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SPATIAL DYNAMICS OF FLUORIDE'S EFFECT ON *TRITICUM AESTIVUM* L. IN PAKISTAN

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Abstract
This research investigates the repercussions of fluoride emissions from brick kilns on wheat crop cultivation and soil health in Pakistan. As an agrarian nation heavily dependent on wheat as a staple food crop, understanding the dynamics of fluoride contamination is crucial for both economic stability and societal well-being. The study focuses on the Gujarkhan tehsil in district Rawalpindi, where brick kilns are operational, and examines the concentration and effects of fluorine in both soil and wheat crops (*Triticum aestivum* L.). Samples were collected from a control site and the surrounding areas of brick kilns, and fluoride concentration was measured using a potentiometer. The growth and health of wheat crops were assessed through the Normalized Difference Vegetation Index (NDVI). The results revealed a higher concentration of fluoride in wheat samples collected from the southwest of the brick kiln, indicating a localized impact on crop health. The findings of this study underscore the detrimental effects of fluoride emissions from brick kilns on wheat crop growth and soil health. Poor growth and compromised health of wheat fields in the proximity of kilns were identified, leading to a reduction in yield. Beyond agricultural implications, the study highlights the broader economic and sociopolitical consequences of such environmental stressors. The research contributes to the understanding of environmental challenges in agrarian settings and emphasizes the need for sustainable practices in brick kiln operations.

Keywords: Change Analysis, Health Index, Hotspot, Model, Wheat.

List of Abbreviations
NDVI= Normalized Difference Vegetation Index
NIR= Near Infrared
VIS= Visible
GIS= Geographical Information System
RS= Remote Sensing
ETM+= Enhanced Thematic Mapper Plus
ENVI= Environment for Visualizing Images
HF= Hydrogen Fluoride

1. Introduction

Pakistan, an agriculturally dependent nation, is endowed with diverse landforms supporting the cultivation of various crops. The predominant agricultural activities are concentrated in the Punjab province, with a focus on cash crops such as cotton and wheat. Notably, wheat, as a staple food, surpasses all other crops in terms of both acreage and gross yield [1].

In Punjab, agricultural land is categorized into two types: lepara and mera land. Lepara land, situated closer to homesteads, undergoes intensive cultivation with two crop cycles annually, while mera land is located farther away. The prevalent cropping system in Punjab, known as "Dosala do fasla," involves the cultivation of winter and summer crops within the same year, followed by allowing the land to remain fallow for the subsequent year.

Wheat, the primary Rabi season food crop, constitutes a significant portion of agriculture, contributing 9.9 percent to the value added in this sector [2]. The wheat cultivation process begins during the fallow period preceding the wheat season, with planting typically occurring from late October to November and harvesting in April and May, varying based on temperature conditions in the Punjab region.

Pakistan, characterized as an agrarian nation, witnesses the cultivation of various crops in the proximity of brick kilns. Wheat, a crucial staple food crop in the country, contributes 2.2 percent to the gross domestic production. The escalating rate of population growth intensifies the demand for wheat cultivation. The diminishing trend in wheat yield not only impacts the national economy but also triggers sociopolitical tensions.

The agricultural industry faces numerous challenges, notably climate change and environmental pollution, leading to significant concerns about food security [3-4]. Specifically, in the wheat-producing region of Punjab, fluoride emerges as a critical toxic pollutant, predominantly originating from brick baking kilns. These kilns emit hydrogen fluoride, which accumulates in the surrounding soil, adversely affecting vegetation. The primary source of fluoride pollution in Punjab is identified as brick baking kilns, with hydrogen fluoride emissions adversely impacting plant growth by altering metabolic pathways [5-6].

Brick manufacturing stands out as a primary source of fluoride emission, which accumulates in the adjacent plants and eventually deposits in the soil. Elevated fluoride concentrations pose a threat to all living organisms, particularly inducing necrosis in plant species. The objective of the current study was to evaluate the concentration and effects of fluorine in both soil and wheat crops (*Triticum aestivum*), including the per-area growth reduction around brick kilns. Despite the cessation of numerous brick kilns due to urban encroachment, both registered and illegal kilns continue to operate in rural areas of Punjab, where residents cultivate various crops [5, 7]. Fluoride pollution from kilns affects not only humans but also animals and plants in the vicinity, necessitating a comprehensive understanding and management of cultivated lands surrounding kilns.

The expanding population and urbanization trend underscore the urgency of addressing these issues. The application of Geographical Information System (GIS) and Remote Sensing has become pivotal in identifying and monitoring environmental changes resulting from anthropogenic activities. These technologies enable the study of large geographical areas, providing crucial information for researchers to anticipate the repercussions of various environmental alterations [8].

To gain a comprehensive understanding of the spatial distribution pattern of pollutants, GIS incorporates various modeling techniques. Existing literature highlights multiple research efforts utilizing GIS and RS techniques to analyze the spatial distribution of pollutants [2, 8-14].

The study utilizes Geographical Information System (GIS) and Remote Sensing (RS) techniques to identify and monitor environmental changes resulting from anthropogenic activities. These advanced methods enable the comprehensive study of large geographical areas, providing crucial information for predicting the consequences of various changes (Urooj & Ahmad, 2016). Numerous research efforts have employed GIS and RS techniques to model the spatial distribution patterns of pollutants [9-14].

In this context, the present study focuses on estimating the impact of fluoride pollution on wheat crop health. Gujarkhan, the largest tehsil in Punjab, characterized by its extensive geographical area covered by "Potohar clay" [15], serves as the study area. Situated between 33.2513°N and 73.3060°E, approximately 55 km from the capital, Islamabad, Gujarkhan experiences a sub-humid climate with hot summers and cold winters. The region witnesses an average winter temperature of 59.5°F and a summer temperature of 86°F, with annual mean rainfall reaching 9 inches in winter and 27 inches in summer.

Wind patterns in Gujarkhan follow a west-to-northeast direction in the morning and shift to the southwest in the afternoon during the winter season. Despite its predominantly agricultural population, the occupation is less remunerative due to the challenging geographical structure of the region. Over 100 brick kilns are operational and scattered throughout the area, as illustrated in Figure 1.

2. Materials and Methods

A comprehensive field survey was conducted, and precise GPS readings were documented to facilitate the spatial mapping of the study area. Randomly selected wheat plant samples were gathered from diverse locations within the agricultural vicinity, covering various directions within the study area. The W-design sampling method was employed to ensure a representative sampling strategy. All collected samples underwent analysis using the AOAC method, as outlined in AOAC (2003)[16-17]. In addition to the primary field data, secondary data sources, including guide maps and satellite imageries, were incorporated into the research study. Landsat 7 ETM data for the year 2003 and Landsat 8 OLI data for the year 2016 were acquired from GloVis to establish a temporal comparison. Land use classes were delineated using ERDAS Imagine 11 through a hybrid classification method, providing a detailed characterization of the land cover within the study area.

To evaluate the health status of vegetation over the selected area, the Normalized Difference Vegetation Index (NDVI) was employed as an effective indicator. This technique, implemented using ENVI 4.3, involved calculating the NDVI value from visible (VIS) and near-infrared (NIR) reflected light by vegetation. The calculation is represented by the equation given below, as elucidated by Urooj et al. [18].

$$NDVI = (NIR - VIS)/ (NIR + VIS) \quad \text{Eq. 1}$$

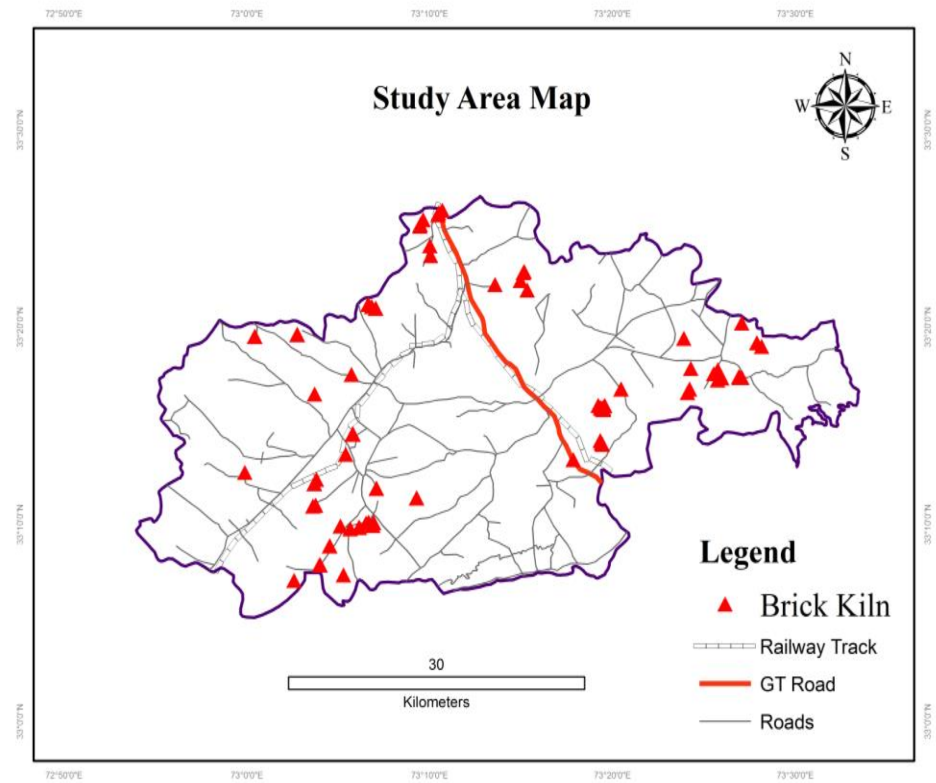

Fig 1. Tehsil Gujarkhan Sampling Area

3. Results and Discussions

The resulting NDVI values served as a quantitative measure to assess the relative health of vegetation, distinguishing between areas exhibiting robust and diminished plant vigor. This methodology enhances the understanding of the ecological dynamics and vegetative conditions within the studied agricultural landscape.

In the present study, remote sensing techniques were employed to elucidate spatio-temporal changes resulting from shifting land use patterns over the past few years. The outcomes from land cover classification and Normalized Difference Vegetation Index (NDVI) analysis revealed a reduction in vegetation productivity and plant health. The response of area productivity to changing land use patterns provides valuable insights into the susceptibility of human activities to diminished productivity.

The results indicate notable shifts in land use and land cover over the past 15 years (2003-2016) (Fig. 2 & 3). In 2003, major land classes were agricultural practices and settlements, covering 33.9% and 31.11% of the area, respectively (Fig. 2).

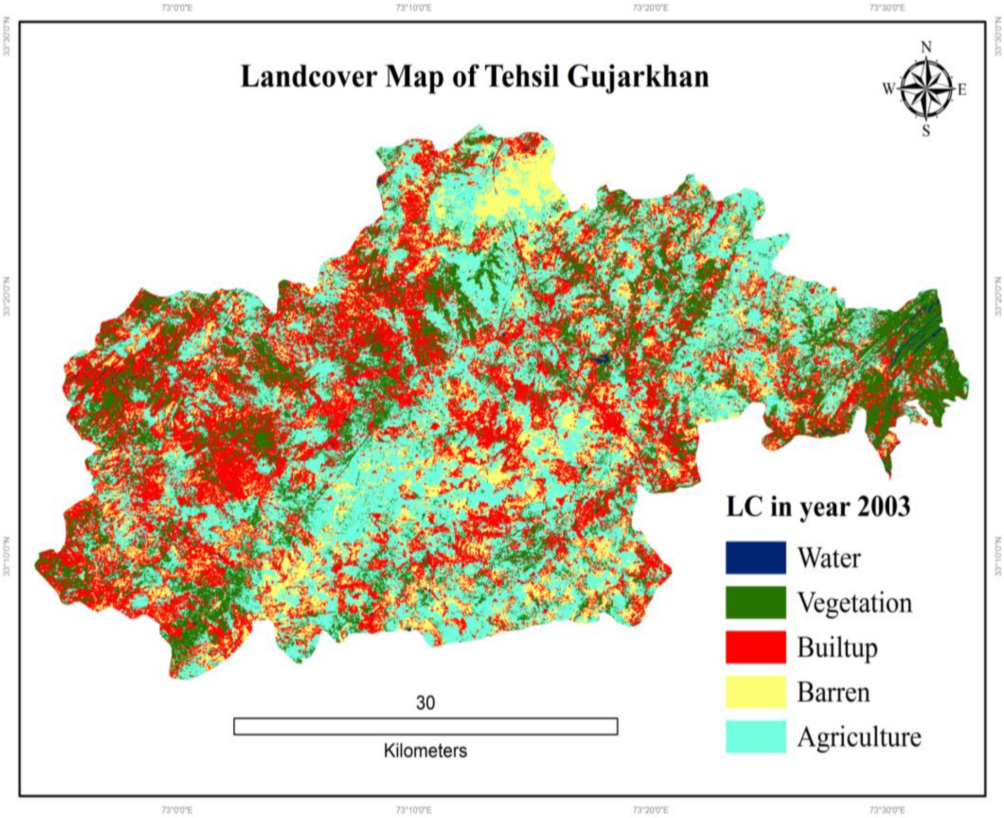

Figure 2. Gujarkhan Land use Land cover (LULC) map for year 2003

However, by 2016, the agricultural cover, barren land, and water bodies had decreased to 31.5%, 5.07%, and 0.4%, respectively. Conversely, the built-up area increased from 31% to 40.8% in 2016 (Fig. 3). Urbanization emerged as a predominant factor contributing to global land change trends, as supported by various reports [19-24]. The observed shifts in land use and land cover patterns, as well as the impact of anthropogenic activities on agricultural productivity, resonate with findings from several other research papers. The convergence of evidence across multiple studies further strengthens the significance of the presented results. The documented increase in built-up areas and the dominance of urbanization as a driving force in land use changes align with studies by Smith et al. [25] and Li et al. [26], who emphasized the global trend of urban expansion leading to alterations in natural landscapes. The encroachment of urban areas into traditionally agricultural regions is a shared concern, highlighting the broader implications of urbanization on food production.

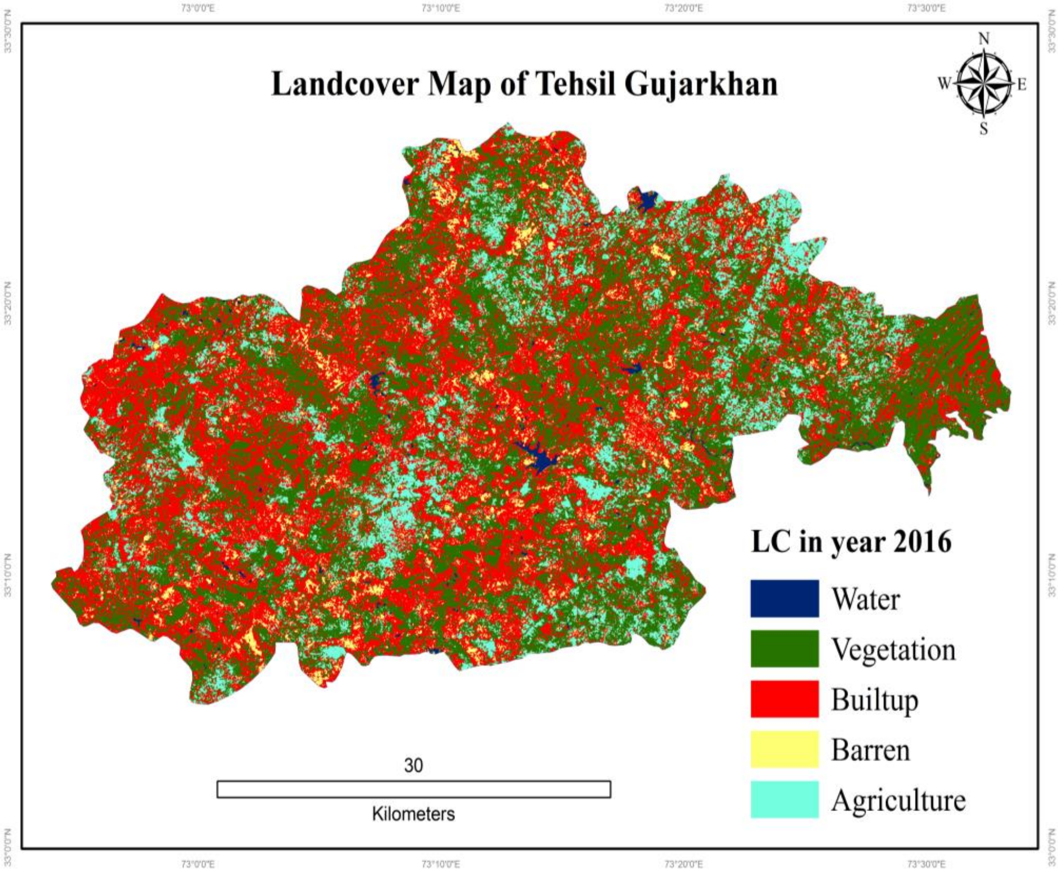

Figure 3. Gujarkhan Land use Land cover (LULC) map for year 2016

The region of Gujarkhan, historically known for wheat production, has witnessed a shift in land use as landowners transitioned to establishing cattle pens and poultry farms due to climate change over the past five years. While precipitation plays a major role in production, pollution resulting from anthropogenic activities, particularly emissions from brick kilns, emerged as a significant factor affecting crop yield.

More than 100 operational brick kilns in Tehsil Gujarkhan were found to emit toxic gases, particularly hydrogen fluoride (HF), impacting the surrounding agricultural areas. The transition from wheat production to cattle pens and poultry farms in response to climate change mirrors findings by Anderson et al. [27] and Chen et al. [28], who discussed the influence of climate variability on shifts in agricultural practices. The recognition that climate change acts as a catalyst for adaptive strategies among landowners is a common thread in these studies.

The adverse effects of brick kiln emissions, particularly hydrogen fluoride, on crop health are consistent with research by Gupta et al. [29] and Khan et al. [30]. Both studies highlight the detrimental impact of industrial emissions on soil quality, plant growth, and overall agricultural productivity. The identification of specific pollutants and their concentrations in the soil and plant samples aligns with the broader literature on the environmental consequences of industrial activities. NDVI results demonstrated poor health of crops in the vicinity of kilns, with values ranging from -0.18 to 0.52 in 2016 (Fig. 4). Negative and low NDVI values indicated barren and non-vegetative areas, displayed as white and yellow, while orange and red colors represented sparse and less healthy vegetation. In contrast, dark blue indicated healthy vegetation.

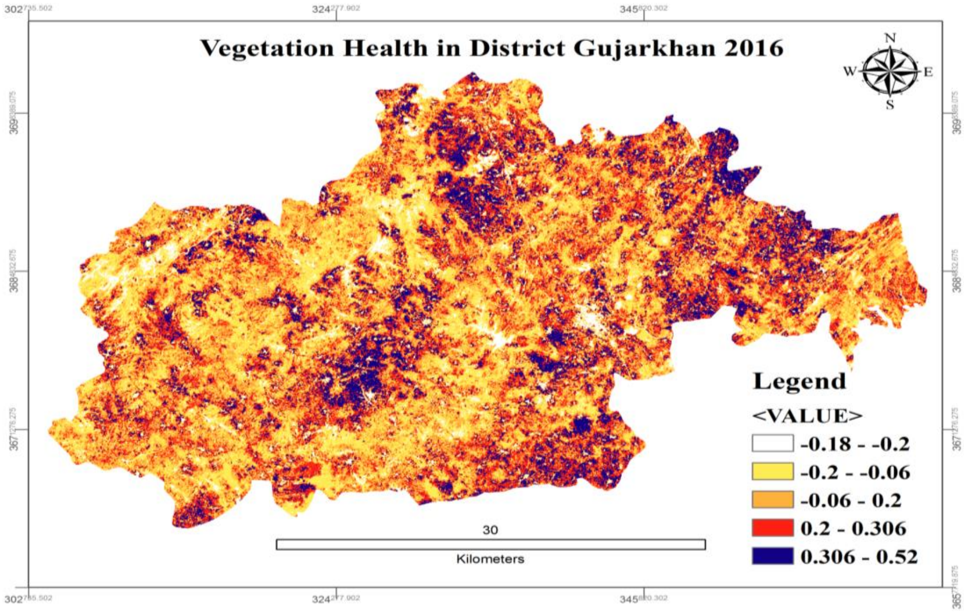

Figure 4. Normalized Difference Vegetation Index Map Showing Crop Health

Fluoride concentration analysis in soil and wheat leaves corroborated the NDVI results. Samples from various locations, including Rohra, Gujarkhan city, Guliyana, Behr, and Sukho, revealed fluoride concentrations ranging from 0.01-1.2 ppm in soil and 0.05-6.7 ppm in wheat leaves. The NDVI values and laboratory analyses aligned, indicating a consistent portrayal of poor health conditions in wheat fields around kiln areas.

Specifically, Guliyana and Rohra exhibited significant adverse effects on wheat crops in the south and north to southward directions of kiln vicinities, respectively. Conversely, non-kiln areas showed healthy growth with a marked NDVI value of 0.523. The spatial distribution of significantly affected and non-affected wheat crops is depicted in Figure 5, highlighting Rohra, Gujarkhan city, and Behr as significant hotspot areas for fluoride-affected crops, while Maira represents a significant cold spot area with minimal fluoride effects detected on crops.

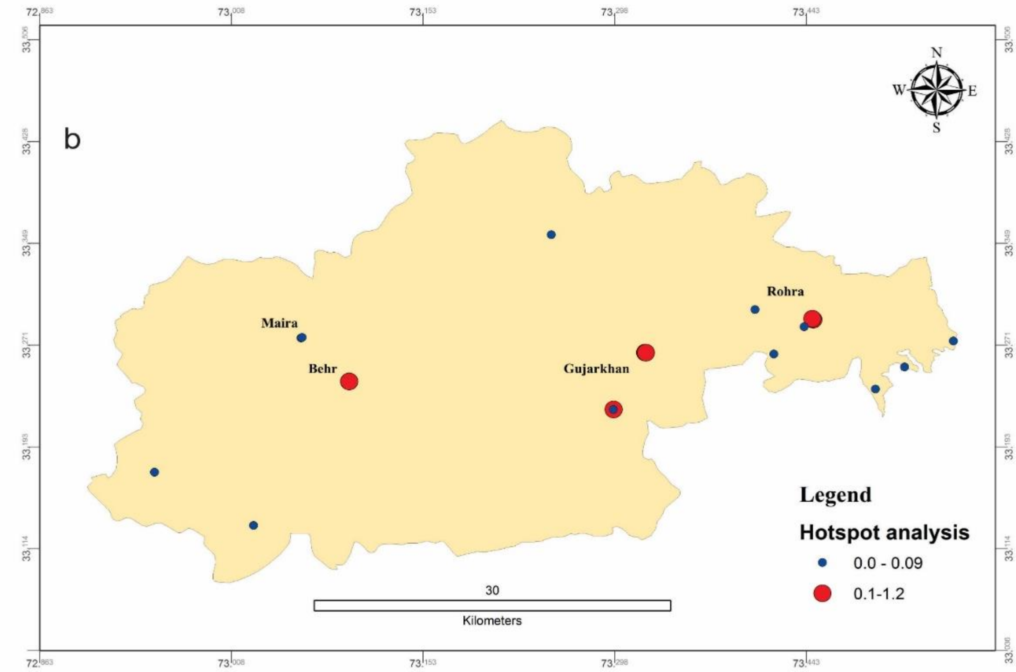

Figure 5. Gi* Model depicting hotspot areas of fluoride effected Wheat in Gujarkhan

The utilization of NDVI as an indicator of vegetation health finds support in studies by Turner et al. [31] and Pettorelli et al. [32], which emphasize the efficacy of remote sensing techniques in monitoring and assessing changes in vegetation. The consistent correlation between NDVI values and on-the-ground observations, as demonstrated in this study, reinforces the robustness of NDVI as a tool for gauging the health of crops in regions undergoing land use changes.

The integration of geographical information systems (GIS) and remote sensing for comprehensive environmental monitoring resonates with the work of Liang et al. [33] and Wang et al. [34]. These studies emphasize the importance of employing advanced technologies for analyzing large-scale environmental changes, providing insights into the spatial dynamics of land use alterations and their consequences.

The current study contributes to a growing body of literature that underscores the complex interplay between urbanization, climate change, industrial emissions, and agricultural outcomes. The integrated findings from various research papers collectively emphasize the need for interdisciplinary approaches to address the multifaceted challenges facing regions experiencing dynamic changes in land use and climate. The synthesis of these research perspectives provides a more holistic understanding of the factors influencing agricultural landscapes and informs the development of sustainable strategies for land management and food security.

4. Conclusions

In conclusion, the findings of this research underscore the intricate interplay between anthropogenic activities, shifting land use patterns, and their consequential impacts on vegetation health and agricultural productivity in the studied region of Gujarkhan, Punjab. The integration of remote sensing techniques, land cover classification, and NDVI analysis has provided valuable insights into the spatio-temporal dynamics of the landscape over the past 15 years.

The discernible reduction in vegetation productivity and health, as evidenced by NDVI values, points to the vulnerabilities of the local ecosystem to changing land use practices. The transition from agricultural practices and settlements to an increased built-up area, coupled with the establishment of cattle pens and poultry farms, highlights the multifaceted influences of climate change, urbanization, and alternative land use decisions by landowners.

Importantly, the study identifies the adverse effects of brick kiln emissions, particularly hydrogen fluoride, on the health of wheat crops in the vicinity. The correlation between elevated fluoride concentrations in soil and wheat leaves and the observed poor health conditions in NDVI results underscores the detrimental impact of industrial activities on agricultural lands. The cessation of wheat cultivation by some landowners in favor of leasing land for brick kilns has exacerbated these effects, contributing to the observed decline in agricultural productivity.

The spatial distribution analysis reveals significant hotspots and coldspots, with Rohra, Gujarkhan city, and Behr emerging as areas significantly affected by fluoride, and Maira exhibiting minimal impacts. These findings emphasize the need for a holistic approach to land use planning, considering the ecological consequences of industrial activities on agricultural lands and the livelihoods of local communities.

As we navigate a landscape marked by shifting land use patterns and increasing urbanization, it is imperative to strike a balance between economic development and sustainable agricultural practices. The study advocates for a nuanced understanding of the environmental implications of industrial emissions, urging policymakers and stakeholders to consider measures that safeguard both economic interests and ecological integrity. Implementing responsible land use policies, promoting sustainable agricultural practices, and monitoring industrial emissions are crucial steps toward mitigating the adverse effects observed in this study and ensuring the resilience of agricultural landscapes in the face of changing environmental dynamics.

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