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Protecting Cultural Heritage with High-Resolution Remote Sensing: A Study on the Ifugao Rice Terraces

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Abstract. This paper explores the protection of cultural heritage using high-resolution remote sensing technology, with the Ifugao Rice Terraces in the Philippines as the study object. By comparing hyperspectral images from different periods, the changes in vegetation cover and soil erosion of the terraces are analyzed, the health status and soil characteristics of the terraces are assessed, and the main factors influencing environmental changes are identified. The results show that the ecological protection efforts for the Ifugao Rice Terraces have achieved some success, but some areas still require attention and timely ecological restoration. The study also integrates Geographic Information System (GIS) technology for comprehensive analysis to enhance the precision and efficiency of protection measures. This paper provides scientific evidence for understanding the spatial distribution and ecological environment of the terraces and offers valuable references for the protection and management of similar terrace areas, demonstrating the important role of high-resolution remote sensing technology in cultural heritage preservation.

Keywords: High-resolution remote sensing; cultural heritage protection; Ifugao Rice Terraces; GIS.

1. Introduction

World Cultural Heritage, designated by the United Nations Educational, Scientific and Cultural Organization (UNESCO) under the Convention Concerning the Protection of the World Cultural and Natural Heritage, represents locations of outstanding universal value to humanity, encompassing both natural and cultural properties. These sites are recognized as the highest standard for cultural preservation and transmission. World Cultural Heritage bears witness to the history and cultural development of human civilization, offering invaluable resources for academic research and education, and holding significant historical, scientific, cultural, and ecological value. However, these heritage sites face severe challenges: damage from natural disasters and global climate change, urban expansion encroaching upon and compromising the integrity of cultural sites, irreversible harm from overdevelopment, tourism pressures, theft and illegal trade, as well as destruction from regional conflicts and wars. Clearly, World Cultural Heritage plays a crucial role in human civilization, and their protection is urgently needed.

The Ifugao Rice Terraces in the Philippines, a distinguished representative of World Cultural Heritage, boast a history spanning over 2,000 years. Situated in Ifugao Province along the Cordillera Mountain range in the Philippines, these terraces were cultivated by the indigenous Ifugao people through long-term adaptation to their natural environment. They form the world's largest man-made irrigation system, reflecting the ingenuity of the local population and possessing significant ecological, cultural, and socio-economic value [1]. The Ifugao people have preserved this unique socio-ecological system through familial and communal inheritance, resulting in a rich ethnic ecological tradition [2]. The terraces not only provide the Ifugao people with their livelihood but also serve as the foundation of their culture. Specific rituals are performed during various stages of labor, such as seed selection, planting, and harvesting. These ancient rituals, some dating back thousands of years, are intended to ensure the healthy growth and bountiful harvest of crops [3], underscoring their important cultural value. However, with the introduction of modern agricultural techniques and the local government's continuous development of tourism in Ifugao, this ancient heritage site faces severe threats from human activities.

Remote sensing technology has broad applications in the protection of ecological environments and cultural heritage. For instance, InSAR technology can be used to detect the geological stability of heritage areas, assessing the risk of geological disasters and enabling the formulation of preemptive measures [4]. Hyperspectral remote sensing imagery can detect changes in vegetation and land use within heritage areas, thus evaluating environmental impacts [5]. Additionally, three-dimensional digital models based on laser scanning and photogrammetry can provide virtual displays and restoration of heritage sites, offering a new method of preservation [6].

This study focuses on the natural agricultural attributes of the Ifugao Rice Terraces, considering the impact of human activities on the terrace environment. By comparing hyperspectral images of the terraces from different periods, we analyze changes in vegetation cover and soil erosion, assess the health status and soil characteristics of the terraces, and identify the primary factors influencing environmental changes. This provides data support and theoretical basis for formulating protection plans for the terraces. Furthermore, by integrating remote sensing data with other sources of data using GIS technology, we perform comprehensive analysis to offer robust support for the management and protection of the terraces, thereby enhancing the precision and efficiency of the analysis.

2. Materials and Methods

2.1. Study Area

The Ifugao Rice Terraces, the highest and largest rice terraces in the world, are primarily located in Banaue and its adjoining areas in Ifugao Province, Northern Luzon (16°56′2.004″N 121°8′12.012″E). With a history spanning over 2,000 years, this region is characterized by high temperatures and abundant rainfall, making it a typical monsoon tropical rainforest climate [7]. Consequently, the water source for the terraces mainly comes from the perennial rainfall of the dense mountaintop forests. These extensive rice terraces feature a complex and comprehensive mountainside irrigation system, including reservoirs, sluice gates, and channels. The surrounding dense forests provide a beneficial barrier and water storage function for the terrace system. Initially, traditional rice varieties were widely planted within the terraces; however, to meet production demands, some terraces have started cultivating modern hybrid rice varieties. These systems complement each other, forming a unique terrace ecosystem. The construction of the Ifugao Rice Terraces mainly relied on the industrious hands and ingenuity of the Ifugao people, symbolizing the diligence and wisdom of the Filipino people. Alongside the development of the terraces, the local people created a rich terrace culture, encompassing daily life, family and marriage, religious beliefs, calendrical knowledge, artistic life, and terrace farming practices [1]. The Ifugao Rice Terraces, with their unique ecological and historical cultural value, have become a significant representative of cultural heritage in the Philippines and the world.

2.2. Data Source

This study selects high-resolution remote sensing images, with data primarily sourced from various remote sensing images and open data platforms, as detailed below:

1. Landsat 8 Imagery: Landsat 8, the 8th satellite in the Landsat series, was launched on February 11, 2013, and includes 11 bands, comprising two thermal infrared bands and one panchromatic band. The images can be accessed through the USGS Earth Explorer website. Multi-temporal images from 2015 to 2024 are chosen to capture the seasonal and annual changes of the Ifugao Rice Terraces.

2. Sentinel-2, developed by the European Space Agency (ESA), consists of two satellites: Sentinel-2A and Sentinel-2B, launched on June 23, 2015, and March 7, 2017, respectively. It carries 13 bands covering visible, near-infrared, and shortwave infrared wavelengths. The Sentinel-2 data can be retrieved and downloaded from the ESA website. The same time range as the Landsat 8 imagery is selected for comparison and data fusion analysis.

The collected data requires image preprocessing. Radiometric correction is applied to Landsat 8 and Sentinel-2 imagery to eliminate atmospheric effects and ensure image comparability. This can be done using the radiometric correction module in ENVI software. To ensure spatial alignment of multi-temporal images, geometric correction is performed using ground control points, utilizing software such as ENVI and QGIS. The Fmask algorithm is used to identify and remove cloud and cloud shadow areas in the images to ensure data quality.

Additionally, for terrain analysis of the Ifugao Rice Terraces area, DEM data is required. DEM data can be obtained from the Earthdata platform. Earthdata, an open data platform under NASA, provides various DEM datasets, including SRTM and GDEM. The necessary DEM data can be searched and obtained using geographic coordinates and time range for subsequent processing and analysis.

2.3. Remote sensing data processing and information extraction

2.3.1. Topographic Feature Extraction.

The DEM data of the target area undergoes processing and analysis. Using ArcGIS, slope and aspect maps are generated to perform slope and aspect analysis. The Ifugao Rice Terraces area is classified based on elevation, slope, and aspect, identifying different topographic units. The impact of slope and aspect on terrace cultivation and soil and water conservation is discussed. Additionally, topographic profiles of the terrace area are drawn to understand the vertical variations in the terrace region. The influence of topographic profiles on terrace layout and farmland management is analyzed. Furthermore, watershed and flow path analyses are conducted for the target area to assess the hydrological characteristics of the terrace area, optimizing the irrigation system [8].

2.3.2. Vegetation Feature Extraction.

To accurately and comprehensively extract vegetation features of the Ifugao Rice Terraces area, multiple vegetation indices can be selected for comprehensive analysis. First, the NDVI is used for an overall assessment. The Normalized Difference Vegetation Index (NDVI) is simple to calculate and can quickly generate vegetation index maps for large areas.

$$NDVI = \frac{(NIR-Red)}{(NIR+Red)} \tag{1}$$

Equation (1) shows the calculation method of NDVI, where NIR is the reflectance in the near-infrared band and Red is the reflectance in the red band. The NDVI value ranges from -1 to 1, with positive values indicating vegetation, and negative values indicating non-vegetation. Higher NDVI values represent healthier and denser vegetation, while lower values indicate sparse or unhealthy vegetation. Based on this, two additional indices, EVI and GNDVI, are selected for further analysis of vegetation features. The Enhanced Vegetation Index (EVI) is less sensitive to atmospheric and soil background effects and can address the saturation problem of NDVI in areas with high vegetation coverage. This makes it very suitable for the Ifugao Rice Terraces' tropical rainforest climate with year-round rainfall and dense vegetation. Its calculation formula is shown in Equation (2), where:

$$EVI = G \times \frac{(NIR-Red)}{(NIR+C_1\times Red-C_2\times Blue+L)} \tag{2}$$

Here, NIR is the reflectance in the near-infrared band, Red is the reflectance in the red band, $Blue$ is the reflectance in the blue band, and G,C_1,C_2 and L are coefficients introduced to account for different environmental conditions: G is the gain factor, typically set to 2.5; C_1 and C_2 are the red and blue correction coefficients, set to 6 and 7.5, respectively; and L is the canopy background adjustment, typically set to 1.

EVI is more sensitive to changes in vegetation cover and can be used to detect subtle changes in vegetation, making it better suited for monitoring crop growth. Additionally, the Green Normalized Difference Vegetation Index (GNDVI), a newer vegetation index, is more sensitive to green vegetation compared to traditional NDVI. It is suitable for detailed assessment of crop health, especially for monitoring crop nitrogen status, and is well-suited for the usage throughout the crop growth cycle in the terraces. Its calculation method is shown in Equation (3), where:

$$GNDVI = \frac{(NIR-Green)}{(NIR+Green)} \tag{3}$$

In contrast to NDVI, GNDVI uses the reflectance in the green band in place of the red band.

Based on the results of different indices, the health status and changing trends of vegetation in the terrace area are comprehensively and accurately analyzed, and management and protection recommendations for the terraces are proposed based on these results.

2.3.3. Soil Feature Extraction.

Similar to the process of vegetation feature extraction, high-resolution hyperspectral satellite imagery can be utilized to extract soil features. The calculation of the Normalized Difference Soil Index (NDSI) in the terrace area can effectively distinguish soil from vegetation, water bodies, and other surface features, aiding in the identification and analysis of different soil types. Equation (4) illustrates the calculation method of NDSI, where:

$$NDSI = \frac{(SWIR-NIR)}{(SWIR+NIR)} \tag{4}$$

Here, $SWIR$ represents the reflectance in the shortwave infrared band, and NIR represents the reflectance in the near-infrared band. Higher NDSI values typically indicate more moist or organic-rich soils, whereas lower values indicate dry or barren soils. Soil moisture content is a critical indicator of soil health. To achieve a more accurate detection of soil moisture variations, the Normalized Difference Water Index (NDWI) is used alongside NDSI. Equation (5) shows the calculation method of NDWI, where:

$$NDWI = \frac{(Green-NIR)}{(Green+NIR)} \tag{5}$$

Here, $Green$ represents the reflectance in the green band, and NIR represents the reflectance in the near-infrared band. NDWI is used to evaluate the distribution of surface water bodies and water content. Compared to NDSI, NDWI is more sensitive to water bodies and can better reflect the soil moisture content in the terraces, thereby detecting the irrigation status of the farmland. By analyzing NDWI in conjunction with NDSI, the utilization and distribution of soil water resources can be precisely monitored, enabling the assessment of soil erosion and water resource management effectiveness in the terrace area.

2.3.4. Historical Change Monitoring.

By utilizing the acquired multi-temporal remote sensing images, various spectral indices of the terrace area can be compared across different periods to effectively reflect changes in soil and vegetation characteristics over the selected timeframe. Additionally, constructing a time series dataset and employing time series analysis methods allows for the examination of change trends and the capture of seasonal variations in the terraces. Statistical methods can be applied to analyze the characteristics of the change areas, assess the causes and impacts of these changes, and subsequently analyze long-term change patterns. This comprehensive analysis provides improved recommendations and strategies for the management and conservation of the terraces.

3. Results and Analysis

3.1. Spatial Distribution and Structural Characteristics of Terraces

Based on the DEM and combined with satellite imagery analysis, Significant elevation changes are observed, ranging from 500 meters to 2000 meters. Most of the terraces are located in mountainous regions, with a few low-lying areas situated on riverbanks at the valley bottoms, which are not suitable for large-scale agricultural development. The terraces are primarily distributed within the elevation range of 800 meters to 1000 meters. These elevations provide ample rainfall and suitable temperature conditions, making them ideal for development and cultivation (Figure 1).

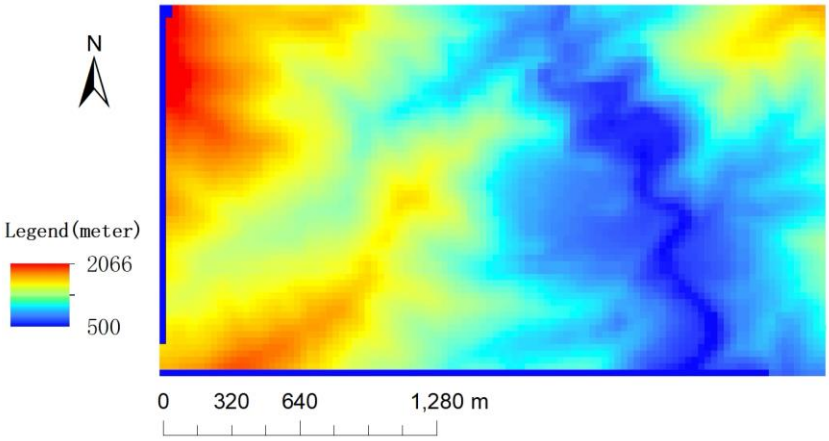

Figure 1. Digital Elevation Model (DEM) of the Ifugao Rice Terraces

By processing the DEM data of the selected area, the slope map is obtained, as shown in Figure 2. The analysis reveals that the slope variation in the Cordillera Mountain range of Luzon Island, where the Ifugao Rice Terraces are located, is extensive, ranging from gentle slopes of 0 degrees to steep cliffs exceeding 60 degrees. This topographical environment is relatively harsh for agricultural development. The terraces are primarily distributed within a slope range of 0 to 30 degrees. Such slopes are not excessively steep, which helps to reduce soil erosion, while also providing a sufficient incline to ensure effective irrigation from the mountaintop downwards.

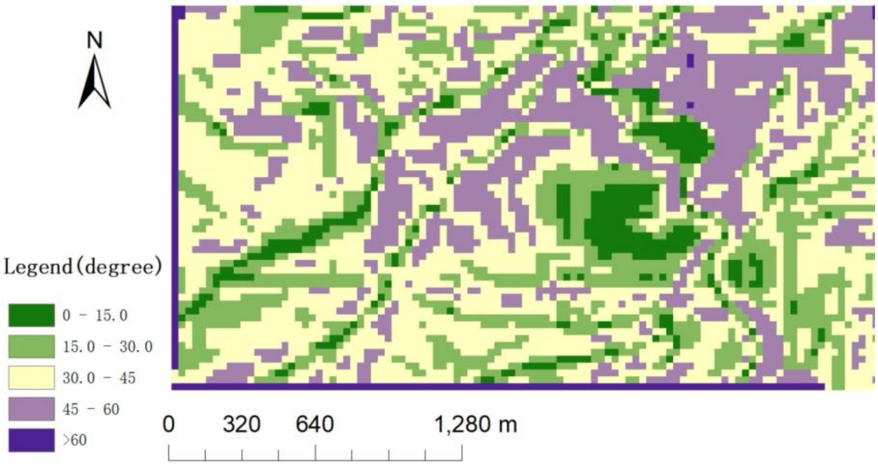

Figure 2. Slope map of the Ifugao Rice Terraces

A representative area of the terraces was selected to create a topographic profile (Figure 3). The profile shows that the terraces were developed according to the mountain terrain, starting on relatively gentle slopes and displaying clear demarcation points. The topographical changes are relatively gradual, maximizing the utilization of land and water resources. Additionally, the terraces exhibit a distinct tiered structure, with a gradual descent that ensures adequate irrigation for all levels of terraces while reducing soil erosion. In summary, elevation and slope are the main factors influencing the distribution and structure of the Ifugao Rice Terraces. These factors work together to ensure the agricultural productivity and ecological stability of the terraces.

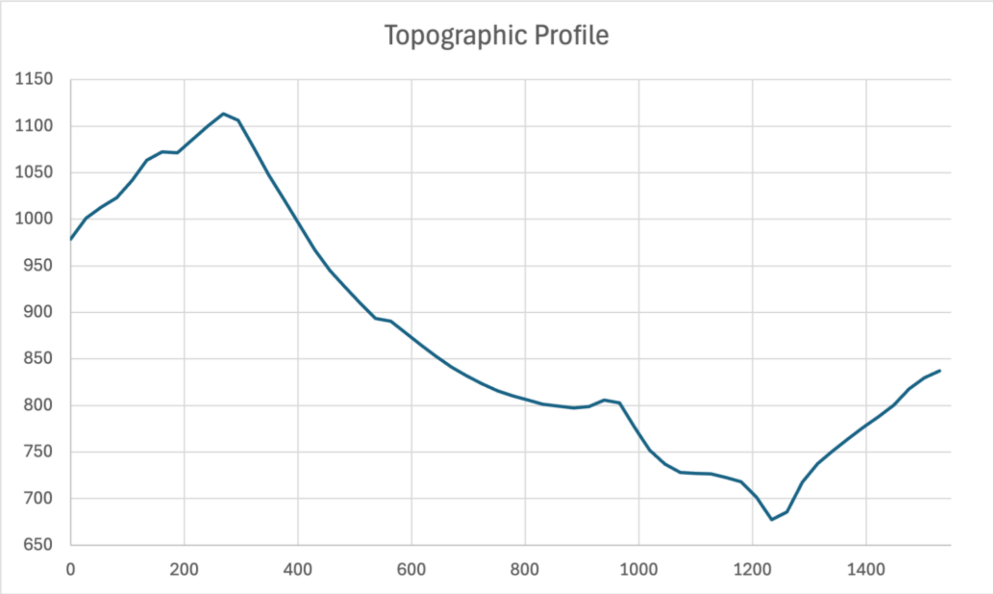

Figure 3. Topographic profile of the terraces

3.2. Vegetation and Soil Characteristics

The NDVI of the selected area was calculated using data from June 2019 as an example (Figure 4). The analysis reveals that the selected area has good vegetation coverage, with high NDVI values primarily distributed in the forest areas surrounding the terraces, with values above 0.7. The NDVI values of the terraces themselves are lower, as agricultural activities impact their vegetation coverage, resulting in a disparity compared to the natural forest areas. The peak NDVI values for the terraces mainly range between 0.4 and 0.6, which can be considered normal growth conditions for farmland vegetation.

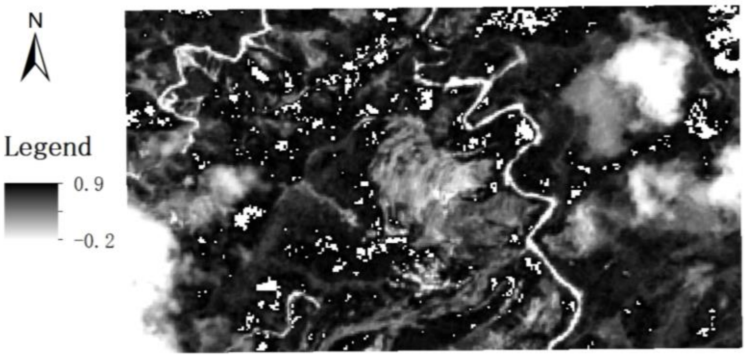

Figure 4. NDVI map of the terrace area

To further assess farmland vegetation health, EVI and GNDVI results were analyzed (Figures 5 and 6). The results indicate that the EVI values in the terrace area mostly range between 0.3 and 0.5. The distribution of GNDVI is similar to that of EVI, indicating that the leaf area index of the vegetation is lower than that of very healthy vegetation. The photosynthetic efficiency of the vegetation is relatively good, but it may be slightly limited by factors such as mild water stress or nutrient deficiency. Additionally, the peak values of GNDVI are slightly lower than those of EVI, as GNDVI is more sensitive to changes in vegetation water content and nitrogen levels. The lower peak values suggest that the health condition of the vegetation in the terrace area is somewhat suboptimal. Furthermore, a small portion of the terraces show significantly lower vegetation indices compared to the surrounding environment, with values around 0.2, indicating incomplete vegetation cover in these areas. This could be attributed to tourism development activities or natural disasters.

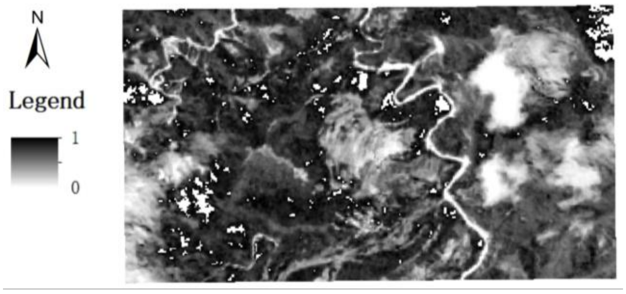

Figure 5. EVI map of the terrace area

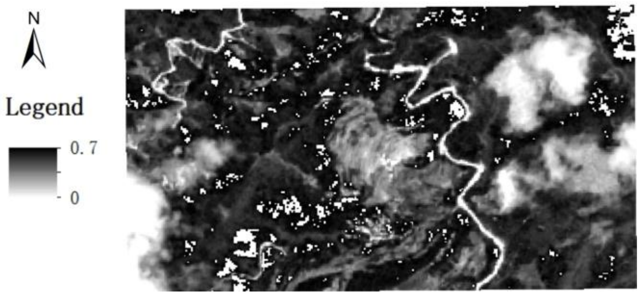

Figure 6. GNDVI map of the terrace area

The soil in the terrace area was analyzed using NDWI and NDSI values, as shown in Figures 7 and 8. The analysis reveals that the NDSI values in the forest areas are mostly negative. This is due to the strong reflectance of vegetation in the near-infrared band and lower reflectance in the shortwave infrared band. High NDSI values, which are negative, are concentrated in the terrace areas, indicating that the soil in these areas has a high moisture content, which is suitable for rice growth. Additionally, the NDWI values in the terrace areas show good responsiveness, confirming that the water resource management in the terrace areas is effective and soil erosion is minimal. However, some parts of the terraces have positive NDSI values, indicating bare soil areas with certain soil issues. These areas require attention to ensure the health of the land.

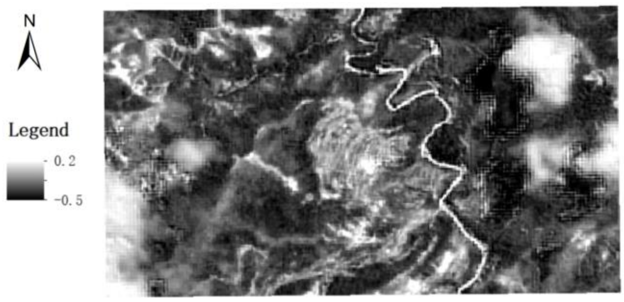

Figure 7. NDSI map of the terrace area

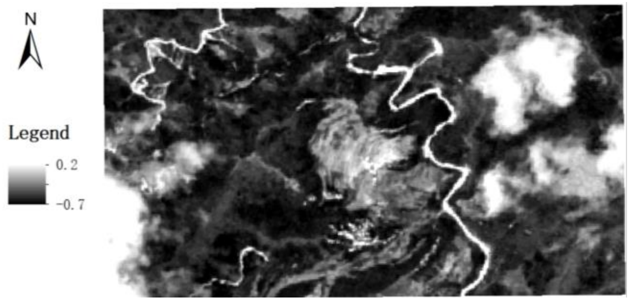

Figure 8. NDWI map of the terrace area

In summary, the overall vegetation in the Ifugao Rice Terraces area is relatively healthy, and the soil conditions are favorable, indicating that the ecological protection efforts in the Ifugao Rice Terraces have been effective. However, there are some plots with low vegetation coverage and poor soil health that require close attention and timely ecological restoration to maintain the sustainable development of the terraces.

3.3. Historical Change and Chronological Analysis

By combining historical records with modern remote sensing imagery, the historical changes in the Ifugao Rice Terraces were analyzed. The results show that after the Ifugao Rice Terraces were designated as a World Cultural Heritage site, this ancient human landmark quickly became a global tourist destination. However, with the continuous development of tourism and the outflow of the rural population, the Ifugao Rice Terraces have been degrading over the past twenty years [9]. During this period, the Ifugao Rice Terraces area experienced significant land use changes, characterized by an increase in buildings and the expansion of non-agricultural land. To address this issue, international organizations such as FAO, along with the Philippine and Ifugao governments, established an Agricultural Cultural Heritage Learning Center in the Ifugao Rice Terraces and drafted the Ifugao Region Tourism Development Guidelines, among other measures, to protect the Ifugao Rice Terraces.

Remote sensing images reveal that since 2015, the average NDVI value in the Ifugao Rice Terraces area has been increasing annually, and vegetation coverage has gradually improved. Although some terraces remain abandoned and in poor condition, the ecological environment of the terraces has significantly improved. Additionally, analyzing images from different periods each year shows that NDVI values exhibit regular changes corresponding to the rice growth cycle, peaking during the rice maturity period from April to June each year. This indicates that the growth rhythm of rice is normal and in good condition. Overall, the conservation efforts for the Ifugao Rice Terraces have played a crucial role and made significant contributions to preserving this valuable cultural heritage. Continuous monitoring and further measures are needed to ensure the sustainable development of this precious cultural heritage.

4. Conclusion

This study analyzes remote sensing data of the Ifugao Rice Terraces area, revealing the spatial distribution, structural characteristics, and comprehensive features of vegetation and soil conditions. The results indicate that the distribution of terraces in this region exhibits a clear spatial pattern. Through the analysis of various remote sensing indices, it was found that the vegetation health in this region is generally good, and the soil moisture is relatively high. However, some areas also face ecological issues such as low vegetation coverage and abandoned terraces, which require close attention. This study not only provides scientific evidence for understanding the spatial distribution and ecological environment of the Ifugao Rice Terraces but also offers valuable references for the protection and management of similar terrace areas, demonstrating the important role of high-resolution remote sensing technology in cultural heritage preservation. The use of remote sensing technology enables more effective monitoring and management of heritage sites, enhancing the efficiency of conservation efforts. Moreover, the research results can guide local governments and communities in formulating scientific policies and measures for the protection, restoration, and sustainable development of the terraces. Future research should further integrate field survey data to validate and supplement remote sensing analysis results. Additionally, exploring the application of higher resolution and multi-temporal remote sensing data can facilitate more detailed monitoring of the dynamic changes in the terraces, ensuring their sustainable development.

Despite the significant role of remote sensing and GIS technology in the protection of the Ifugao Rice Terraces, there are limitations. Due to the tropical location of the Ifugao Rice Terraces, abundant annual rainfall results in severe cloud cover in remote sensing images, making some short-duration images unusable and disrupting the continuity of monitoring, leading to incomplete data. Additionally, the terraces' unique land environment, with its high soil moisture content, can sometimes result in confusion with water bodies during water resource monitoring. Furthermore, high-resolution remote sensing satellites represent the latest technological advancements of the 21st century. For the Ifugao Rice Terraces, a cultural heritage site with over 2000 years of history, historical tracking and comparison often cannot fully leverage the benefits of these technologies, requiring integration with other materials to more effectively identify small-scale agricultural changes and minor vegetation variations. Moreover, remote sensing imagery primarily provides information on natural and environmental aspects, possibly failing to comprehensively cover the complexity and variability of socio-economic factors in the study.

As remote sensing technology continues to advance, improvements in spatial resolution, spectral resolution, and temporal resolution will provide stronger support for the monitoring and protection of cultural heritage sites. Higher resolution images can help more accurately identify specific features of different objects, enabling more targeted conservation plans. The continuous enhancement of satellite networks makes global all-weather monitoring possible, significantly enriching data and helping to gain a more comprehensive understanding of heritage sites. Additionally, with the development of big data technology, software like Google Earth, which integrates satellite imagery, GIS technology, and big data, greatly lowers the threshold for technology use, allowing non-professionals to utilize remote sensing and GIS technology to obtain desired products.

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