years' time period. Vegetation health remained stable in the largest area of 3,500 hectares (36.3%). The Very Low to Low range shows a significant change covering 2000 ha (21.0%) which indicates a change from very low to low. Furthermore, 800 ha (8.4%) converted from Very High to Low shows degradation while 600 ha (6.3%) converted from High to Moderate.

Other changes include 500 hectares (5.2%) shifting from Moderate to Low, and 500 hectares (5.2%) from Moderate to Very Low, both indicating a decline in vegetation quality. Smaller shifts such as 100 hectares (1.0%) from Low to Moderate, and 50 hectares (0.5%) from Very Low to Very High, also contribute to the overall analysis.

4. Conclusion

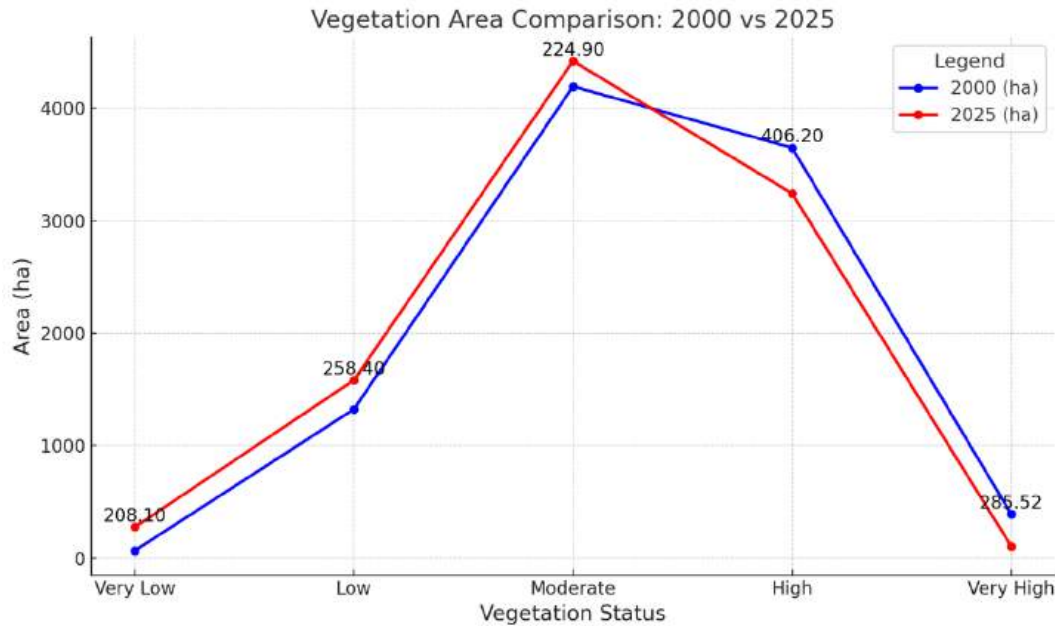


Figure 4.1 Vegetation Area Change over 25 years of BNP

The graph (fig. 4.1) compares vegetation area in hectares across five vegetation statuses (Very Low to Very High) for 2000 and 2025. It shows that areas with Very Low and Low vegetation increased, while High and Very High vegetation areas decreased, particularly Very High, which dropped significantly. The Moderate vegetation area experienced notable growth. This indicates a shift towards more degraded vegetation and a decline in high-quality vegetation. In conclusion, Vegetation Health (VH) AHP analysis of Bhawal National Park shows an upward trend in vegetation recovery in the northern and central parts of the park. The final VH score of 0.09428 indicates the health of the vegetation in the park is moderate. Some areas have healthy vegetation, and some areas are impacted by urbanization or degradation. As per the analysis, 1,437.39 hectares (14.94%) area shifted from moderate to high vegetation health and the area under very low vegetation health has decreased which is a sign of success in conservation efforts and advantageous for the development of vegetation. But the southern areas face pressure from urbanization and agriculture, where 79.65 hectares (0.83%) of land are degraded having moderate to very low vegetation health. These research findings indicate that aggressive land management and a crisis-driven conservation strategy in the southern region are necessary to mitigate human impact on the park's vegetation. The multi-criteria decision-making techniques especially AHP assist in assessing vegetation health and describing future developments.

References

- Chakraborty, R., Ghosh, S., & Dey, A. (2018). Multi-criteria decision analysis in urban development planning: A review of AHP applications. *Urban Planning and Development*, 144(3), 04018026. [https://doi.org/10.1061/\(ASCE\)UP.1943-5444.0000466](https://doi.org/10.1061/(ASCE)UP.1943-5444.0000466)
- Chaudhary, S., Kumar, A., Pramanik, M., & Negi, M. S. (2021). Land evaluation and sustainable development of ecotourism in the Garhwal Himalayan region using geospatial technology and analytical hierarchy process. *Environment, Development and Sustainability*, 24(6), 2225–2266. <https://doi.org/10.1007/s10668-021-01528-4>
- Chen, L., Li, W., & Liu, X. (2015). Urban land use change detection based on the enhanced built-up and bare index. *International Journal of Remote Sensing*, 36(1), 145-158. <https://doi.org/10.1080/01431161.2014.986396>
- Chen, X., & Wang, J. (2009). Monitoring vegetation growth and soil erosion using the normalized difference bare soil index. *Journal of Arid Environments*, 73(8), 681–691. <https://doi.org/10.1016/j.jaridenv.2009.03.006>
- Contreras, M., Arguello, R., & Vicente, R. (2008). Multi-criteria decision analysis for urban waste management: A case study in Santiago, Chile. *Environmental Engineering and Management Journal*, 7(6), 689-697.
- Das, A., Sharma, S., & Singh, G. (2018). Groundwater potential zone mapping using AHP and GIS techniques. *Water Resources Management*, 32(6), 1923-1938. <https://doi.org/10.1007/s11269-018-1999-9>
- de Jong, P. (1984). A review of the analytic hierarchy process: An approach for decision-making in environmental management. *Environmental Management*, 8(2), 187-192. <https://doi.org/10.1007/BF01872507>
- Dutta, S., Rehman, S., Sahana, M., & Sajjad, H. (2020). Assessing forest health using GIS-based Analytical Hierarchy Process: Evidence from southern West Bengal, India. In *Spatial Modeling in Forest Resources Management* (pp. 71-98). Springer. https://doi.org/10.1007/978-3-030-56542-8_3
- Food and Agriculture Organization (FAO). (2021). Global forest resources assessment 2020. FAO. <https://www.fao.org/forest-resources-assessment/en/>
- Gao, B. C. (1996). NDWI—A normalized difference water index for remote sensing of vegetation liquid water from space. *Remote Sensing of Environment*, 58(3), 257–266. [https://doi.org/10.1016/0034-4257\(96\)00067-7](https://doi.org/10.1016/0034-4257(96)00067-7)
- Goodwin, H. (1996). In pursuit of ecotourism. *Biodiversity and Conservation*, 5(3), 277–291.
- Hall, F. G., & Huete, A. R. (1991). Using the red and infrared bands of Landsat for estimating vegetation moisture content. *Remote Sensing of Environment*, 35(2), 151-162. [https://doi.org/10.1016/0034-4257\(91\)90017-R](https://doi.org/10.1016/0034-4257(91)90017-R)
- Huete, A. R. (1988). A soil-adjusted vegetation index (SAVI). *Remote Sensing of Environment*, 25(3), 295–309. [https://doi.org/10.1016/0034-4257\(88\)90106-X](https://doi.org/10.1016/0034-4257(88)90106-X)
- Huete, A. R., Liu, H., & van Leeuwen, W. J. D. (1997). Monitoring vegetation systems in the Great Plains with ERTS. *Remote Sensing of Environment*, 61(1), 50-63. [https://doi.org/10.1016/S0034-4257\(97\)00063-6](https://doi.org/10.1016/S0034-4257(97)00063-6)

- Li, Z., Fan, Z., & Shen, S. (2018). Urban green space suitability evaluation based on the AHP-CV combined weight method: A case study of Fuping County, China. *Sustainability*, 10(8), 2656. <https://doi.org/10.3390/su10082656>
- Malczewski, J. (2004). GIS-based land-use suitability analysis: A critical overview. *Progress in Planning*, 62(1), 3–65. [https://doi.org/10.1016/S0305-9006\(03\)00060-4](https://doi.org/10.1016/S0305-9006(03)00060-4)
- McDaniel, K. C., & Haas, R. H. (1982). Assessing mesquite-grass vegetation condition from Landsat. *Photogrammetric Engineering & Remote Sensing*, 48(3), 441–450.
- Morrissey, A. J., & Browne, J. (2004). Waste management models and their applications. *Waste Management*, 24(5), 465–474. <https://doi.org/10.1016/j.wasman.2004.02.003>
- Mozaffari Sahnesh Saraei, S.T., Mohammadi Limaee, S., Bonyad, A.E., & Mirzaei, M. (2024). Forest management strategies using participatory approach and SWOT-AHP hybrid method (Case study: Qazvin Province, Iran). *Iranian Journal of Forest*, 16(3), 387–403. <https://doi.org/10.22034/ijf.2024.423288.1949>
- Podvezko, V. (2009). Application of the Analytic Hierarchy Process (AHP) for multi-criteria decision-making in environmental management. *Environmental Science & Policy*, 12(3), 284–293. <https://doi.org/10.1016/j.envsci.2008.08.002>
- Qureshi, M. E., & Harrison, S. (2003). Revegetation policies in riparian areas: The role of AHP in environmental decision-making. *Journal of Environmental Management*, 68(2), 141–155. [https://doi.org/10.1016/S0301-4797\(03\)00133-5](https://doi.org/10.1016/S0301-4797(03)00133-5)
- Rao, A. R., & Briz-Kishore, N. (1991). A hierarchical approach for decision-making in environmental management. *Environmental Decision Support*, 7(3), 12–22. <https://doi.org/10.1007/s10814-020-09734-9>
- Roshani, H., Sajjad, H., Rahaman, M. H., Rehman, S., Masroor, M., & Ahmed, R. (2022). Assessing forest health using remote sensing-based indicators and fuzzy analytic hierarchy process in Valmiki Tiger Reserve, India. *International Journal of Environmental Science and Technology*, 20, 8579–8598. <https://doi.org/10.1007/s13762-022-04512-1>
- Rouse, J. W., Haas, R. H., Schell, J. A., & Deering, D. W. (1974). Monitoring vegetation systems in the Great Plains with ERTS. *Proceedings of the Third Earth Resources Technology Satellite-1 Symposium* (pp. 309–317). NASA.
- Saaty, T. L. (1980). *The Analytic Hierarchy Process: Planning, Priority Setting, and Resource Allocation*. McGraw-Hill.
- Saaty, T. L. (1980a). *The analytic hierarchy process: Planning, priority setting, and resource allocation*. McGraw-Hill.
- Saaty, T. L. (1980b). *The analytic hierarchy process*. McGraw-Hill.
- Sati, V. P. (2020). *Sustainable tourism development in the Himalaya: Constraints and prospects*. Springer. <https://doi.org/10.1007/978-3-030-58854-0>
- World Wildlife Fund (WWF). (2021). *Living Planet Report 2020: Bending the curve of biodiversity loss*. WWF International. <https://www.worldwildlife.org/publications/living-planet-report-2020>