Geospatial Assessment of Agricultural Productivity in Jefferson Davis Parish: A Focus on Rice Cultivation

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Abstract

The variability in rice yields due to fluctuating environmental conditions poses a significant challenge for agricultural productivity in Jefferson Davis Parish, Louisiana. This study addressed this problem by conducting a comprehensive geospatial assessment of rice cultivation in the region. The research utilized advanced remote sensing and GIS techniques to evaluate the spatial distribution of critical environmental factors, such as precipitation patterns, soil moisture, and vegetation health, and their influence on rice yields. By analyzing Landsat and spectral indices such as the Normalized Difference Vegetation Index (NDVI), Moisture Stress Index (MSI), and historical climate and agricultural records, the study pinpointed areas within the parish particularly vulnerable to yield variability. Crop yield data from USDA and USA weather data validated the satellite data and provided deeper insights into local farming practices. Employing Pearson's correlation using R, the study's findings revealed a negative correlation (–0.55) between NDVI and MSI such that a deficit in moisture content will affect the health of the rice farms. The study recommended that decision-makers and stakeholders focus on precision agriculture and sustainable water management practices to enhance resilience and ensure long-term food security in Jefferson Davis Parish.

1.0 Introduction

Globally, rice (*Oryza sativa*) is a staple food, feeding more than half of the world's population and serving as a primary dietary component in Asia, Africa, and Latin America. Rice has the potential to contribute to achieving the Global Sustainable Development Goal 2 (SDG 2) which focuses on achieving zero hunger by the end of 2030. In 2023, global rice production reached a record high, estimated at approximately 518.1 million tons (milled basis), supported by extensive cultivation across Asia, where over 90% of rice is produced and consumed (USDA ERS, 2023) and (FAO, 2023). India and China are the world's largest producers, accounting for roughly half of this total output, with India as the leading exporter (FAO, 2023).

In the United States, rice production primarily occurs in six states: Arkansas, California, Louisiana, Mississippi, Missouri, and Texas. In 2023, total U.S. rice production was projected at approximately 220.5 million hundredweight (cwt), marking a significant increase of nearly 38% from the previous year due to expanded acreage and favorable yields (USDA ERS, 2023). Arkansas is the leading rice-producing state, accounting for around 50% of U.S. production, followed by California and Louisiana. Arkansas's rice farmers benefit from yield and acreage advantages, with total production reaching about 106.5 million cwt in 2023. Despite recent droughts affecting its crop size, California contributed significantly, especially in medium- and short-grain rice. The U.S. rice industry contributes to domestic food supplies and supports global food security through exports. The United States is a major exporter of rice, shipping to markets in Northeast Asia, Central America, and the Caribbean. In 2023, U.S. rice exports were projected to reach 27 million cwt, with trade primarily involving long-grain rice varieties (USDA ERS, 2023)

Louisiana State in the USA is the nation's third-largest crop producer of staple foods such as Rice, soybeans, and others. The state's warm climate, abundant water, and water-retaining clay soil are well-suited for growing rice. Rice production in southwestern Louisiana, particularly in Jefferson Davis Parish, has a rich history dating back to the late 19th century. The industry expanded rapidly, with

Louisiana becoming the leading rice-producing state by 1889 (Coclanis, 2015). The region's rice production was revolutionized through mechanization and large-scale farming techniques, transforming the prairie lands (Coclanis, 2020). In 2009 Louisiana had approximately 456,000 acres of rice, with long-grain varieties dominating 89% of the acreage (Salassi and Deliberto, 2013). However, the industry faces challenges from invasive pests like the Mexican rice borer, which has been expanding its range in Louisiana since 2008, potentially causing significant damage to rice crops. Despite these challenges, the rice industry in Jefferson Davis Parish and surrounding areas remains a strong backbone of Louisiana's agricultural economy.

Rice production faces numerous challenges across different regions. Common issues include plant diseases, pests, and weeds, which reduce yields and crop quality (Fahad et al., 2019) and (Norton, 2010). Limited access to improved seeds, fertilizers, and modern farming equipment hinders productivity, particularly for small-scale farmers (Atsriku, 2020). Insufficient capital and poor access to credit further constrain farmers' ability to invest in their operations (Karlan, 2014). Environmental stresses, such as water scarcity and climate change, threaten rice production (Wassmann et al., 2009). In China, declining arable land, labor shortages, and increasing demand for high-quality rice varieties present further challenges (Redfern et al., 2012). Researchers recommend developing high-yielding, stress-resistant rice varieties, improving crop management practices, and strengthening extension systems.

Rice production in Jefferson Davis Parish, Louisiana, encounters multiple challenges, notably regarding water availability, climate variability, and salinity concerns. Approximately 60% of rice fields rely on irrigation from deep wells, while the remaining 40% depend on surface water due to its lower energy costs compared to deeper sources (LSU AgCenter, 2023). This reliance on water sources poses difficulties during drought conditions, where rainfall in Louisiana fluctuates impacting water access for irrigation (Merem et al., 2012). During droughts, an added problem arises as saline water from the Gulf of Mexico encroaches on freshwater systems, which affects the freshwater rice crop's ability to thrive. For example, recent damage to locks along the Gulf Intracoastal Waterway allowed more saline water to flow north, further intensifying salinity issues in irrigation sources and risking yield reductions in Jefferson Davis Parish and neighboring areas (LSU AgCenter, 2023). Furthermore, the impacts of climate change, including extreme weather events, exacerbate these conditions. Hurricanes and tropical storms have been causing damage to rice fields and other farmlands since it is prevalent in Louisiana. Hurricanes lead to damage from growth stages and disrupt storage, creating additional uncertainties for local rice producers (Sivakumar,2020).

USA weather data shows Jefferson Davis Parish is a severely dry area (**Figure 1**) characterized by slow crop planting and growth, creating temporary water deficits. These dry spells can limit soil moisture, essential for healthy crop development, and may reduce overall yields if irrigation resources are inadequate (USA Weather Data, 2023). Conversely, excessive rainfall can lead to waterlogging, where soils become overly saturated. This impedes root oxygen intake, stunts plant growth, and, in severe cases, causes crop loss. These wet periods can also affect harvesting schedules, and soil structure, and increase the risk of diseases and pests that thrive in moist environments (Drought.gov,2023). Considering all environmental, physical, and natural factors affecting rice production, the study conducted a comprehensive geospatial assessment of rice cultivation in the region. This objective helped to analyze the spatial distribution of vegetation health and productivity across the region. This involves utilizing remote sensing indices, such as NDVI (Normalized Difference Vegetation Index) and MSI (Moisture Stress Index), to identify areas where rice crops thrive against those experiencing stress. By examining these spatial patterns, the study aims to understand how environmental factors such as precipitation variability, soil moisture, and drought impact rice yields.

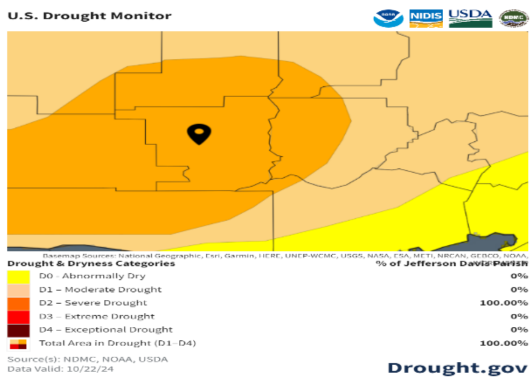

Figure 1.0: U.S Drought Monitor of Jefferson Davis Parish Source: drought.gov 2023

2. Methods

2.1 Study Area

Jefferson Davis Parish (**Figure 2**) was one of the last incorporated parishes in the state of Louisiana, with a population of approximately 31,435 and a total land area of 652 square miles. The parish has a young population, with about 26.2% below 18 years and 14.8% aged 65 or older. The median household income is around $42,716, with a poverty rate of 16.9%, highlighting both economic strengths and challenges within the parish (LSU AgCenter, 2023). Agriculture is the largest economic sector in Jefferson Davis Parish, particularly rice farming, which utilizes over 80,000 acres and contributes significantly to Louisiana's total rice production. Key agricultural commodities include soybeans, crawfish, sugarcane, hay, turf, and beef cattle, totaling $156 million. These commodities are central to the parish's economy, providing both employment and export income. Jefferson Davis Parish in Louisiana features diverse soils ideal for the region's major agricultural activities, especially rice cultivation. The parish is part of the Lower Mississippi River Valley, where soils are largely composed of alluvial deposits from centuries of river sediment, making them nutrient-rich and suitable for crops requiring high water retention, such as rice. The clay and silt loam textures typical in these alluvial soils are advantageous for water-intensive crops, as they hold moisture well, essential for rice cultivation in flooded and rotated crawfish-rice fields (LSU AgCenter, 2023).

Figure 2*: Map of the study area*

2.1 Data Processing and Analysis

Landsat 8 & 9 level 2 satellite data for the years 2020 and 2023 were acquired from the United States Geological Survey (USGS) to locate rice farmlands within the parish and measure the vegetation health and moisture content of these rice farmlands. To reduce the rate of atmospheric error and seasonal variation, the Landsat images with maximum cloud cover were already set as <10%, which made the images free from atmospheric noise. Landsat satellite data scene with <10% indicates no need for additional geo-rectification or image-to-image registration for image pre-processing (Kafy et al., 2019). The acquired Landsat was supported and validated with Google Earth Imagery. The Landsat data sets were subjected to ArcGIS, and QGIS for image processing and indices calculation. Information on the images acquired from the USGS online data repository with a spatial resolution of 30m.

2.2 Normalized Difference Vegetation Index

Normalized difference vegetation index (NDVI) is an indicator used to identify the photosynthetic activity of land cover. The Normalized Difference Vegetation Index (NDVI) is a key metric in remote sensing that measures vegetation health and density by analyzing how visible and near-infrared light is absorbed and reflected by plant surfaces. NDVI values range from -1 to +1, where higher values (e.g., 0.3 to 0.8) indicate healthy, dense vegetation, and lower values suggest bare soil, water, or stressed vegetation.

$$NDVI = \frac{NIR+Red}{NIR-Red}$$

For this study, NDVI was used to monitor and map the spatial distribution of vegetation health across rice fields. This helped in identifying areas of high productivity against zones experiencing stress, such as drought-affected or nutrient-poor regions.

2.2 Moisture Stress Index (MSI)

The Moisture Stress Index (MSI) measures the water stress level in vegetation by analyzing the reflectance of near-infrared (NIR) and shortwave infrared (SWIR) light from plant surfaces. MSI is calculated as the SWIR to NIR reflectance ratio, with higher MSI values indicating greater moisture stress, often due to water scarcity, low soil moisture, or drought conditions. The index is particularly useful in agricultural studies, as it enables early water stress detection, allowing for timely intervention to mitigate crop loss and maintain productivity.

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

MSI is directly relevant to exploring rice farmlands in Jefferson Davis Parish because it complements NDVI by specifically focusing on water availability in plants. This is an important factor for rice, which requires high water input. By combining MSI with NDVI, the study gained a dual perspective on vegetation health and water stress, providing a clearer understanding of areas that may be underperforming due to water shortages. Higher MSI values suggest that the soil lacks sufficient water to support healthy plant growth, leading to stress conditions for crops. As moisture stress increases, vegetation health typically declines, often reflected in lower NDVI values. This can result in stunted growth, wilting, and lower overall vigor in plants.

2.3 Secondary Data

Secondary data from Drought.gov, a U.S. portal managed by the National Integrated Drought Information System (NIDIS), provides timely and comprehensive information on drought conditions across the United States. Drought.gov integrates data from sources such as the U.S. Drought Monitor and NOAA's National Centers for Environmental Information (NCEI), covering various indicators, including drought severity, duration, precipitation deficits, soil moisture, and more. Crop yield data was sourced from and total production for specific crops, providing a solid basis for trend analysis. In Jefferson Davis Parish, rice yield data from USDA offered a detailed view of productivity levels and patterns between 2020 to 2023, enabling an understanding of how varying environmental conditions, including drought, affect crop output.

2.4 Geostatistical methods

In this study, Pearson correlation was developed using RStudio Version 22 to explore the relationship between environmental factors such as the health of rice farmlands (NDVI), soil water content (MSI), and farmland size affect crop yield per annum. Pearson correlation is effective for assessing the strength and direction of linear relationships between continuous variables, making it ideal for examining variables like NDVI (vegetation health), MSI (moisture levels), and yield interact in rice cultivation as used by other authors in similar fields (Kumar et al., 2020; Mohamed et al., 2019; Thamaga-Chitja et al., 2016)

The equation is given as:

$$r = \frac{\sum(xi - x)\,(yi - \bar{y})}{\sqrt{\sum(xi - x)2\,\sum(yi - \bar{y})2}}$$

USDA's National Agricultural Statistics Service (NASS) which provides annual crop yield data across multiple regions, detailing the productivity of essential crops like rice. USDA's data includes information on acreage, yield per acre,

Where r is the correlation coefficient of the linear relationship between the variables x and y. x_i is the value of the x-variable in a sample x is the mean of the values of the x-variable y_i – the values of the y-variable in a sample. $\bar{y}$ is the mean of the values of the y-variable. The results of the correlation will be between -1 and + 1. Where +1 indicates a perfect positive correlation, -1 indicates a perfect negative correlation and 0 indicates no correlation.

3.0 Results and Discussion

This section presents the findings and discussion of a geospatial assessment conducted on rice cultivation in Jefferson Davis Parish, focusing on the years 2020, 2021, 2022, and 2023. The analysis utilizes key indices such as the Normalized Difference Vegetation Index (NDVI) and Moisture Stress Index (MSI) to evaluate vegetation health and moisture levels across rice farmland. Accompanying these indices, crop yield data provides a comprehensive understanding of agricultural productivity in the parish. The relationships between these variables are explored through correlation analysis, highlighting important insights into the factors influencing rice production.

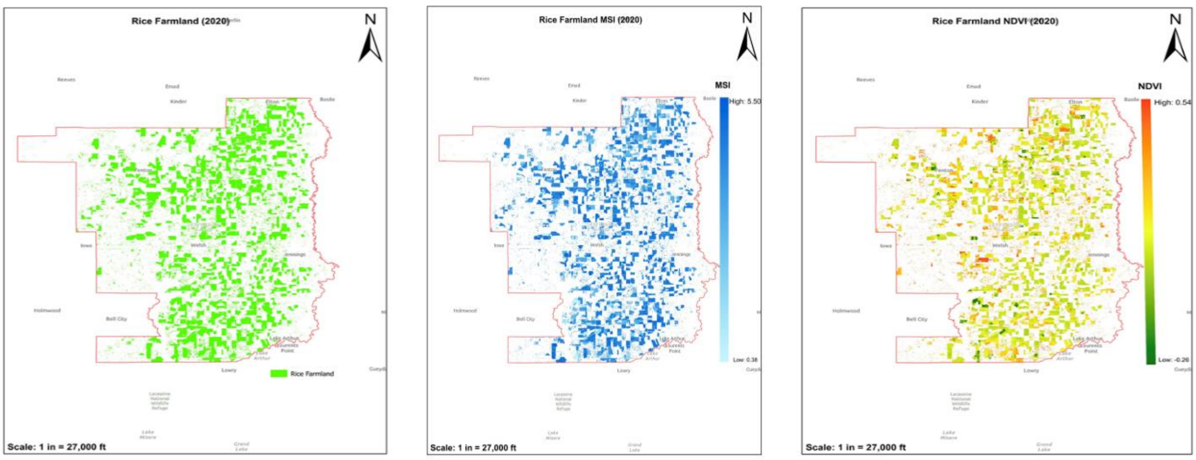

Figure 4: Rice farmland, MSI, and NDVI for 2020

The analysis of rice cultivation in Jefferson Davis Parish from 2020 to 2023 highlights the interconnectedness of vegetation health, moisture availability, and crop yield. In 2020 (**Figure 4**), the NDVI map revealed high vegetation health in several areas, with values reaching up to 0.54, indicating robust rice plants thriving under optimal water and nutrient availability conditions. This was complemented by the MSI map, which showed high moisture levels (up to 5.50), suggesting effective irrigation practices that supported healthy vegetation. The rice farmland distribution further

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illustrated that these healthy plants were in areas rich in agricultural activity, leading to a reported crop yield of 3.39 tons per hectare. However, in 2021 (**Figure 5**), while the NDVI remained relatively high, the yield dropped slightly to 3.34 tons per hectare although rice farmland increased, suggesting that factors beyond plant health influenced productivity. The MSI showed adequate moisture levels, indicating that water availability was not the primary issue. Instead, this disparity may be attributed to competitive resource use among the healthy plants or management practices affecting yield. In 2022 (**Figure 6**), both NDVI and MSI values showed declines, with NDVI dropping to 0.49 and MSI to 1.58, leading to a further reduction in yield to 3.12 tons per hectare. This decrease in vegetation health and moisture stress points to environmental challenges that may have impacted rice production, highlighting the critical need for effective farming practices and water management.

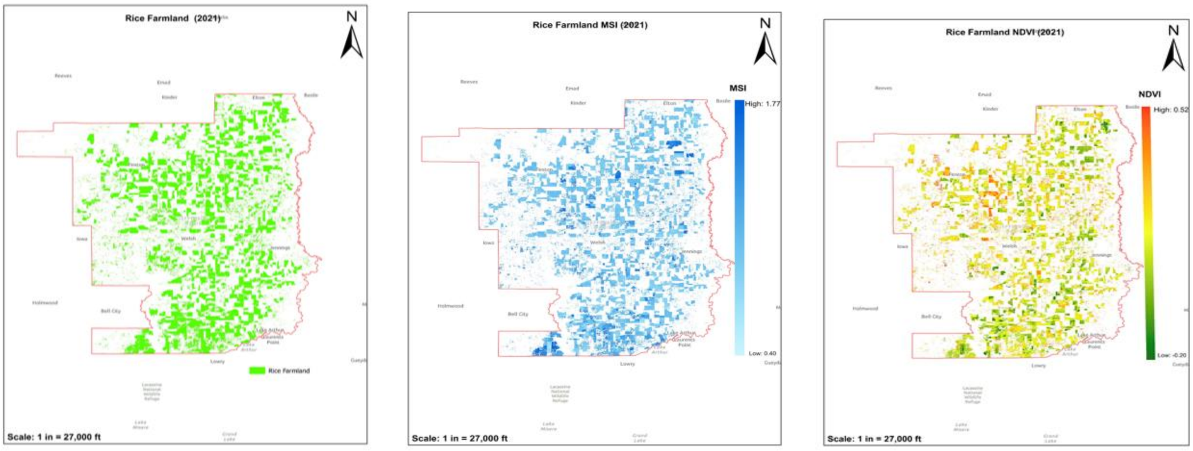

Figure 5: Rice farmlands, NDVI, MSI for 2021

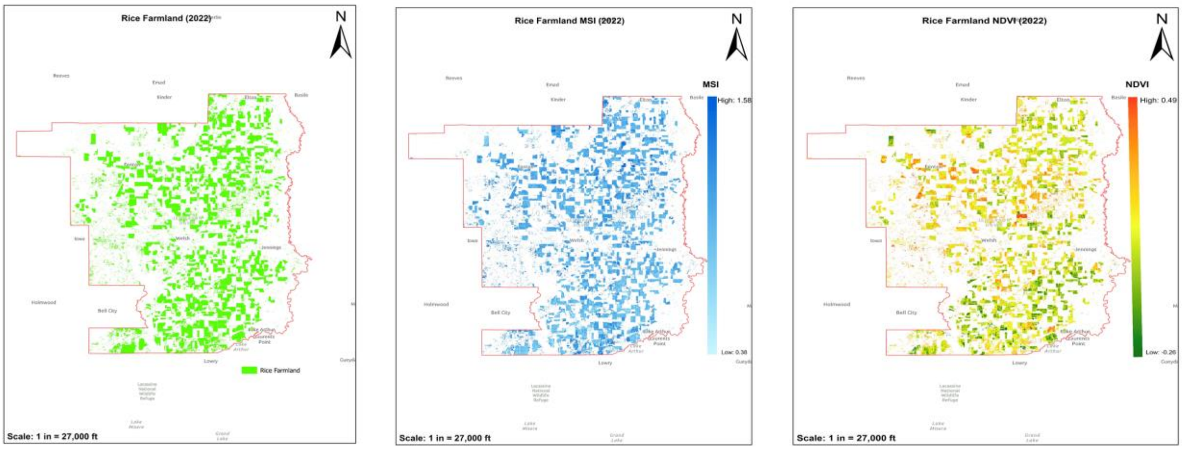

Figure 6: Rice farmland, NDVI, and MSI 2022

Although there was a reduction in farmland in the Southwestern part of the parish in 2023 (**Figure 7**), the NDVI slightly improved to 0.50, and the MSI increased significantly to 3.50, reflecting enhanced moisture conditions that were likely beneficial for plant growth. The yield recovered to 3.28 tons per hectare, indicating that better moisture management contributed positively to rice production. This progression illustrates how improved moisture levels can enhance vegetation health and influence yield. The Pearson correlation values explained the relationships between various factors affecting rice cultivation in the Parish.

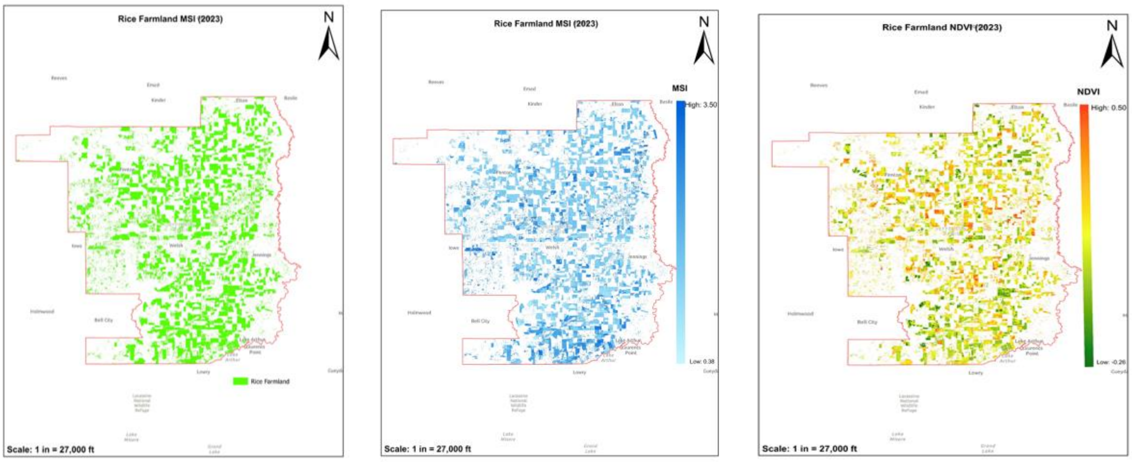

Figure 7: Rice farmland, MSI, and NDVI for 2023

The negative correlation of -0.94 (**Figure 8**) between yield and NDVI suggests a complex interaction where healthier vegetation does not necessarily lead to higher rice production. This finding is consistent with Huang and Han (2014) whose study found a strong negative correlation between NDVI and crop yield. This finding indicates that even with robust plant health, other underlying issues, such as resource competition or environmental stressors, may hinder yield potential. For instance, in areas with high NDVI values, plants may compete for limited nutrients and water, ultimately impacting the overall yield. The weak positive correlation of 0.22 between yield and MSI highlights that while moisture levels may contribute to improved rice production, the relationship is not strong enough to be a primary predictor of yield.

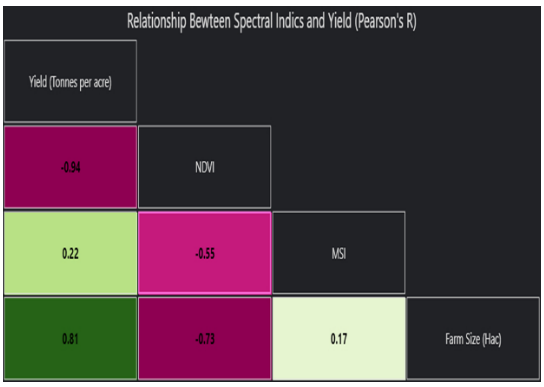

Figure 8: Pearson correlation values of spectral indices and yield

This suggests that while moisture is essential for rice growth, it alone cannot account for yield variations. Farmers may need to consider additional factors, such as soil health and management practices, alongside moisture levels to enhance their production outcomes. This finding is consistent with (Jayasree et al., 2008) whose study found a positive correlation between MSI and maize crop yield. The relationship between the Moisture Stress Index (MSI) and the Normalized Difference Vegetation Index (NDVI) is reflected in a moderate negative correlation of -0.55, indicating an inverse relationship between these indices. This shows that as moisture stress increases, vegetation health tends to decline. Higher MSI values signify that plants are experiencing stress due to insufficient moisture, leading to lower NDVI values, which represent less vigorous plant growth. This relationship highlights the importance of moisture in maintaining healthy vegetation. Monitoring moisture levels is essential for farmers, as areas with high MSI may require improved irrigation practices or soil management to enhance plant health. The relationship between NDVI and MSI further reveals that vegetation health will likely suffer during droughts or periods of low water supply. Furthermore, the significant negative correlation of -0.73 between NDVI and farm size indicates that larger farms may face challenges in maintaining vegetation health. This could be attributed to management difficulties in larger areas, where resources may be spread thin, making it harder to monitor and care for crops effectively. On the other hand, smaller farmers may have more manageable plots that allow for better oversight and potentially healthier plants.

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4. Conclusion

In conclusion, this study explores the relationship between the Moisture Stress Index (MSI) and the Normalized Difference Vegetation Index (NDVI) in understanding rice cultivation dynamics in Jefferson Davis Parish. By examining NDVI and MSI over the years 2020 to 2023, it was evident that healthier vegetation, as indicated by higher NDVI values, does not always translate to increased yields, particularly in the context of competition for resources and environmental stressors. The moderate negative correlation between NDVI and MSI explains the importance of adequate moisture for sustaining plant health. In contrast, the weak positive correlation between yield and MSI highlights that moisture levels contribute to but do not solely determine crop productivity as farmers can rely on irrigation regardless of how dry the land may be. The moderate negative correlation observed between these two indices reveals that as moisture stress increases, vegetation health declines, adversely affecting crop productivity. The classification of the area as a severely dry region indicates that farmers are likely to face significant challenges such as prolonged drought in sustaining healthy rice crops. This persistent moisture stress could lead to decreased yields and threaten the viability of rice farming in the future. To combat these issues, farmers need to adopt innovative water management practices, improve irrigation techniques, and implement strategies that enhance soil moisture retention. By prioritizing the interplay between MSI and NDVI, stakeholders can develop adaptive approaches that ensure the resilience of rice farms and secure food production in an increasingly challenging environmental landscape.

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