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Multi-Sensor Image Fusion for Improved Delineation of Aquaculture Ponds: A Comparative Study

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Abstract

Recognizing the environmental impact of aquaculture, a study was conducted to investigate the feasibility of generating aquaculture data using ResourceSat LISS-IV and PAN data in a section of coastal Andhra Pradesh, southern India. The study involved database preparation, including georeferencing and radiometric normalization, on-screen visual interpretation of spaceborne multispectral and multitemporal data, and the creation of area statistics.

The ResourceSat LISS-IV data enabled the identification of areas where aquaculture is practiced, while the LISS-IV and PAN-merged data facilitated the detection of individual aquaculture ponds due to improved spatial resolution. Between 1986 and 2001, the area under aquaculture expanded significantly.

The study aimed to assess the potential of various image fusion techniques, namely:

i. Hue-Intensity-Saturation (HIS),
ii. Principal Component Analysis (PCA),
iii. Brovey transformation,
iv. Cubic spline wavelet transformation,
v. Multiplicative transformation, and
vi. High-pass filter (HPF) transformation,

for delineating salt-affected soils in the Kaikalur area of Andhra Pradesh using data from the Indian Remote Sensing Satellite (IRS-ID) Linear Imaging Self-Scanning Sensor (LISS-IV) and Panchromatic sensor data.

The results indicate that, compared to commonly used approaches like IHS transformation, wavelet transformation provides more accurate delineation of salt-affected soils. Furthermore, IHS and HPF transformations have been found to outperform PCA transformation in terms of accuracy and performance.

Keywords: Aquaculture; LISS-IV; PAN-data; Image Fusion

Introduction

Aquaculture, the farming of aquatic organisms such as fish and shellfish, accounts for approximately a quarter of the world's total fish supply and is expected to become increasingly important as the global population continues to grow. The East Coast of India, particularly West Bengal (traditional bheries), Andhra Pradesh, Odisha, and Tamil Nadu, is a major hub for brackish water aquaculture. On the West Coast, Kerala dominates the traditional paddy-shrimp culture system, followed by Karnataka and Goa.

The rapid expansion of coastal aquaculture has significant socioeconomic and environmental impacts, including the salinization of groundwater and agricultural lands, as well as the loss of natural resources and ecosystem services. Additionally, copper and barium concentrations in freshwater have been observed to be higher than in brackish waters.

Chemical elements were found to be more abundant in brackish water pond soils compared to freshwater pond soils. Effluents discharged from prawn farms contained high concentrations of sulfides, nitrites, and ammonia. The accumulation of sulfur in older ponds was primarily due to the precipitation of iron pyrite in anaerobic soil layers. Furthermore, significant phosphorus accumulation was observed in older ponds where high doses of fertilizers were applied.

To mitigate these environmental concerns, integrated planning and management within the framework of sustainable coastal zone management should promote practices that are technically feasible, commercially viable, environmentally sustainable, and socially acceptable.

In recent years, many tropical and subtropical countries have witnessed rapid growth in shrimp and prawn farming. However, this expansion has faced setbacks due to disease outbreaks and increasing awareness of the environmental and social consequences of shrimp farming. Effective shrimp farm inventory and monitoring are essential tools for decision-making in aquaculture development, covering aspects such as regulatory compliance, environmental protection, and revenue collection. Given that shrimp farms are often located in remote areas, their identification and monitoring must be prioritized as part of the government's aquaculture development policy.

Despite the growing significance of aquaculture, there remains a lack of reliable and timely data on the nature, extent, spatial distribution, and temporal patterns of degraded lands, particularly those affected by aquaculture. Such data are crucial for effective reclamation and management. The objective of this study was to assess:

i. The feasibility of using IRS-1C/1D LISS-IV and PAN data to determine the type and extent of aquaculture.
ii. The impact of aquaculture activities on agricultural land.

Detection of Aquaculture / Wetlands

Initially, aerial photographs were used to identify wetlands. A seasonal color-infrared snapshot provides sufficient detail to delineate wetland areas as small as 0.5 hectares and 20 meters in width. The use of high-altitude color-infrared images to document surface water boundaries was explored by Carter and Stewart (1977).

In Bangladesh, both black-and-white and infrared color aerial images have been utilized to delineate and monitor the spatial extent of shrimp farming (aquaculture) zones (M. Abdus Shahid et al., 2008). Additionally, multispectral data from the Multispectral Scanner System (MSS) and Thematic Mapper (TM) aboard the Landsat satellite series, as well as the Multispectral Linear Array (MLA) aboard SPOT-1, were employed to detect shrimp aquaculture clusters. Md. Abdus et al. (2008) observed an expansion of shrimp farming areas into paddy fields while inventorying and monitoring shrimp cultivation using aerial photographs, Landsat MSS, and SPOT data.

Vibulsresth et al. (1993) used temporal LANDSAT data to identify a 1.49% decrease in mangrove coverage in Thailand between 1991 and 1992, primarily due to the expansion of shrimp aquaculture. Similarly, Venkataratnam et al. (1997) analyzed temporal satellite data over coastal Andhra Pradesh, southern India, for the years 1973, 1985, 1990, and 1992, revealing a consistent increase in prawn farming areas.

Tripathi et al. (2000) demonstrated that Landsat TM data could effectively distinguish between active and abandoned shrimp aquaculture sites in Thailand.

Role of Remote Sensing:

Spectral Reflectance Pattern of Water

The ability to identify water bodies using remote sensing data requires a thorough understanding of their spectral response patterns. The energy-matter interactions of water in the visible spectrum are more complex than those of other natural surfaces. The energy reflected from a water body can originate from its surface, suspended particles, or bottom materials.

Water bodies absorb nearly all incident radiation in the near-infrared and middle-infrared regions of the spectrum. Consequently, in the reflective infrared portion of the spectrum, water bodies exhibit significantly lower reflectance than vegetation or soil. Jensen et al. (2000) analyzed data from a high-resolution airborne multispectral scanner system over a swampy area along the Savannah River. Additionally, pre-dawn thermal infrared images were used to document flooded and non-flooded conditions (D.S. Negri and Shines, 1985).

The typical absorption features of water bodies were utilized to identify them using multispectral Landsat-MSS/TM and SPOT-MLA observations (Moore and North, 1974). However, detecting water bodies within dense forests using optical sensor data is challenging due to vegetation cover. In areas with minimal vegetation or during dormant/leafless seasons, visible and infrared imagery can effectively map water distribution.

Microwave sensor data has also been used for water body detection in forests. In the microwave spectrum, open water acts as a specular reflector, producing a very low backscatter signal, whereas dry and flooded vegetation generate medium and strong return signals, respectively. Due to limited canopy penetration at shorter wavelengths, L-band radar systems have proven effective in detecting water spread or flooding within forests. Studies have shown that HH-polarized C-band radar systems can detect forest flooding even in spring when trees have no leaves.

To create a sub-canopy flood boundary map, Gesch (1990) combined SAR data from Shuttle Imaging Radar (SIR-B) with tidal surface information, generating a sub-canopy Digital Terrain Model (DTM). Toyra et al. (2000) demonstrated that combining Radarsat SAR data with SPOT Multispectral Linear Array (MLA) images significantly improved flood mapping accuracy in the Peace-Athabasca Delta in northeastern Alberta, Canada.

Remote Sensing (RS) and Geographic Information Systems (GIS) have been widely used for detecting and monitoring water quality (Carper et al., 1990; Lillesand, 1990).

Study Area

The study's objectives were realised in the neighbourhood of Kaikalur town in Krishna district, coastal Andhra Pradesh, southern India, extending between 15° 53' 53" and 16° 05' 03" N latitude and 80° 53' 05" to 81° 03' 57" E longitude (Figure-1). The majority of the test site was formerly used for paddy farming before being converted to aquaculture ponds. As a result, it's a good test location for researching the effects of aquaculture on soil qualities.

Database

To delineate and monitor temporal changes in the spatial extent and distribution patterns of aquaculture, ResourceSat-1 LISS-IV digital data and CartoSat PAN data were utilized. Additionally, LISS-IV, PAN data, and PAN-merged digital datasets were employed to analyze aquaculture practices in specific regions in greater detail.

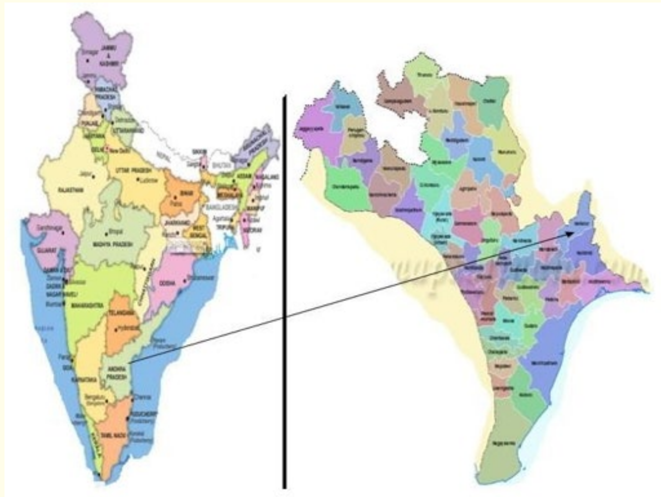

Figure 1: Test Site.

Approach

In the approach section, we will discuss about various image fusion techniques and delineation of aquaculture ponds:

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In this section, we discuss various image fusion techniques and the delineation of aquaculture ponds.

Various Image Fusion Techniques

Image fusion enhances spatial and spectral resolution by integrating images from different sensors. The resolution merge feature allows the combination of images with different spatial resolutions (Price et al., 1987). Fusion can be applied to intra-sensor images (e.g., SPOT Panchromatic with SPOT XS) or inter-sensor images (e.g., SPOT Panchromatic with Landsat TM). A key advantage of image fusion is that it preserves thematic information from multiband raster images (Chavez et al., 1988).

However, image fusion has limitations. For example, fusing AVHRR imagery (1,100 m pixels) with SPOT Panchromatic (10 m pixels) will not yield an AVHRR image with 10 m resolution (Chavez et al., 1983). Various image fusion techniques are available in ERDAS IMAGINE, with the wavelet transform being notable for enhancing spectral quality without improving spatial resolution.

Wavelet Transform (Zhou et al., 1998)

The panchromatic band is decomposed into four components:

- LL - Low-resolution approximation component.
- LH - Horizontal wavelet coefficients.
- HL - Vertical wavelet coefficients.
- HH - Diagonal wavelet coefficients.

In multispectral images, the low-resolution component is replaced with one of the spectral bands, and this process continues until all bands are converted. The altered bands undergo a reverse wavelet transform to generate the fused multispectral image.

Multiplicative Fusion

This technique multiplies all multispectral bands with the panchromatic band, increasing correlation and altering spectral characteristics.

Brovey Transformation

Developed to address the limitations of the multiplicative method, the Brovey technique normalizes all multispectral bands before multiplying them with panchromatic data. However, both Brovey and Multiplicative techniques prioritize spatial over spectral information.

Intensity-Hue-Saturation (IHS) Fusion

This method transforms three multispectral bands from RGB to IHS color space, where the panchromatic band replaces the intensity component. The modified IHS image is then transformed back to RGB. While effective for single-sensor data, results are less accurate for multi-temporal or multi-sensor datasets.

Principal Component Analysis (PCA)

PCA converts correlated variables into an uncorrelated linear combination of the original data, creating a new feature space for analysis. The first principal component is often replaced by panchromatic data before applying an inverse PCA transformation to restore the multispectral image. Unlike Brovey and IHS, PCA is not limited to three bands.

High-Pass Filter (HPF) Fusion

The spatial resolution ratio between panchromatic and multispectral images determines the size of a high-pass convolution kernel. This kernel filters high-resolution input data, which is then merged with all multispectral bands. The final fused image undergoes a linear stretch to match the mean and standard deviation of the original multispectral data. HPF fusion is effective for multi-sensor and multi-temporal datasets.

Delineation of Aquaculture Ponds

Aquaculture ponds, characterized by their water content and structured shape, are identifiable in satellite imagery through distinct spectral response patterns. In LISS-IV images, aquaculture ponds appear in various shades of blue, while croplands are visible in different shades of red (Figure 3).

However, due to similar spectral responses, distinguishing prawn farms from fishponds is challenging. Differentiating these two is crucial for environmental management because:

- ***Fish farming*** uses freshwater.
- ***Prawn farming*** relies on brackish water, which increases soil salinity and degrades groundwater quality.

Since prawn ponds are typically narrow and elongated compared to fish ponds, an attempt was made to classify them based on their shape. The dataset was used to digitize aquaculture pond boundaries, as their bunds are clearly visible in LISS-IV and PAN-merged images (Figures 2 & 3).

By accurately delineating prawn cultivation areas, mitigation measures can be implemented to prevent further land degradation and protect agricultural productivity.

Analyses and comparisons

The comparisons of the different fusion techniques were made visually.

Statistical comparison

	Brovey	*HPF*	*IHS*	*Multiplicative*	*PCA*	*Wavelet*
PAN	90.14	92.16	98.48	98.31	90.63	80.32

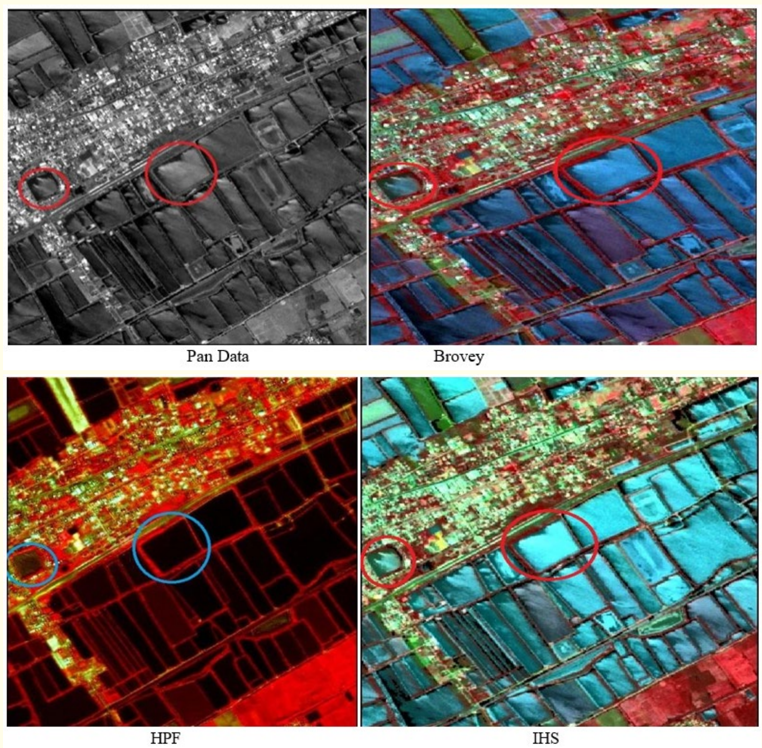
Table 1: Correlation between pan data and different fused Techniques.

	LISS-IV Brovey	*LISS-IV HPF*	*LISS-IV HIS*	*LISS-IV Multiplicative*	*LISS-IV PCA*	*LISS-IV Wavelet*
LISSIV-1	33.553	46.9	35.44	37.939	27.18	45.83
LISSIV-2	31.928	26.46	59.81	28.038	31.78	35.28
LISSIV-3	37.081	5.66	61.09	13.603	21.56	19.886

Table 2: Standard Deviation by subtracting LISS-IV bands from different fused techniques.

Visual comparisons

The visual comparison is made among the pan data and other fused techniques in which Wavelet transformation has shown good accuracy compared to other techniques.



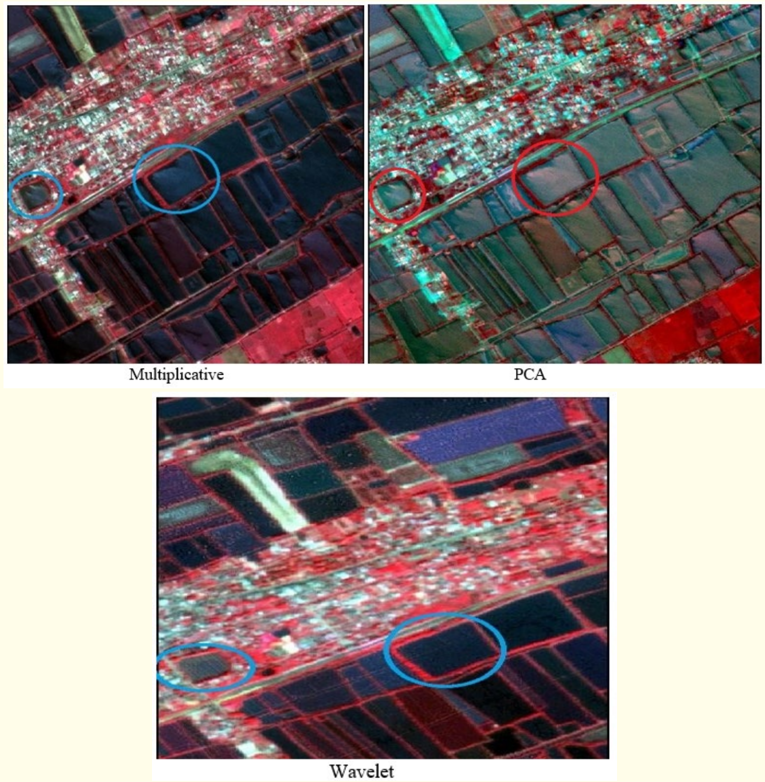
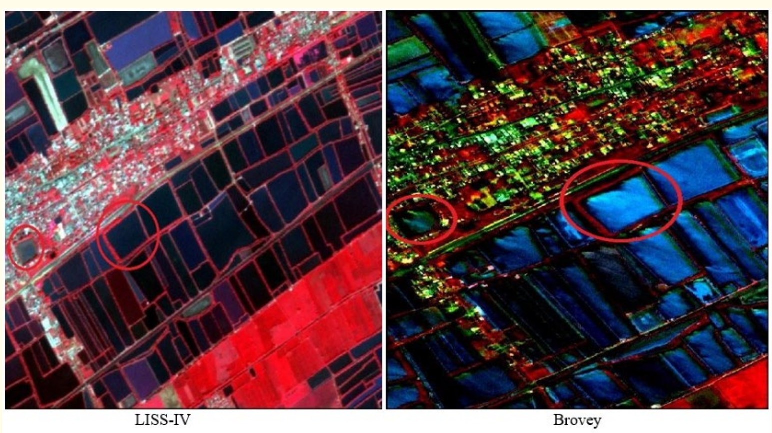


Figure 2: Visual Comparison among the different techniques using PAN data.

Visual comparison among the LISS-IV data and Fused Image-PAN



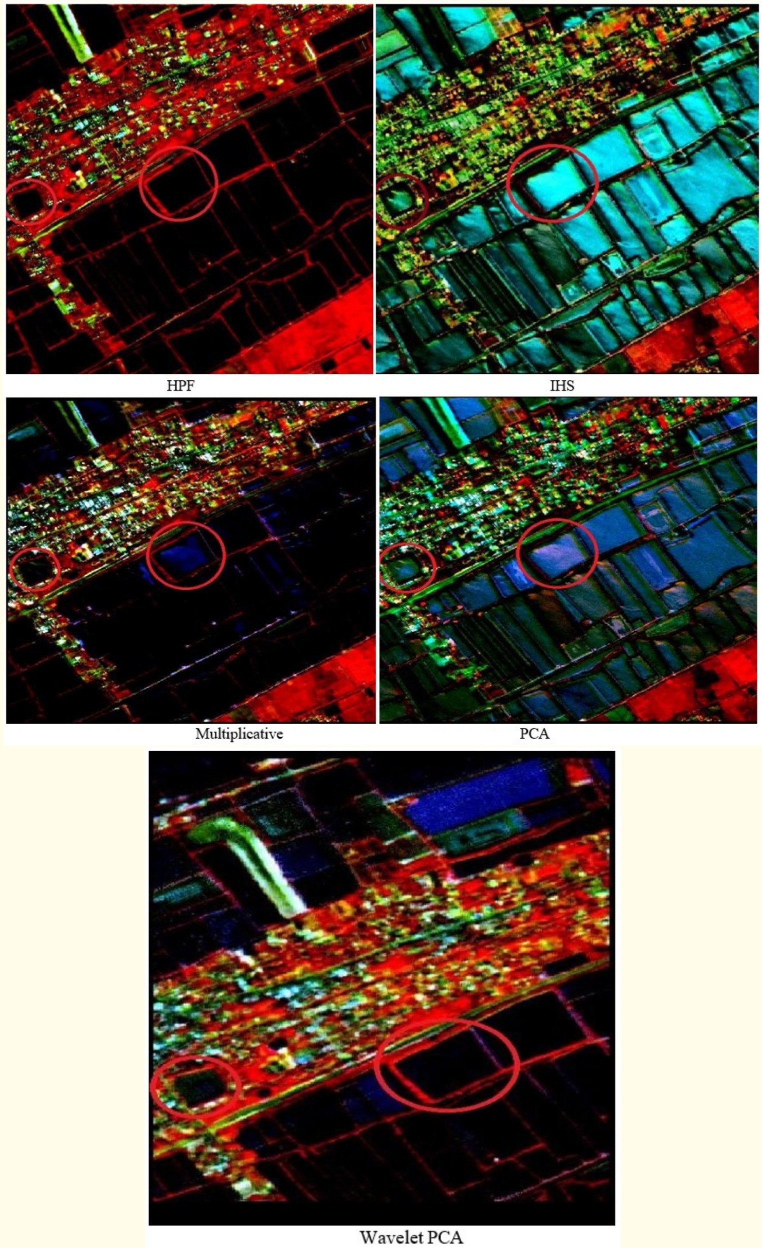


Figure 3: Visual Comparison among the different techniques using LISS-IV data.

Results and Discussions

Figures 2 and 3 illustrate that among the available fusion approaches, Wavelet Transformation has demonstrated good accuracy compared to other methods, as evidenced by visual comparisons and statistical computations (Tables 2 and 3). However, Table 1 shows that the correlation value is the lowest for the wavelet approach among the techniques listed in Table 2. The Wavelet technique has proven effective in delineating salt-impacted soils, particularly in identifying the conversion of paddy lands into aquaculture ponds, making it one of the most reliable methods among the current techniques.

Conclusions

Aquaculture regions can be effectively detected using space-borne multispectral data due to their distinctive spectral response patterns and association with channels and drains. Multi-temporal space-borne multispectral data facilitates the study of the temporal behavior of aquaculture regions. Within these areas, combining high-spatial-resolution space-borne data with multispectral data enables the identification of individual aquaculture ponds. Additionally, the unique shapes of fish ponds allow for their differentiation from prawn ponds. Traditional ground sampling methods and subsequent chemical analysis can be employed to assess the impact of aquaculture on soil properties. Findings indicate that the electrical conductivity of soils in prawn ponds, where brackish water is used for cultivation, has significantly increased. In the current study, pond boundaries have been digitized and labelled for delineation. However, advancements in edge recognition and shape-based object delineation could further enhance the digital classification of fish and prawn ponds. For modeling the environmental impact of aquaculture, Geographic Information System (GIS) technology can facilitate the integration of spatial and attribute data related to soil characteristics, improving analysis and decision-making.

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