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Climate Change Impacts on Vegetation and Water Availability: A Remote Sensing Analysis of Hazarganji-Chiltan National Park

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Abstract

Understanding the dynamics of natural resources, especially in the face of climate change, is critical for sustainable management. Traditional methods of monitoring and assessment, though essential, are often time-consuming and limited in spatial coverage. Remote sensing techniques, coupled with Geographic Information Systems (GIS), offer efficient and accurate solutions. This study leverages satellite imagery from 1998, 2008, and 2018 to assess land cover change and vegetation health in Hazarganji-Chiltan National Park (HCNP). By employing indices such as NDVI, SAVI, MSAVI, and MSI, we quantified changes in vegetation cover and water availability. Our analysis revealed significant land cover transformations within HCNP. Vegetation cover declined substantially, from 1380.047 ha in 1998 to 656.7827 ha in 2018. Conversely, barren land increased from 2784.229 ha in 1998 to 3511.11 ha in 2018. Water bodies also diminished, shrinking from 2.465488 ha to 0.55492 ha over the study period. The calculated vegetation indices further corroborated these findings. NDVI, SAVI, and MSAVI indicated a decline in vegetation health, while MSI highlighted increased moisture stress in 2018. These results underscore the pressing need for effective conservation strategies to mitigate the impacts of climate change and anthropogenic pressures on HCNP.

Key words: GIS, Remote Sensing, Normalized Difference Vegetation Index, Soil Adjusted Vegetation Index, Moisture Stress Index, Land Surface Water Index.

1. Introduction

Protected areas are defined as "an area of land and/or sea, especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means" (IUCN, 1994). These areas play a crucial role in conserving biodiversity, driving economic development, and promoting social inclusion, as emphasized by the Convention on Biological Diversity. Achieving the objectives of protected areas requires clear property rights, robust institutional and administrative frameworks, and sufficient funding for effective management (Getzner et al., 2012). National parks, as the largest type of protected areas, are characterized by their natural richness and exceptional scenic value. Their primary aim is the conservation of flora, fauna, and landscapes in their natural state, while also allowing public access for research, recreation, and education (Knudsen, 1999). The term "park" encompasses various elements managed by the National Park Services, including monuments, seashores, and historic parks. National parks are significant cultural and natural assets, offering immense spiritual, aesthetic, and recreational value. They are a source of national pride, emphasizing public stewardship of heritage. However, increasing visitor numbers, expanding infrastructure, and external environmental pressures threaten the ecological and aesthetic integrity of many parks (National Research Council, 1992). Issues such as air pollution, water contamination, sedimentation, and the introduction of pests further compound these challenges. Pakistan spans approximately 88 million hectares, extending from the northeast to the southwest. The country's predominantly arid climate sees three-fourths of its annual precipitation falling below 250 mm, with 20% receiving less than 125 mm (Salma et al., 2012). Balochistan, the largest province, covers 347,190 square kilometers and features diverse geography, including high mountains and a 770-kilometer-long coastline. Rain and snow typically occur between December and March (Khan and Siddiqui, 2011).

Vegetation, the plant life covering a region, plays a fundamental role in the biosphere. Its benefits depend on vegetation type and the extent of slope degradation. Woody vegetation stabilizes slopes by modifying hydrology and preventing soil erosion. Conversely, vegetation loss increases the likelihood of slope failure (Gray and Sotir, 1998). The extent of vegetation can be assessed using vegetation indices, which are derived from spectral reflectance data obtained through remote sensing techniques (Ibrahim and Mashagbah, 2016).

Advancements in technology, including Remote Sensing (RS), Geographic Information Systems (GIS), and Global Positioning Systems (GPS), have revolutionized the monitoring and management of vegetation and land use. RS provides timely and cost-effective spatial data, while GIS processes and analyzes these data for various applications (Alam et al., 2024; Urooj et al., 2019; Zafar et al., 2011). These tools are particularly useful for monitoring vegetation dynamics, detecting land-use changes, and supporting conservation efforts.

Remote sensing employs various spectra, including ultraviolet (10–380 nm), visible light (blue: 450–495 nm, green: 495–570 nm, red: 620–750 nm), and near- and mid-infrared (850–1700 nm), to assess vegetation health and coverage. Fully grown green plants typically exhibit an emissivity rate of 0.96–0.99, while stressed or dry plants show lower values (Xue and Su, 2017). Satellite-based remote sensing offers high spatial resolution, enabling the extraction of consistent long-term data. However, challenges remain, including limited revisit times and difficulties in acquiring data under cloud cover (Xue and Su, 2017).

These technologies hold significant promise for biodiversity conservation, forestry, urban green infrastructure, and agriculture, making them indispensable for addressing modern environmental challenges (Urooj et al., 2017).

Vegetation indices such as NDVI), SAVI, MSAVI, MSI and LSWI are used for estimation of water quality, soil noise and vegetation cover by means of satellite data containing spectral reflectance. The techniques of digitizing and visiting locations via satellite imageries of selective areas also benefits in the estimation of annual vegetation degradation (Ibrahim, 2016).

Over the last three decades, vegetation indices applying two or more spectral bands have been advanced and used. Since, multi spectral band analysis gives more accurate data compared to single band analysis. These indices are calculated by using radiance, reflectance, and reflectance red and near-infrared values (Schmidt and Karnieli, 2001).

Vegetation associated records are performed by attaining electromagnetic wave reflectance information, from canopies via passive sensors. The light spectra reflectance from plants deviates per plant type, water content, and another intrinsic element. The chemical and morphological characteristics of the surface of organs or leaves control and regulate the emission and reflectance characteristic of vegetation to the electromagnetic spectrum. Vegetation information obtained from remote sensed images is mostly understood by alteration and dissimilarities of green leaves from the canopy and plant's spectral features (Xue and Su, 2017).

2. Materials and Methods

Hazarganji Chiltan National Park (HCNP) is one of the 23 officially declared national parks in Pakistan, established in 1980. It is geographically located between latitudes 29°59' to 30°07' N and longitudes 66°24' to 66°54' E, approximately 20 km southwest of Quetta, the capital of Balochistan (Khan and Siddiqui, 2011). The park serves as a vital sanctuary for the endemic Chiltan Markhor (*Capra falconeri chialtanensis*) and supports a diverse range of flora native to Balochistan. In addition to its ecological significance, HCNP offers educational, recreational, and aesthetic opportunities to both local and international visitors. However, unregulated ecotourism activities have negatively impacted the park's biodiversity and ecosystem health (Khan and Siddiqui, 2011). To assess the vegetation health of HCNP over three decades, a comprehensive field survey was conducted using both primary and secondary data. A guide map of the park was procured from the Geological Survey of Balochistan, while satellite imagery for the years 1990, 2000, and 2018 was obtained from the United States Geological Survey Global Visualization Viewer (USGS Glovis). The analysis employed Landsat 4-5 Thematic Mapper (TM) and Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) datasets, using the path/row designation 153/39 (Urooj et al., 2020).

Remote sensing techniques were utilized to evaluate changes in vegetation and soil health within the park. Preprocessing and analysis of the satellite imagery were performed using ArcGIS 10.5 software. Raster Calculator within ArcGIS was employed to process the imagery, which involved radiometric and geometric corrections, vegetation index calculations, and image classification. The processed images were subsequently projected to the desired coordinate system and exported as thematic maps for interpretation and analysis.

3. Results

The analysis of vegetation health in Hazarganji Chiltan National Park (HCNP) from 1998 to 2018 was conducted using five vegetation indices: Normalized Difference Vegetation Index (NDVI),

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Land Surface Water Index (LSWI), Soil-Adjusted Vegetation Index (SAVI), Modified Soil-Adjusted Vegetation Index (MSAVI), and Moisture Stress Index (MSI). These indices were calculated using satellite imagery processed through the ArcGIS platform.

The assessment leveraged the spectral reflectance properties of vegetation, particularly the variations in the near-infrared (NIR) and visible (VIS) bands. Healthy vegetation exhibited higher reflectance in the NIR spectrum and lower reflectance in the VIS spectrum, allowing for a detailed evaluation of vegetation vigor and stress levels across the park.

The NDVI and SAVI indices primarily highlighted changes in vegetative cover, while MSAVI refined these measurements by minimizing soil brightness influences. LSWI and MSI provided additional insights into soil moisture levels and water stress conditions affecting vegetation health. The results revealed temporal variations in vegetation and soil health over three decades, offering a comprehensive understanding of ecological changes within HCNP. These indices provided critical insights into spatial patterns of degradation and areas requiring conservation interventions.

3.1. Normalized Difference Vegetation Index (NDVI): Normalized Difference Vegetation Index was employed to examine the relationship between spectral variability and vegetation growth dynamics within Hazarganji Chiltan National Park (HCNP). The analysis revealed a slight increase in NDVI values between 1998 and 2008, with ranges recorded as 0.34 to 0.51 in 1998 and 0.35 to 0.56 in 2008, indicating moderate vegetation health and areas of stressed plant material. However, by 2018, the NDVI values had decreased significantly, ranging from 0.28 to 0.47, suggesting a decline in vegetation health and overall coverage. This trend highlights a marked reduction in vegetation vigor over the study period.

The spatial NDVI maps indicated that a substantial portion of HCNP's land was categorized as barren or devoid of vegetation, as represented by NDVI values near zero. These areas correspond to non-vegetative surfaces such as soil or rock. Analysis of the multispectral imagery showed that NDVI values between 0.00 and 0.33 effectively captured the distribution of sparse vegetation in 1998 and 2008 (Figures 1 and 2). However, in 2018, negative NDVI values were observed in some areas (Figure 3), further confirming a decline in vegetation.

The observed decrease in NDVI values in 2018 can be attributed to high reflectance in the red band and reduced reflectance in the near-infrared (NIR) band, a characteristic of low vegetation cover or degraded soil conditions. The high red band reflectance and low NIR reflectance indicate increased exposure of bare soil and less vigorous vegetation. These findings underline the deterioration in vegetation health and emphasize the need for effective conservation measures.

3.2. Soil Adjusted Vegetation Index (SAVI): The Soil-Adjusted Vegetation Index (SAVI) provided results comparable to NDVI but demonstrated improved accuracy, particularly in areas with exposed soil and sparse vegetative cover. By incorporating a soil adjustment factor (L = 0.5), SAVI effectively minimized the influence of soil reflectance, offering enhanced differentiation of vegetation health. Over the three-decade analysis, SAVI consistently yielded below-average values, aligning with the general decline observed in vegetation indices.

The maximum SAVI values, recorded in 2008, ranged between 0.5246 and 0.8452, indicating relatively healthier vegetation conditions in certain regions (Figure 5). Conversely, the minimum SAVI values were observed in the earlier year, with a range of 0.22694 to 0.3412, as depicted in Figure 4. These lower values reflect the predominance of exposed soil and sparse vegetation cover during this period.

The index values were also influenced by reflectance from non-vegetative features such as settlements, which affected the overall accuracy of vegetation assessments. Despite these variances, SAVI effectively highlighted differences in vegetation health across varying soil exposure levels, offering a robust tool for monitoring ecological changes in the Hazarganji Chiltan National Park. This analysis underscores the necessity for conservation interventions to address declining vegetation health and mitigate further degradation.

3.3. Modified Soil Adjusted Vegetation Index (MSAVI): The Modified Soil-Adjusted Vegetation Index (MSAVI), an enhancement of SAVI, was utilized to address the limitations of NDVI and reduce the influence of bare soil reflectance on vegetation assessment. The analysis revealed variations in MSAVI values across different time periods, with the greener regions predominantly located in the southeastern part of Hazarganji Chiltan National Park (HCNP).

In 1998, MSAVI values ranged from 143.674 to 197.68, highlighting moderate vegetation density in specific areas. By 2008, a slight increase in MSAVI values was observed, ranging from 146.548 to 217.859, as shown in Figure 7. This increase indicates an improvement in vegetation conditions during this period.

The enhanced sensitivity of MSAVI to vegetation health, particularly in areas with low vegetation cover and exposed soil, underscores its efficacy in monitoring ecological changes within HCNP.

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These results provide critical insights into the spatial and temporal dynamics of vegetation, offering a refined understanding of the park's ecological health.

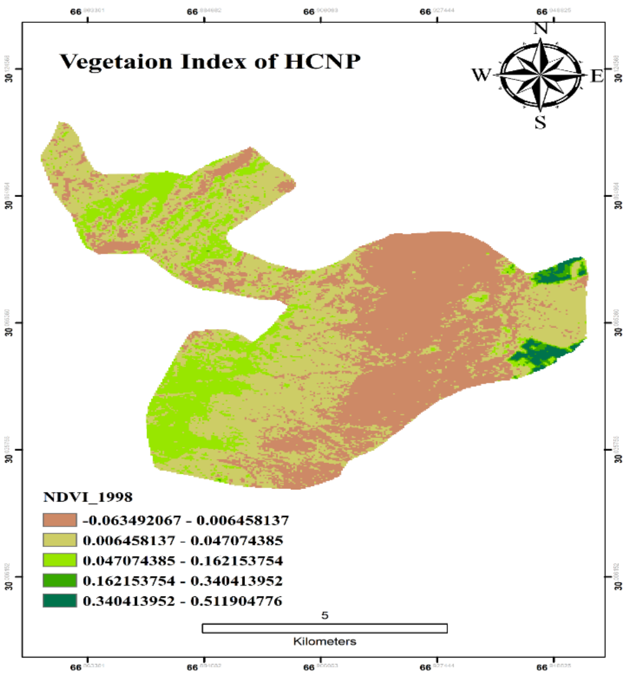

Fig.1 NDVI of HCNP of year 1998

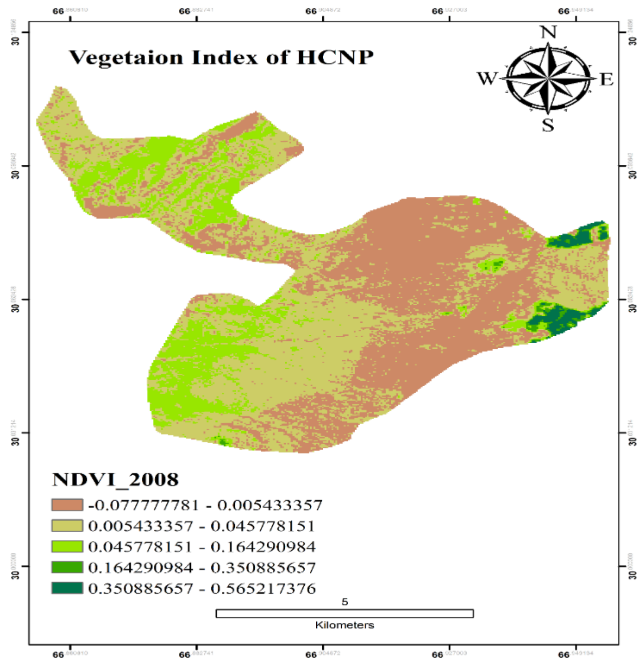

Fig.2 NDVI of HCNP of year 2008

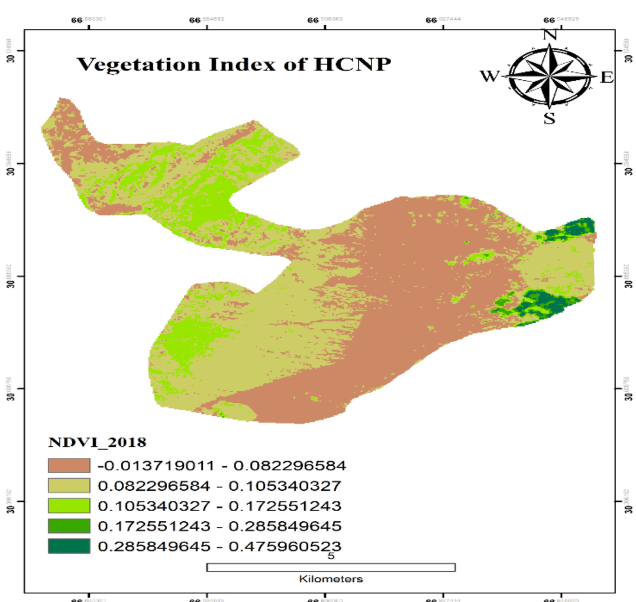

Fig.3 NDVI of HCNP of year 2018

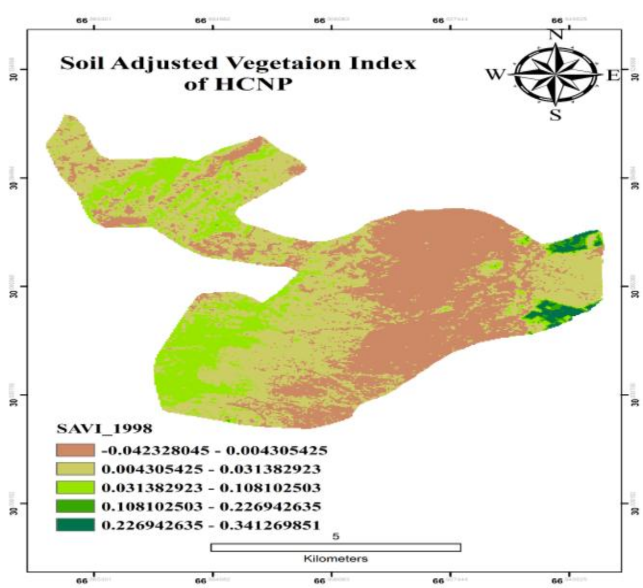

Figure 4. SAVI of HCNP of year 1998

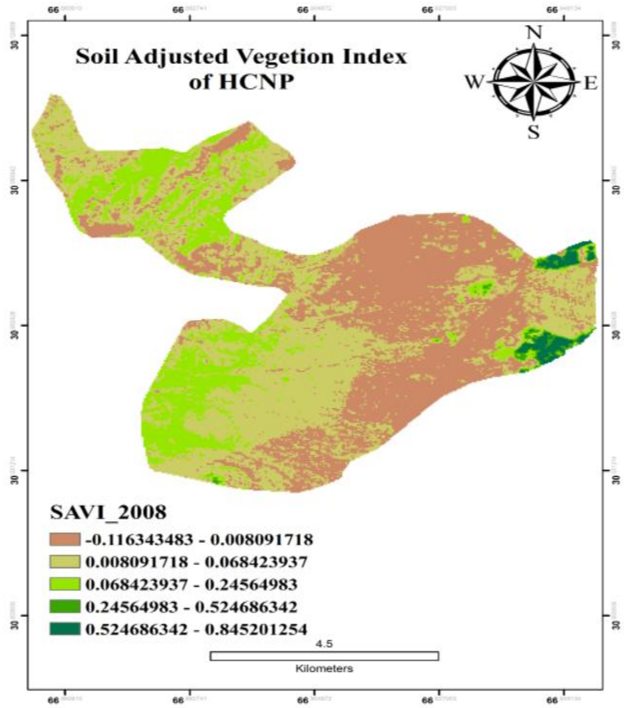

Fig. 5 SAVI of HCNP of year 2008

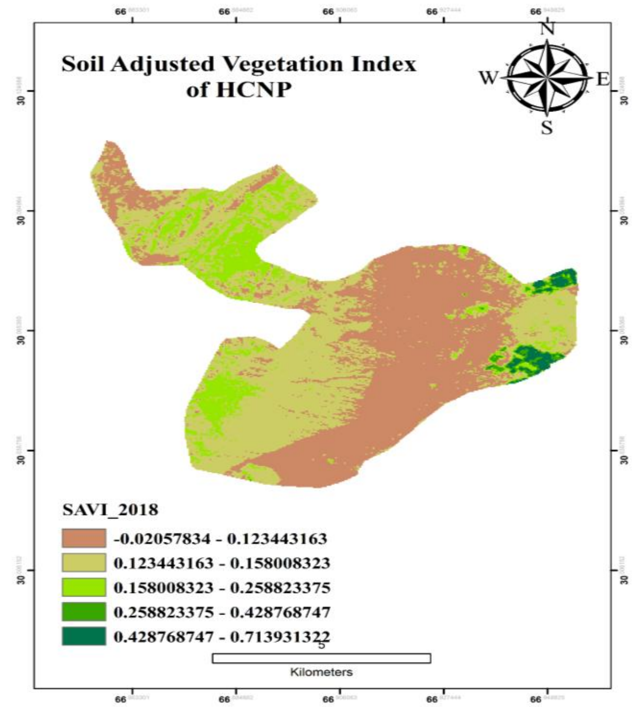

Fig. 6 SAVI of HCNP of year 2018

3.4. Land Surface Vegetation Index (LSWI): The Land Surface Water Index (LSWI) was utilized to quantify the water content in vegetation canopies by analyzing the interaction between liquid water molecules and solar radiation. The results indicated temporal variations in LSWI values over the three-decade study period.

In 1998, the highest LSWI value recorded was 0.1512, reflecting baseline water content in the vegetation canopy. By 2008, a moderate increase was observed, with LSWI values rising to 0.2593, indicating improved water availability or vegetation conditions during this period (Figure 11). A significant increase in LSWI values was documented in 2018, highlighting further enhancement in canopy water content (Figure 12).

The observed trend suggests changes in vegetation water status, potentially influenced by environmental factors such as precipitation, soil moisture, and vegetative cover dynamics within the Hazarganji Chiltan National Park. These results underscore the utility of LSWI in monitoring hydrological and vegetation health changes over time.

3.5. Moisture Stress Index (MSI): The Moisture Stress Index (MSI) was employed to assess variations in leaf water content by analyzing the reflectance ratio in the near-infrared (NIR) and

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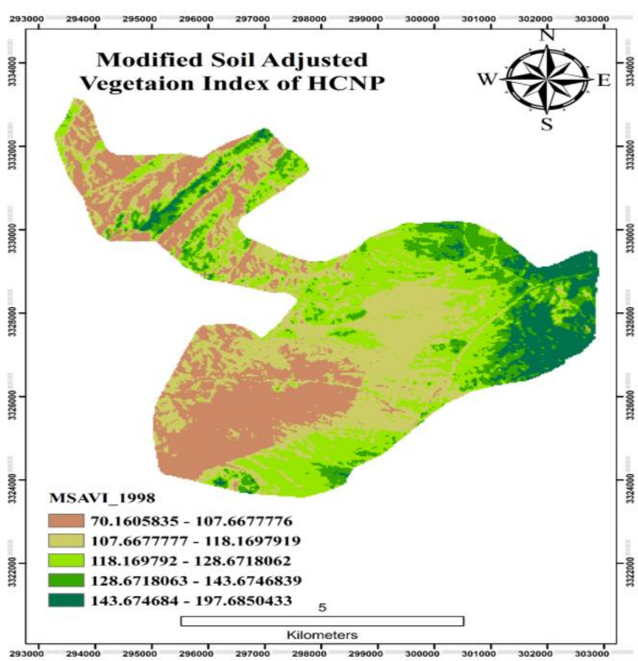
middle-infrared (MIR) bands. The results revealed significant spatial and temporal changes in moisture content across Hazarganji Chiltan National Park (HCNP).

Figure 13 highlights increased moisture stress in the southeastern regions of HCNP compared to previous years, indicating a marked decline in water availability in these areas. In 2008, MSI values revealed a reduced moisture content, with a prominent recorded value of 2.8165 observed across much of the park's land cover (Figure 15).

These findings underscore the heightened vulnerability of vegetation in HCNP to moisture stress, particularly in areas with minimal water retention capacity. The MSI analysis effectively delineates regions of high ecological stress, offering critical insights for targeted water management and conservation interventions.



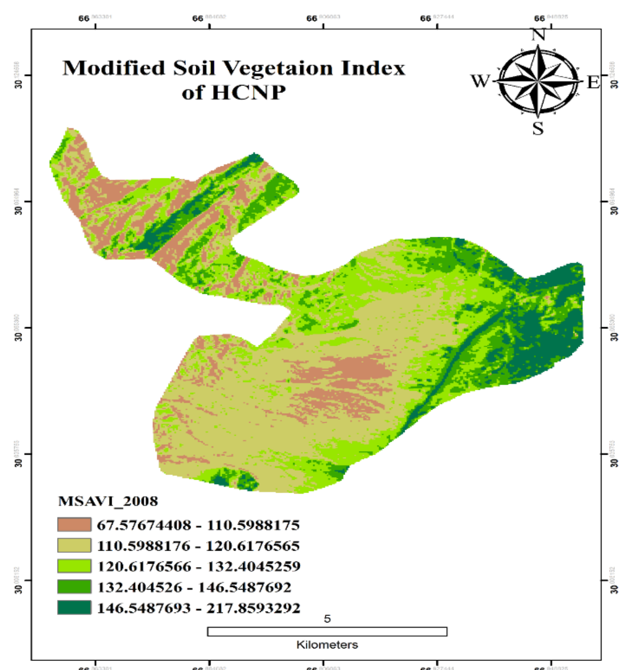


Figure 7. MSAVI of HCNP of year 1998

Figure 8. MSAVI of HCNP of year 2008

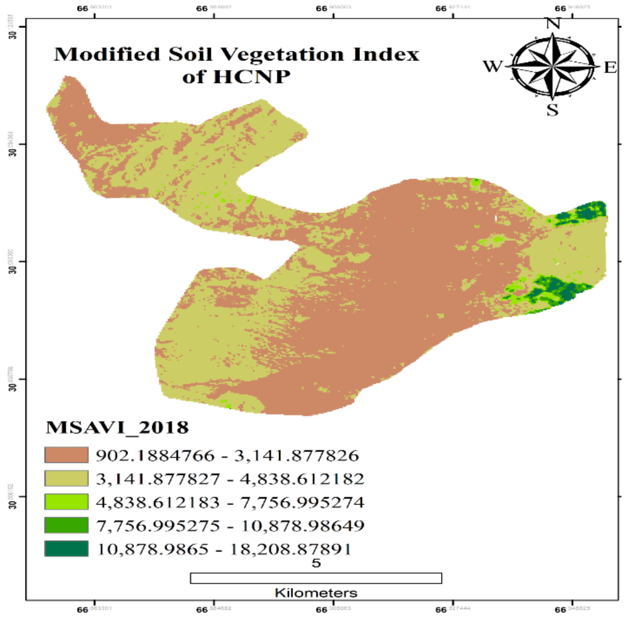


Fig. 9 MSAVI of HCNP of year 2018

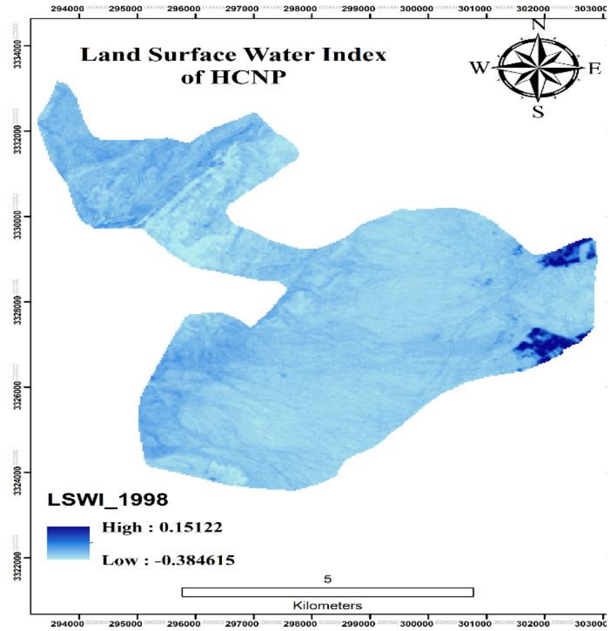


Fig. 10 LSWI of HCNP of year 1998

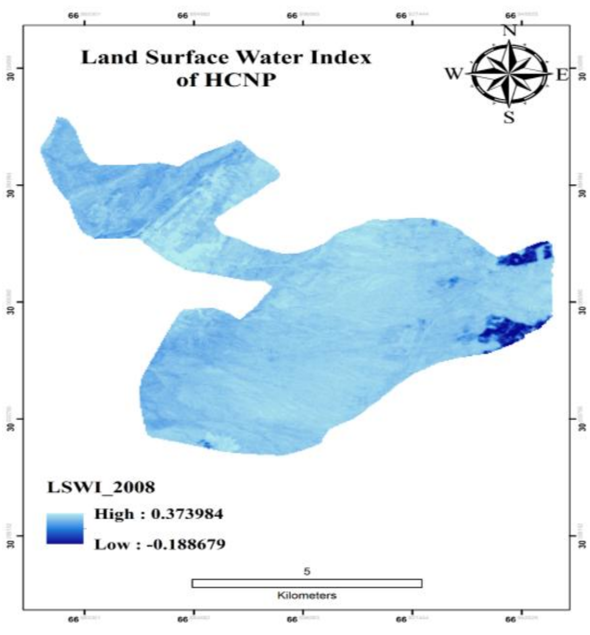


Fig. 11 LSWI of HCNP of year 2008

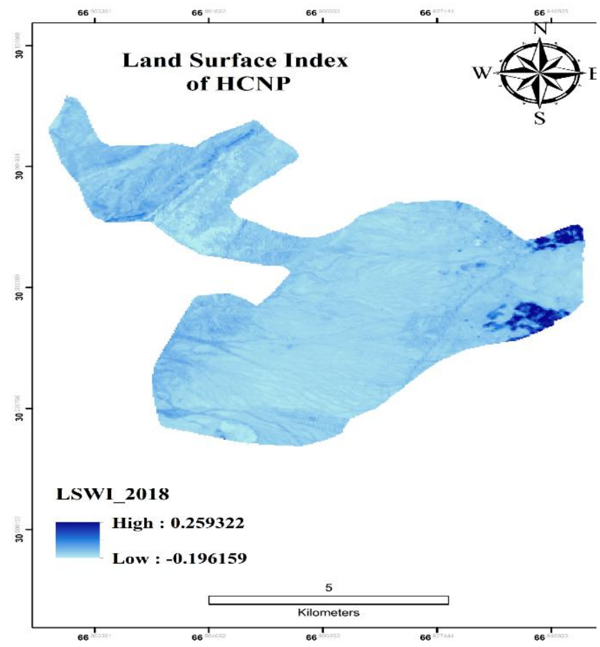


Fig. 12 LSWI of HCNP of year 2018

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3.6. Land Cover: The land cover analysis revealed a progressive decline in vegetation and water resources over the study period, accompanied by an expansion of barren land within Hazarganji Chiltan National Park (HCNP). These changes indicate significant ecological shifts driven by environmental stressors and anthropogenic activities.

In 1998, the vegetation cover spanned 1,380.047 hectares, as illustrated in Figure 16. This area increased modestly to 1570.19 hectares by 2008, indicating a temporary recovery or improvement in vegetative growth (Figure 17). However, by 2018, vegetation cover drastically declined to 656.7827 hectares, reflecting extensive degradation (Figure 18).

Water bodies within HCNP also experienced a steep decline over the study period. In 1998, the water-covered area measured 246.5488 hectares (Figure 16). This figure dropped significantly to 0.5565 hectares in 2008 (Figure 17) and further declined to 0.5549 hectares in 2018 (Figure 18), signaling severe hydrological stress.

Conversely, barren land exhibited a consistent increase throughout the study period. In 1998, barren land covered 2,784.229 hectares, which expanded to 3511.1 hectares by 2018 (Figure 18).

The observed trends in land cover highlight critical ecological imbalances, including loss of vegetation and water resources, coupled with increasing desertification. These findings underscore the urgency for implementing effective conservation strategies to mitigate further land degradation and restore the ecological integrity of HCNP.

3.7. Accuracy Assessment of Classification: The accuracy assessment is a crucial step in evaluating the reliability of classified images in the image classification process. This was performed using error matrices, also referred to as confusion matrices, for images from the three selected decades. The assessment determined the level of agreement or accuracy by comparing the probability values assigned to image pixels with the classification results of reference pixels.

For the classified images of 2018, the overall classification accuracy was determined to be 95.83%, indicating a high level of reliability. Errors were categorized into two types: Omission Error (OE) and Commission Error (CE). Commission Error (CE) occurred when pixels were incorrectly assigned to a class other than their true class, while Omission Error (OE) occurred when pixels that belonged to a reference or truth class were misclassified into other categories.

To further evaluate classification accuracy, the Kappa coefficient, a discrete multivariate statistical measure, was calculated. The Kappa coefficient accounts for chance agreement and provides a

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robust measure of classification consistency. The Kappa statistic for the classified images of 1992 was 0.934, indicating strong agreement and high classification accuracy.

This comprehensive accuracy assessment underscores the robustness of the classification methodology and provides confidence in the spatial and temporal analyses derived from the classified imagery.

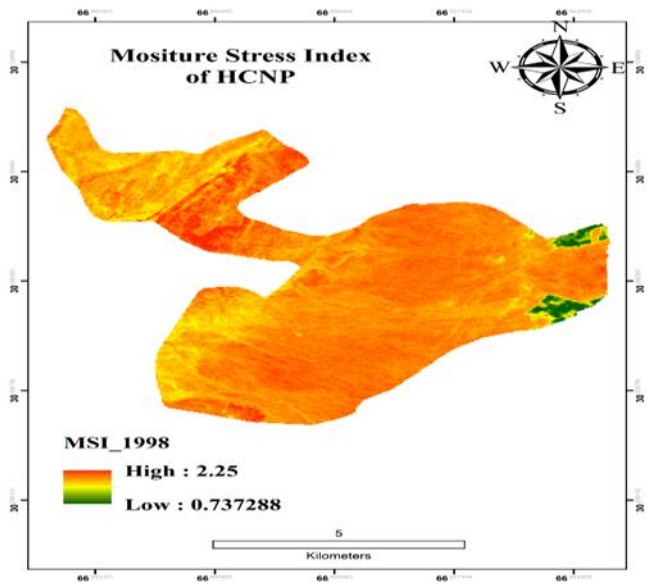

Fig. 13. MSI of HCNP (1998)

Fig. 14. MSI of HCNP (2008)

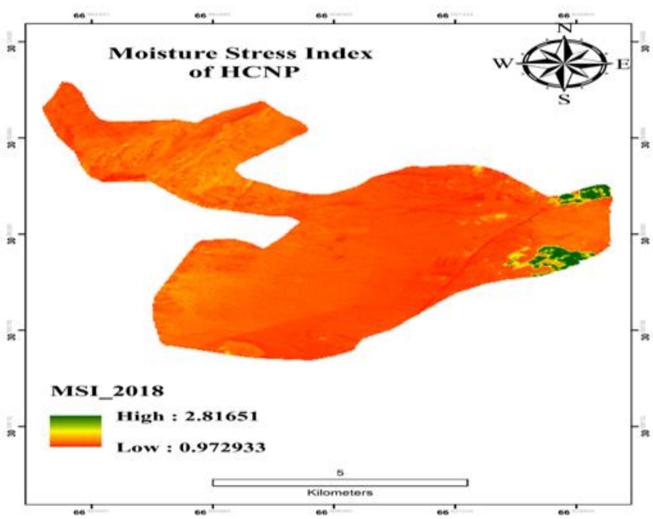

Figure 15. MSI of HCNP (2018)

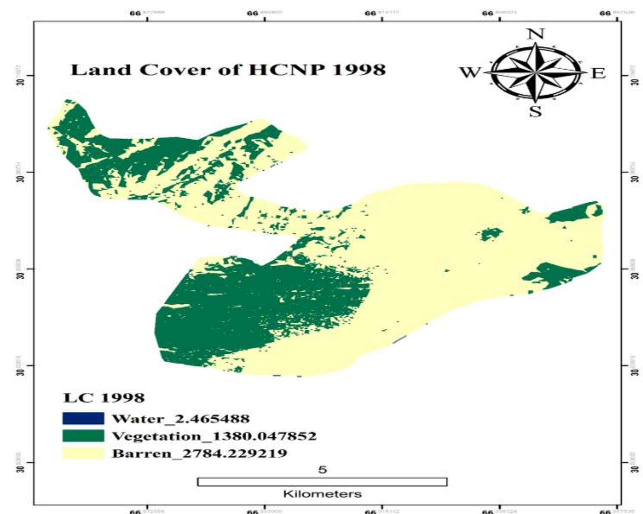

Fig. 16 Land Cover of HCNP of year 1998

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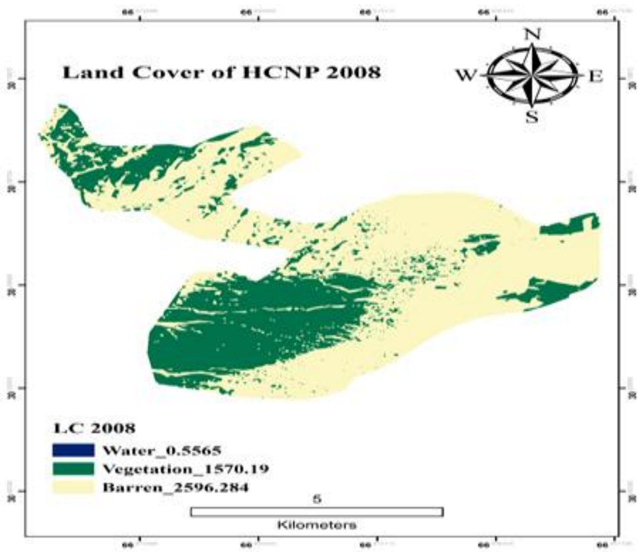

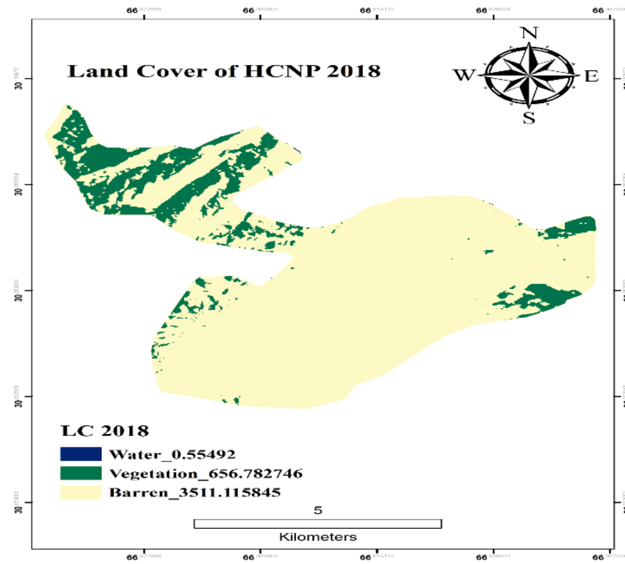

Fig. 17 Land Cover of HCNP of year 2008 **Fig. 18 Land Cover of HCNP of year 2018**

4. Discussion

Between 1998 and 2018, significant changes in rainfall and temperature patterns were recorded in Hazarganji Chiltan National Park (HCNP), which affected its vegetation cover. In June 1998, average rainfall was 0.064 mm (Fig. 19), and the temperature was 22.6°C. By June 2018, rainfall had increased slightly to 0.089 mm, with the same maximum temperature of 22.6°C (Fig. 21). However, in 2008, HCNP experienced the lowest rainfall of 0.037 mm (Fig. 20) and a reduced temperature of 19.4°C, reflecting an unstable climatic trend. These fluctuations underscore the influence of climate change on the region's hydrological cycles and vegetation dynamics.

Vegetation cover decreased dramatically from 1380.047 ha in 1998 to 656.7827 ha in 2018, despite a temporary increase to 1570.19 ha in 2008. Simultaneously, barren land expanded from 2784.229 ha in 1998 to 3511.11 ha in 2018, highlighting the intensifying land degradation. Water bodies also shrank significantly, from 2.46548 ha in 2008 to just 0.55492 ha in 2018, correlating with declining vegetation health. This degradation points to a strong connection between water availability, precipitation, and vegetation health, emphasizing the role of climatic variability.

Upright and stable management practices of protected park and variation in precipitation and temperature has changed the land cover pattern and vegetation coverage of HCNP. Vegetation health has many links with hydrological cycle and temperature. Whereas land cover type can affect

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infiltration and runoff percentage of precipitation (Hougton, 1995). Surface runoff and groundwater both can be affected by land cover type (Abebe, 2005).

The results have revealed the decrease vegetation cover and poor health of HCNP in the year 2018 as compared to the previous study years. The average increase in the vegetation cover was shown in the year 2008 shown in Fig 17. While there can be several explanations behind vegetation reduction. As vegetation cover is related directly availability of water availability and climatic condition. Strong relationship was seen between water availability and climatic condition (Abebe, 2005).

Normalized Difference Vegetation Index (NDVI) and Soil Adjusted Vegetation Index (SAVI) analyses confirmed the decline in vegetation. NDVI values in 2018 were the lowest among the studied years, reflecting sparse vegetation and high soil reflectance. In 2008, SAVI values were higher due to the presence of grass patches and shrubs, but by 2018, these had largely diminished. Modified SAVI (MSAVI), which adjusts for soil background effects, indicated that vegetation coverage in 2018 had dramatically declined compared to 1998 and 2008. These indices underscore the impact of reduced precipitation and rising temperatures on vegetation.

Soil Moisture Index (SMI) analysis showed moderate soil moisture in 2018 due to slightly improved rainfall, while 2008 exhibited the lowest soil moisture levels. Land Surface Water Index (LSWI) values in 2018 suggested an increase in soil water content, likely tied to increased precipitation, but the overall water availability remained insufficient to restore vegetation. Research supports the observation that improved precipitation can enhance soil moisture and vegetation recovery, but these effects were limited in HCNP due to erratic rainfall and poor water retention.

The land cover change from year 1998 to 2018 is shown in the figure 16-18. The results showed that in 1998 the land covered by vegetation was 1380.047 ha that shifted into 1570.19 ha in the year 2008 and in 656.7827 ha during the year 2018. Shifting was also occurred in barren land and water bodies. Like 2784.229 ha area of barren land increased into 3511.11 ha in year 2018. While the recorded cover of water was 2.46548 ha in the year 2008 which has decreased up to 0.55492 ha in the year 2018.

Peng and Fei (2008) stated that NDVI images reflect land cover as entire and easily differentiate green vegetation and changes that occurs in it. SAVI images give importance to the information of internal difference of the vegetation. The NDVI values of the HCNP showed decline in the vegetation in year 2018 comparative to the year 1998 and 2008, confirming vegetation coverage changes of HCNP. The lowest values were found because reflection from the soil was high.

The higher SAVI response was shown as compared to NDVI in year 2008 due to the existence of some grass patches and shrubs. Whereas lower values of NDVI reflected the effect of soil backgrounds. Huete and Liu, (1994) revealed that the soil-type between 40% and 75% vegetative cover had the greatest effect on NDVI values. In general, the results showed somewhat comparable values of NDVI and SAVI in year 2018. Cakir et al. (2006) have presented that NDVI produce limited discriminating potential, in areas less covered by vegetative cover types. Overall, the variations in the NDVI values were also caused due to change in precipitation and vegetation dynamics over that time.

MSAVI is a modification of the SAVI substituting soil adjustment factor with a self-adjusting soil factor L. MSAVI automatically modifies the soil adjusting factor L, while SAVI requires manual adjustment. Many researchers i.e., (Qi et al., 1994) submitted that MSAVI increase the response of the vegetation dynamic and reduces the soil background disparities using soil adjustment functions. Areas with higher vegetation cover MSAVI behaved same as NDVI while with in-between vegetation cover MSAVI performed like SAVI. The MSAVI values of year 1998 and 2008 expressed marginally similar values. Whereas, in year 2018 the values were entirely changed indicating shift in vegetation cover.

Soil moisture index was used to estimate the soil moisture status of HCNP. Index classification was calculated in low and high value categories. The value of MSI in year 2018 clearly showed moderate moisture with slightly good precipitation. Whereas less moisture was recorded in year 2008 with low precipitation. Whereas, in 1998 the moisture stress was usual at HCNP site and average rainfall was medium. Many researchers such as Haas, (2010) perceived that precipitation distribution should also be studied together with indices.

The increase of LSWI was recorded in year 2018. This validates clearly, that LSWI can recognize the liquid water content increase in in the soil. The water availability is also greater due to increase in the precipitation in this year. While, in 1998 less precipitation was recorded while the value of LSWI was low at the same time. Many researchers (Chandrasekar et al., 2011) stated that monsoon and higher number of precipitations increases the soil water availability of any region. It can also increase the crop production.

However, on a greater scale Pakistan is facing degradation and fragmentation of the national resources. Loss and destruction of habitat plays greater role in the degradation of natural resources. To achieve sustainable development good management practice is obligatory. The lack of comprehensive management plan also contributed to the degradation of vegetation cover of HCNP in all these years. There were numerous gaps and needs related to management of HCNP, which can be filled through harmonized efforts of every segment of society such as National and International organizations that will provide funding, the conferenced Government/other department that will access the management facilities of park, public that provide awareness regarding any kind of destruction or degradation trending in the HCNP. Khan (2011) stated that issues that contributed to degradation of natural resources were due to weakness in law enforcement, poor management practices, and shortage of funding and lack of community involvement.

The degradation of HCNP's vegetation is exacerbated by climate change, habitat loss, poor management practices, and inadequate law enforcement. Sustainable development of HCNP requires a comprehensive management plan that addresses these gaps. Collaborative efforts between national and international organizations, government agencies, and local communities are crucial for reversing environmental degradation. Improved funding, enforcement of conservation laws, and public awareness campaigns can significantly enhance HCNP's resilience to climate change.

Table 1. Change in Land Cover of HCNP from 1998 to 2018

Year / LC	1998	2008	2018
Vegetation Cover	1380.047 ha	1570.19 ha	656.7827 ha
Barren Land	2784. 229 ha	2596.27 ha	3511.11 ha
Water Bodies	2.465488 ha	0.5565 ha	0.55492 ha

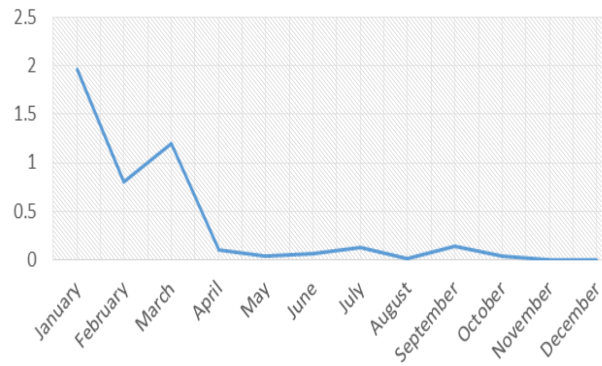

Fig. 19 Precipitation of HCNP of year 1998

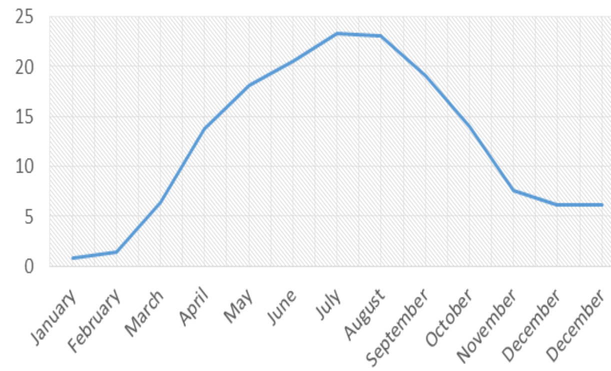

Fig. 20 Temperature of HCNP of year 1998

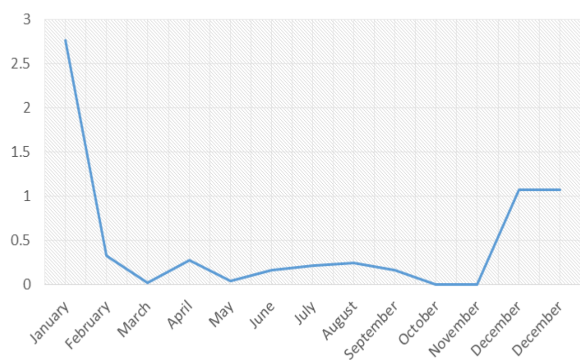

Fig. 21 Precipitation of HCNP in year 2008

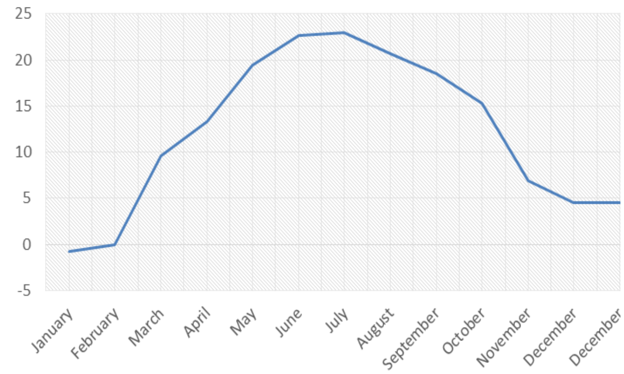

Fig. 22 Temperature of HCNP in year 2008

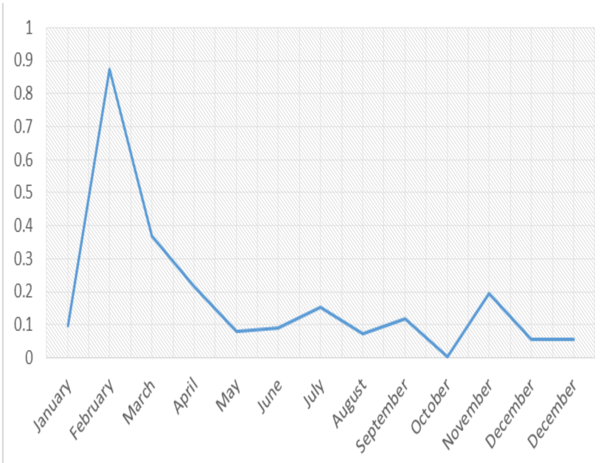

Fig. 23 Precipitation of HCNP in year 2018

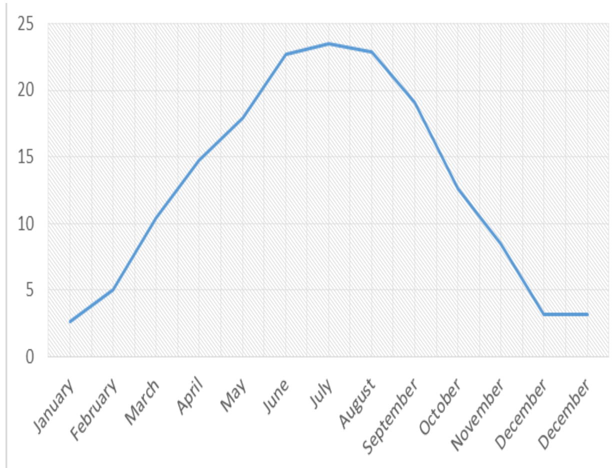

Fig. 24 Temperature of HCNP in year 2018

5. Conclusions

The findings from HCNP reveal the severe impact of climate change on vegetation and ecosystem health. The park's vegetation decline over two decades underscores the urgent need for adaptive management strategies to mitigate the adverse effects of changing climatic conditions. Integrating scientific tools like NDVI, SAVI, and MSAVI with sustainable management practices will be essential to preserve this critical ecosystem. This study demonstrates the effectiveness of remote sensing for land cover mapping and monitoring changes in natural resources within national parks. Specifically, the health of vegetation in Hazarganji Chiltan National Park (HCNP) was assessed in relation to land cover classes, water availability, and climatic factors. The findings revealed a decline in vegetation coverage from 2008 to 2018, accompanied by an expansion of barren land. Furthermore, significant land cover changes were observed between 1998 and 2019.

The study highlights that poor management practices, insufficient law enforcement, and a lack of public awareness are key contributors to resource degradation in HCNP. However, targeted restoration efforts have the potential to increase vegetative cover within the park. The integration of remotely sensed techniques and methodologies proved instrumental in providing accurate and reliable data for monitoring and managing HCNP. As a model study, this research offers valuable insights for the conservation and sustainable management of HCNP, a critical hub of biodiversity in Quetta, Balochistan. It underscores the importance of enforcing conservation policies, particularly those outlined in the Balochistan Environmental Protection Act 2012. Additionally, the study's findings can serve as a foundation for future planning and resource management initiatives, ensuring the protection and sustainability of HCNP for generations to come.

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