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The Application of Remote Sensing-Based Technology in The Field of Tea Identification and Distribution

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Abstract. As a significant economic crop cultivated and consumed globally, the yield and quality of tea are directly correlated with the stability and growth of the international tea market. The application of remote sensing technology enables the precise monitoring of tea plant growth, the real-time assessment of soil moisture and nutrient distribution, and the identification of pests and diseases. This technology facilitates the implementation of scientific management practices, thereby enhancing the yield and quality of tea. This paper begins by providing an overview of the remote sensing data sources that can be used for tea monitoring. It then selects two newer remote sensing methods and discusses their potential applications to tea plantations in West Lake, Hangzhou and Bangladesh. There are numerous categories of remote sensing data sources, including satellite remote sensing data and unmanned aerial vehicle (UAV) low-altitude imagery. In the initial case study, the HRNetV2 base deep learning model was employed to detect Longjing tea in West Lake, Hangzhou. The technique integrated satellite remote sensing data with a machine learning model, resulting in a relatively low error rate. The second case study delves into assessing Bangladesh's suitability for sustainable tea land production, leveraging an expert system with satellite remote sensing data and Geographic Information Systems (GIS). This integrated research methodology presents a holistic, precise, and trustworthy framework indispensable for propelling the progression of the tea industry within the country's context.

Keywords: Tea; Satellite Remote Sensing; Machine Learning; GIS.

1. Introduction

Tea is an important cash crop, widely planted and consumed around the globe. The yield and quality of tea are directly related to the stability and development of the global tea market. As a major tea-producing country, China has the largest tea planting area and the highest tea production in the world. In 2019, China accounted for 45.15% of the global tea production, making the development of the tea industry a crucial aspect of China's agricultural economy [1].

However, Næsset and other scholars have demonstrated that the tea tree is cultivated in mountainous or hilly regions, where the environment is complex and variable [2]. This, coupled with the inherent limitations of traditional monitoring methods, makes it challenging to achieve large-area, high-precision monitoring of tea plantations, which in turn gives rise to significant management challenges in this sector. The advancement of mapping remote sensing technology has enabled the rapid acquisition of high-resolution aerospace remote sensing imagery within a specified time frame. Consequently, in recent years, the utilization of remote sensing technology for the monitoring of tea tree growth and the enhancement of tea quality has been extensively investigated. Duan et al. investigated the impact of the new red-edge band of Gaofen-6 on crop monitoring [3]. Ren et al. utilized Gaojing-1 satellite remote sensing imagery to identify tea plantations, offering a unique perspective on agricultural monitoring. Concurrently, Das, Noguchi, and their collaborators introduced innovative indices including the Normalized Moisture Difference Index (NDMI), Normalized Vegetation Index (NDVI), and Leaf Area Index (LAI), along with yield mapping, derived from Sentinel-2 satellite data, significantly advancing the capabilities of satellite-based agricultural assessment. This was done by using remote sensing in combination with the standardized precipitation index (SPI) to assess the drought conditions in tea plantations [4].

This paper initially presents a summary of the sources of remote sensing data for tea monitoring, before selecting two relatively new remote sensing methods and discussing their application to tea plantations in West Lake, Hangzhou and Bangladesh.

2. Remote Sensing Data Sources in the Field of Tea Monitoring

The majority of studies in this field employ satellite remote-sensing data as a data source for research purposes. Zhang et al. proposed that a multi-source remote sensing approach was employed to monitor the changes in the area of tea plantations. The remote sensing data utilized in this study are a long-term series of remote sensing data images, including those from Sentinel-2 and Landsat series satellites. The Landsat series satellites include Landsat 8, Landsat 5, and Landsat 7, and the data are sourced from the Earth Observation Sharing Programme system of the Institute of Space and Astronautical Information Innovation of the Chinese Academy of Sciences (http://ids. The data are obtained from the Earth Observation Sharing Programme system of the Institute of Space and Astronautical Information Innovation of the Chinese Academy of Sciences (http://code.ac.cn/index.aspx), with a spatial resolution of 30 m and a revisit period of 16 d. The data from Sentinel-2 satellites are employed to monitor the change in tea plantation areas based on multi-source remote sensing. Sentinel-2, which sources its data from the European Space Agency's (ESA) Copernicus Data Centre, is the second satellite of the European Space Agency's Global Monitoring for Environment and Security (GMES) program. It was launched on 23 June 2015 and is equipped with a Multispectral Imaging System (MSI), which a two-axis MSI powers. It is the second satellite of the ESA GMES programme, launched on 23 June 2015. It carries the MSI, which consists of two satellites and can acquire information in 13 bands, with a width of up to 290 km, 10 m resolution, 10-day revisit period. In their study of the Xihu Longjing tea plantation using satellite remote sensing, Yang et al. employed a range of satellite data, including JL01, GF-6, Sentinel-2, Landsat8, and others [5]. They primarily utilized high-resolution remote sensing images, complemented by low- and medium-resolution multispectral images. To delineate the tea planting area, they employed multi-period images of different seasons.

3. Application of HRNetV2-Based Deep Learning Model for Recognition of West Lake Longjing Tea in Hangzhou

The study employed the JL01 high-resolution remote sensing satellite as the primary data source, complemented by medium- and low-resolution multispectral remote sensing images. Additionally, the comprehensive features of the Hangzhou West Lake Longjing tea plantation area were considered. The instance segmentation method and the improved HRNetV2 (High-resolution net) were utilized for this purpose. A novel convolutional neural network (CNN) architecture for machine learning, proposed by Microsoft Research Asia in 2019, was employed for the preliminary automatic extraction of the West Lake Longjing tea plantation. This CNN, which is based on deep learning and features multi-resolution remote sensing data fusion, is referred to henceforth as the new HRNetV2 model. The fine spatial distribution and area statistics of the tea plantation were subsequently obtained by combining the automatic extraction results with manual interpretation [5].

3.1. Technical Approach

In investigating the precise identification of Longjing tea planting areas through remote sensing, the researchers employed a multi-dimensional sample collection and optimization strategy. This diversified approach exemplified the scientific and systematic nature of the experimental design. Specifically, the following four aspects of the data analysis approach are worthy of note:

(1) Reliance on existing data and use of prior results: the researchers initially utilized the extant Longjing tea feature distribution data in Hangzhou as the basis for their sample, a strategy that

conserves resources and guarantees the geographic accuracy of the samples. This approach effectively integrates and utilizes existing research resources, thereby establishing a robust foundation for subsequent model training.

(2) A combination of manual visual interpretation and field study was employed. The researchers select samples through manual visual interpretation for features with relatively simple characteristics. While this approach is time-consuming, it ensures the accuracy and relevance of the sample selection. Concurrently, for features with intricate characteristics that are challenging to ascertain, the researchers employed the field manual inspection method, which is an exhaustive and meticulous approach that guarantees the superior quality and dependability of the sample data.

(3) The deployment of multispectral feature classification technology: Furthermore, the researchers employed multispectral feature classification technology in conjunction with the abundant spectral data present in the low- and medium-resolution images, thereby facilitating the extraction of additional tea raster products. Incorporating this technical tool not only expands the sample source but also enhances the diversity and comprehensiveness of the sample data, thereby providing a richer and more complex dataset for model training.

(4) The new HRNetV2 model demonstrates a robust capability. Once the sample acquisition and optimization process is complete, the researchers employ the newly trained HRNetV2 model to segment and extract the images, thereby obtaining the automatic segmentation results for the West Lake Longjing features. This outcome serves to illustrate the model's capacity for robust recognition in intricate contexts, while also substantiating the efficacy of the previously outlined sample acquisition and optimization approach.

3.2. Sample Set of West Lake Longjing

The primary focus of the novel HRNetV2 model is the type, quality, and quantity of samples. In this study, a total of 800 samples were collected and optimized in four ways, including 200 tea samples and more than 600 additional samples. Firstly, the samples are selected based on the distribution results of existing Longjing tea features in Hangzhou. Secondly, the samples are selected by manual visual interpretation for features with simple characteristics. In the case of features with complex characteristics that are difficult to determine, a manual inspection is conducted in the field. Thirdly, the multi-spectral feature classification technique is employed to extract tea raster products by combining the rich spectral information of the medium- and low-resolution images. Fourthly, the new HRNetV2 model is utilized to segment and extract the images by utilizing the trained new HRNetV2 model, and the new HRNetV2 model is employed to extract the tea samples. The objective is to utilize the model to segment and extract the image, thereby obtaining the automatic segmentation results of West Lake Longjing features.

3.3. Results and Analyses

The results of the remote sensing identification of the new HRNetV2 model of Xihu Longjing tea plantation are presented in Figure 1 [5]. Subsequently, the automatic extraction results are corrected to a certain extent through manual judgment, meeting the requirements for individual patch and coverage accuracy. In the event of uncertainty regarding the results of the automatic extraction, a second field verification was conducted, the findings of which were incorporated into the existing samples, thereby enhancing the diversity of the sample set and optimizing the accuracy of the recognition process.

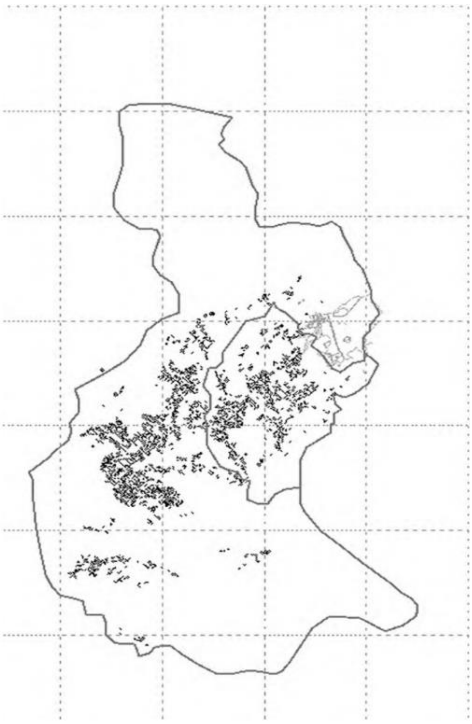

Fig. 1 Remote sensing identification of the new HRNetV2 model in the Xihu Longjing tea plantation [5]

The boundaries of the tea plantations identified by the new HRNetV2 model are delineated, encompassing residential areas and forests on the hills. The model's accuracy is primarily based on the JL01 high-resolution remote sensing satellites, with the addition of medium and low-resolution multispectral remote sensing images. The area of the West Lake Longjing tea plantation, as identified by satellite remote sensing, was found to be 1,400.63 hm^2. This is in comparison to the area of the tea plantation in West Lake District, as recorded in the Statistical Yearbook of the Hangzhou Municipal Bureau of Statistics for 2022, which was 1,524.2 hm^2. The area of the tea plantation identified by remote sensing was less than 123.65 hm^2, representing a discrepancy of approximately 12%. The accuracy rate of identification was found to be close to 92%. The margin of error associated with remote sensing identification is constrained by the resolution of satellite data. This results in the omission of scattered, minute tea plantation patches and the inability to identify some tea land situated beneath tall trees. Secondly, the satellite image is affected by the presence of multiple objects with varying spectra, which can lead to misclassification. This is because the same type of features may exhibit dissimilar colors and textures, or different features may display similar colors and textures. Thirdly, the satellite image is affected by the presence of multiple objects with varying spectra. Thirdly, there is still a degree of uncertainty in the assessment of the suspected tea plantations. Despite confirming the suspected patches through field investigation, misjudgment of some patches remains inevitable [6].

4. Integrating an Expert System, Satellite Remote Sensing, and Geographic Information System for Recognition of Tea Production in Bangladesh

4.1. Area of Study

This study focuses on the Sylhet Division, situated in the northeastern quadrant of Bangladesh. The Sylhet Division encompasses four districts. The Sylhet Division is comprised of four districts: Habiganj, Moulvibazar, Sunamganj, and Sylhet, which are further subdivided into 38 sub-districts. The populace of the targeted locale approximates 10 million individuals, comprising less than 7% of Bangladesh's overall demographic. This research domain spans latitudes ranging from 23°58′N to

25°12′N and longitudes extending from 90°56′E to 92°30′E. Geographically, it is demarcated to the north, east, and south by the Indian states of Assam, Meghalaya, and Tripura respectively, while Dhaka, Chattogram, and Mymensingh divisions flank it to the southwest and west. The total landmass encompasses 122,984 hectares, with an elevational profile not exceeding 335 meters. The monsoon season imparts ample precipitation, creating a favorable environment conducive to the cultivation of tea, a key agricultural activity in the region [7].

4.2. Research Methodology

Land use and land cover (LULC) data, derived from Sentinel-2 datasets with a resolution of 20 meters, were employed to assess the suitability of land for a range of purposes, including forestry, high-quality agricultural land, tea plantations, human settlements, wetlands, and water bodies. This analysis yielded crucial insights into the spatial distribution of land cover types and their respective potential applications. The study employed the NDVI, a well-established vegetation index correlated with numerous biophysical parameters and crop indices, to measure the phenological differences in vegetation across the region.

Tea plants exhibit remarkable adaptability, thriving across a vast elevational spectrum, ranging from sea level to approximately 2,200 meters above sea level. [8]. The highland areas, which are typically free from waterlogging, offer favorable conditions for tea cultivation. Precipitation is another crucial factor. The study area receives an annual rainfall of between 1000 and 2300 mm, which is deemed optimal for tea cultivation. Precipitation data, procured from the Bangladesh Agricultural Research Council, underwent meticulous processing utilizing the mean rainfall figures spanning the period from March through November.

The temperature is a crucial factor in tea cultivation, with the optimal range during the growing season being between 18°C and 25°C [9]. These conditions ensure that tea plants are able to grow satisfactorily. The slope is another crucial factor, as slopes between 25° and 5° are deemed optimum for tea cultivation, while slopes exceeding 35° or flat terrain are unsuitable. Furthermore, loamy soils are especially conducive to tea plant growth, yielding leaves rich in polyphenols, caffeine, and amino acids.

The pH level of the soil is also of great importance, with tea plants demonstrating optimal growth in soils with a pH range of 4.5 to 5.5 [10]. The pH can be maintained or optimized through the application of nitrogenous fertilizers, including urea and ammonium sulfate, which enhance yield. It is similarly crucial to ensure adequate soil drainage, as tea plants are unable to survive in conditions of waterlogging. Adequate drainage has been demonstrated to increase yields by 30-35% [11], thus representing a crucial factor in cultivation. The hilly regions of north-eastern Bangladesh, particularly in Sylhet, are characterized by brown soils, which are conducive to tea cultivation.

The proximity of the site to roads is another factor that should be taken into consideration, as the minimization of transportation costs is essential for the supply of inputs and the distribution of tea. Furthermore, the Sylhet division is traversed by several major rivers, including the Kushiyara, Surma, Manu, and Khowai, as well as numerous smaller rivers. The proximity of these rivers offers logistical advantages for transporting fertilizers and processing tea leaves.

4.3. Results and Analyses

This research presents a methodology leveraging GIS, satellite remote sensing, and the Analytic Hierarchy Process (AHP) to identify optimal land parcels for tea cultivation in Bangladesh. Among the evaluated criteria, precipitation emerged as the paramount factor (accounting for 23% of the total weight), closely followed by temperature (15%) and drainage (19%), with other factors contributing the remainder. AHP-based weighted overlay analysis determined that merely 41,460 hectares (3.37% of the total area) qualified as highly suitable, while an additional 110,767 hectares (9.01%) were deemed moderately suitable. The majority of the study area, totaling 613,367 hectares (49.87%), was assessed as marginally suitable. Conversely, a substantial 464,246 hectares (37.75%) were found to be unsuitable for tea farming. With regards to the distribution of existing tea estates, 58% were located in moderately suitable zones, 23% in highly suitable regions, 18% in marginally suitable areas, and less than 1% in low suitability zones. These findings on land suitability for tea cultivation in Bangladesh have profound implications for decision-making processes to foster sustainable land management practices and boost production efficiency. Consequently, it becomes apparent that land suitability assessments constitute a pivotal step in deciphering future land use patterns and production dynamics within the tea sector, ultimately facilitating the prosperous growth of the tea industry in Bangladesh.

5. Conclusion

China is a major tea producer and exporter, with tea cultivation playing an important role in its agricultural economy. The traditional monitoring methods are inadequate for achieving high-precision monitoring of tea plantations on a large scale, due to the complex and changing nature of the environment in which they are situated. In recent years, the development of surveying and mapping remote sensing technology has enabled the rapid acquisition of high-resolution aeros1pace remote sensing images within a specified time window, which represents a significant advancement in the accurate monitoring of tea cultivation. This study presents two illustrative examples of tea identification based on remote sensing.

In the initial case study, the tea plantation at West Lake in Hangzhou was employed as a case study. The detection of the tea plantation area was conducted based on Gaojing-1 satellite remote sensing images, and NDMI, NDVI with LAI. Furthermore, the study developed yield maps utilizing Sentinel-2 satellite imagery, offering a spatial visualization of tea productivity. These yield maps were subsequently integrated with the Standardized Precipitation Index (SPI) to evaluate the extent of drought conditions affecting tea plantations comprehensively. In the monitoring of the Longjing tea plantation area, the improved new HRNetV2 model was employed for the precise identification of the spatial distribution of West Lake Longjing tea plantations. The novel HRNetV2 model employed a range of techniques to gather and enhance over 800 samples, comprising 200 tea samples and over 600 additional samples. The utilization of high-resolution images is of significant importance for a multitude of visual tasks, including target detection and pose recognition. Manual visual interpretation was also employed to select the samples, with the primary objective being the field examination of suspected patches that were manually verified to exhibit color and texture characteristics analogous to those observed in tea plantation areas. For instance, upon field examination, suspected patches that appeared granular in the image were subsequently identified as sparse woodland. The technique of multi-spectral feature classification is employed, combining the rich spectral information of low and medium-resolution images. This not only broadens the sample source but also enhances the diversity and comprehensiveness of the sample data, thereby providing a richer and more complex dataset for model training. There is a notable enhancement in classification accuracy relative to the conventional supervised classification approach.

The second case study aimed to identify an appropriate methodology for the cultivation of suitable land in Bangladesh, based on satellite remote sensing and GIS. Land use and land cover data constructed from Sentinel-2 at a resolution of 20 meters were employed to examine forests, tea gardens, and high-agricultural land with wetlands for rice cultivation in Bangladesh. The classification process was conducted using ArcGIS, followed by the NDVI. The latter has the advantage of being highly efficient, providing information on the cover and health of vegetation over a wide range of scales, and allowing continuous tracking of changes in vegetation through dynamic monitoring. Furthermore, it applies to a wide range of environments and domains. The greatest impact was attributed to precipitation (23%), followed by temperature (15%), drainage (19%), and other factors. Of the 135 tea gardens, 58% were situated in areas of moderate suitability, 23% in high suitability, 18% in mild suitability, and less than 1% in areas of unsuitability. Furthermore, a hierarchical analysis was employed, which is both operational and interpretable. By decomposing the problem into multiple levels, it is possible to consider the impact of multiple factors, thereby enhancing reliability and accuracy while reducing the potential for subjective interference.

Authors Contribution

All the authors contributed equally and their names were listed in alphabetical order.

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