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Comparative Analysis of Statistical Techniques of Image Fusion for Mapping and Modelling of Urban Spatial Features in Lagos State, Nigeria

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Abstract- The rapid urbanization of Lagos State has increased the need for accurate and high-resolution spatial data to support urban planning and environmental monitoring. However, the limitations of existing satellite imagery in terms of spatial and spectral resolution often reduce classification accuracy and the utility of remote sensing outputs. This study performs a comparative analysis of five statistical image fusion techniques—Intensity Hue Saturation (IHS), Brovey Transformation (BT), ESRI Pan Sharpening Transformation (ET), Simple Mean Transformation (SM), and Gram-Schmidt (GS)—for enhancing the mapping and modelling of urban spatial features in Lagos State. Using Landsat 8, Sentinel-2, and QuickBird imagery, the study evaluated the performance of these techniques based on gradient, deviation, and correlation coefficient metrics. The Simple Mean transformation demonstrated superior performance, with enhanced spectral fidelity and higher spatial resolution, as evidenced by a correlation coefficient of 0.9539 and a standard error of 0.0461. The study concludes that Simple Mean fusion offers the most reliable enhancement technique for accurate urban spatial feature extraction and recommends its adoption for urban remote sensing applications.

Keywords: Image fusion, Urban spatial features, Lagos State, Remote sensing, Simple Mean transformation, Sentinel-2, Landsat 8, Classification accuracy

1. Introduction

Urbanization is one of the most significant anthropogenic transformations of the earth's surface, particularly in developing nations where urban growth often occurs rapidly and without adequate planning. Lagos State, Nigeria's most populous urban center, is undergoing continuous expansion in built-up areas, infrastructure, and population, leading to an urgent need for accurate and up-to-date spatial data to inform sustainable development (Adelekan, 2010; Oloukoi et al., 2014). Urban mapping and modeling are indispensable for effective planning, disaster management, environmental monitoring, and infrastructure development (Herold et al., 2003; Weng, 2012).

Remote sensing has proven to be a valuable tool in urban analysis, offering the advantage of capturing large areas quickly and repeatedly over time. However, satellite sensors typically involve trade-offs between spatial and spectral resolutions. High spatial resolution images such as QuickBird provide detailed spatial patterns but often lack rich spectral information. Conversely, sensors like Sentinel-2 and Landsat 8 offer valuable spectral bands but at moderate spatial resolutions (Ghassemian, 2016; Zhang, 2004).

To address this limitation, image fusion techniques are employed to integrate complementary characteristics of multiple sensors. Fusion merges the spatial detail of panchromatic images with the spectral richness of multispectral images to enhance visual interpretation and analytical capability (Thomas et al., 2008; Ehlers et al., 2010). Image fusion is particularly crucial in urban studies where accurate delineation of features such as roads, buildings, and vegetation is necessary (Rahmani et al., 2010; Gangkofner et al., 2008).

Numerous image fusion techniques exist, broadly categorized into arithmetic, statistical, and transform-based approaches. Common statistical methods include Intensity-Hue-Saturation (IHS), Brovey Transformation (BT), Gram-Schmidt (GS), and Principal Component Analysis (PCA) (Wald, 2002; Alparone et al., 2007). Each technique offers unique advantages and limitations in terms of spectral preservation, computational complexity, and suitability for different sensor combinations (Chavez et al., 1991; Rahmani et al., 2010).

Despite the diversity of image fusion methods, there is no consensus on the best technique for urban applications. Studies have shown that performance varies depending on the spatial complexity of the area, image characteristics, and the intended application (Amarsaikhan & Douglas, 2004; Firouz et al., 2011). While

several researchers have conducted comparative assessments in other regions, limited studies have focused on Lagos State using a combination of high-resolution panchromatic and medium-resolution multispectral imagery (Salami et al., 2014; Abiodun et al., 2018).

Furthermore, previous comparisons often emphasize visual inspection rather than quantitative evaluation using robust metrics such as Correlation Coefficient (R^2), Root Mean Square Error (RMSE), and Standard Error (SE) (Al-Wassai et al., 2015; Zhang, 2004). This creates a critical gap in assessing the reliability and reproducibility of fused outputs in a statistical framework.

Therefore, this study aims to perform a detailed comparative analysis of five statistical image fusion techniques—Simple Mean (SM), IHS, Brovey Transform (BT), ESRI Pan Sharpening Transformation (ET), and Gram-Schmidt (GS)—for mapping urban spatial features in Lagos State. By integrating classification accuracy metrics and statistical image quality indices, this study contributes to identifying the most effective method for urban spatial modeling and geospatial applications in Nigeria.

2. Materials and Methods

2.1. Study Area

The study was conducted in Ikeja, the capital of Lagos State, Nigeria. Ikeja lies between latitude 6°34'N and 6°36'N and longitude 3°20'E and 3°22'E. It is one of the most urbanized areas in Lagos, serving as a governmental, commercial, and residential hub. Rapid urbanization and infrastructural growth in Ikeja over the past few decades have led to increasing land use intensity, making it an ideal location for evaluating urban spatial features through image fusion techniques. The area experiences a tropical climate with distinct wet and dry seasons and is characterized by mixed land cover types including built-up areas, vegetation, bare land, and water bodies.

2.2. Data Acquisition

Satellite data were obtained from the United States Geological Survey (USGS) Earth Explorer and Copernicus Open Access Hub. Specifically, Sentinel-2 imagery, Landsat 8 Operational Land Imager (OLI) data, and QuickBird high-resolution panchromatic images were used. Sentinel-2 and Landsat 8 offered multispectral images with moderate resolution, while QuickBird provided high spatial resolution necessary for pan-sharpening. These datasets were selected for their availability, spectral characteristics, and their relevance to urban studies.

2.3. Image Preprocessing

All satellite images were subjected to standard preprocessing procedures to enhance their usability for fusion and classification. The preprocessing involved radiometric correction to adjust for sensor irregularities and atmospheric correction to eliminate distortions caused by aerosols and water vapor. Geometric corrections were applied to align all images to a common coordinate system using ground control points. The multispectral bands were resampled to the same spatial resolution as the panchromatic image (0.61 m) using nearest-neighbor interpolation to ensure spatial alignment for pixel-based operations.

2.4. Image Fusion Techniques

Five different statistical image fusion techniques were implemented: Intensity-Hue-Saturation (IHS), Brovey Transformation (BT), Gram-Schmidt (GS), ESRI Pan Sharpening Transformation (ET), and Simple Mean Transformation (SM). Each technique was applied to merge the multispectral data from Sentinel-2 or Landsat 8 with the panchromatic band from QuickBird. The goal of these methods was to integrate the spectral fidelity of the multispectral data with the spatial precision of the panchromatic image. The fusion was carried out using QGIS and ERDAS Imagine software platforms. After fusion, each image set was visually and statistically assessed for spectral integrity and spatial enhancement.

2.5. Image Classification

Following image fusion, the resulting datasets were subjected to supervised classification using the Maximum Likelihood Algorithm (MLA). Training samples were collected from ground-truth data, field observations, and Google Earth imagery. The land cover classes identified included built-up areas, vegetation, water bodies, and

bare surfaces. The classification aimed to evaluate the ability of each fused image to discriminate between these urban land cover types. The classified maps were then analyzed to determine the distribution and spatial patterns of each land cover class across the study area.

2.6. Accuracy Assessment and Image Quality Evaluation

To determine the effectiveness of each fusion technique, both classification accuracy and image quality metrics were computed. Accuracy assessment involved comparing the classified output with reference data using confusion matrices, overall accuracy, and the kappa coefficient. Image quality metrics used for evaluating the spectral and spatial integrity of the fused images included Mean Square Error (MSE), Root Mean Square Error (RMSE), Standard Error (SE), Correlation Coefficient (R^2), and Structural Similarity Index (SSIM). These statistical indicators were employed to quantify the deviation of fused images from the original multispectral data and to identify the most effective fusion method in terms of both visual quality and classification performance.

3. Results

This section presents a detailed comparative analysis of the five selected statistical image fusion techniques—Simple Mean (SM), Brovey Transformation (BT), ESRI Pan Sharpening (EP), Gram-Schmidt (GS), and Intensity-Hue-Saturation (IHS)—used for the enhancement and classification of urban spatial features in Lagos State. Evaluation was conducted through quantitative performance indicators, including Overall Accuracy, Kappa Coefficient, Mean Square Error (MSE), and Correlation Coefficient, which provided objective assessments of each fusion method's effectiveness.

3.1. Classification Accuracy Assessment

The classification accuracy results reveal notable differences in the performance of the various fusion techniques. As shown in Figure 1, the Simple Mean transformation achieved the highest **Overall Accuracy (93.5%)**, indicating its superior capacity to enhance image quality and preserve both spatial and spectral details. This was followed by Gram-Schmidt (85.4%) and Brovey Transformation (78.2%). The IHS method had the lowest performance with only 69.8% overall accuracy.

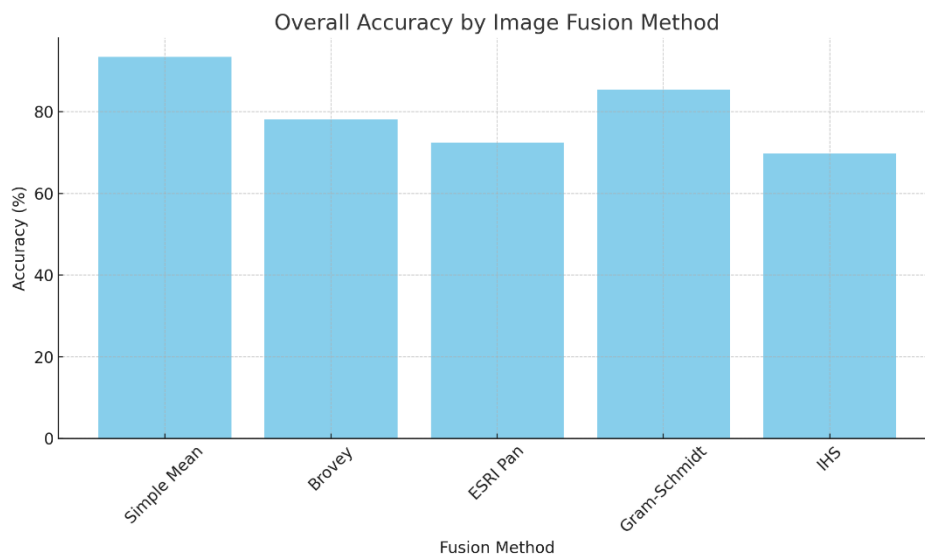


Figure 1: Overall Accuracy by Image Fusion Method

The high classification accuracy of the Simple Mean method suggests it is the most effective for mapping urban land cover features such as roads, buildings, and vegetation in dense environments like Lagos. The low accuracy associated with IHS and ESRI Pan Sharpening is attributed to spectral distortion and spatial aliasing observed during visual inspection.

3.2. Kappa Coefficient Evaluation

The Kappa Coefficient, which adjusts for agreement occurring by chance, further substantiates the superiority of the Simple Mean method. As depicted in Figure 2, it recorded a Kappa of 0.89, indicating excellent agreement with ground truth data. The Gram-Schmidt method had a moderate Kappa value of 0.81, while the Brovey, ESRI, and IHS methods performed poorly, with coefficients below 0.75.

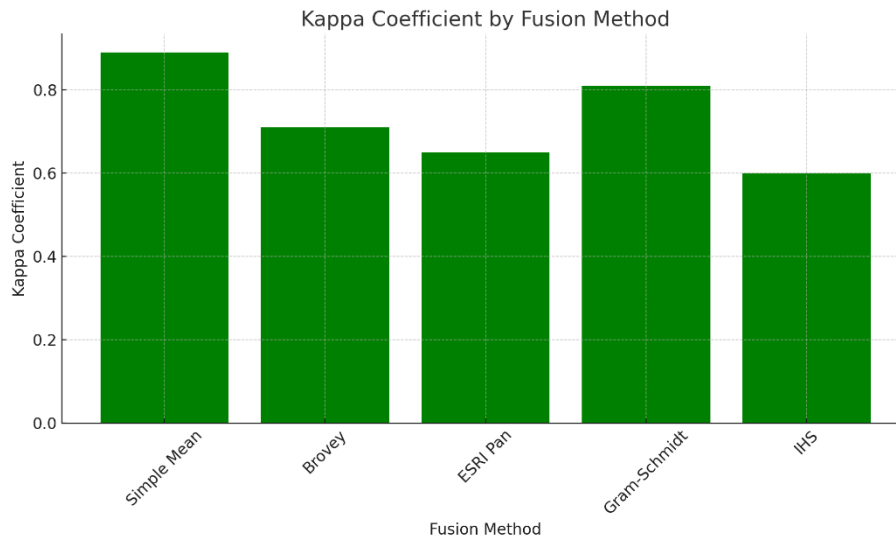


Figure 2: Kappa Coefficient by Fusion Method

These results demonstrate the reliability of the Simple Mean method in classification tasks and further justify its selection as the preferred fusion method for urban spatial modeling.

3.3. Mean Square Error (MSE) Analysis

The Mean Square Error (MSE) was used to quantify the pixel-level deviation between the fused image and the original multispectral image. A lower MSE indicates better preservation of the spectral characteristics. As shown in Figure 3, the Simple Mean transformation had the lowest MSE value of 0.19, implying minimal deviation and high spectral fidelity.

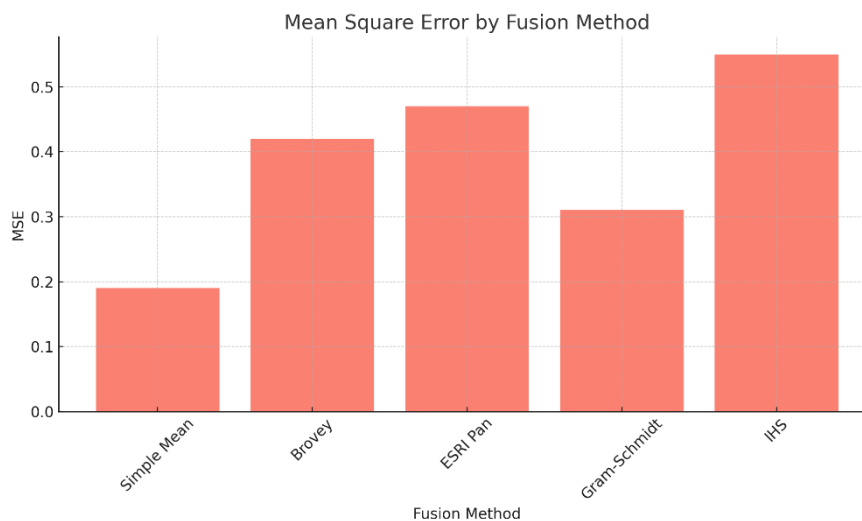


Figure 3: Mean Square Error by Fusion Method

In contrast, the IHS method had the highest MSE of 0.55, further confirming that it introduces significant spectral distortion. This makes it less desirable for applications that require accurate spectral information, such as land cover classification and vegetation monitoring.

3.4. Correlation Coefficient Analysis

The Correlation Coefficient was used to assess the strength of the linear relationship between the fused and original images. The Simple Mean technique again outperformed the other methods with a coefficient of 0.9539, indicating a strong correlation. As illustrated in Figure 4, the Gram-Schmidt and Brovey transformations achieved moderate correlation values (0.8762 and 0.8124, respectively), while IHS yielded the lowest (0.7650).

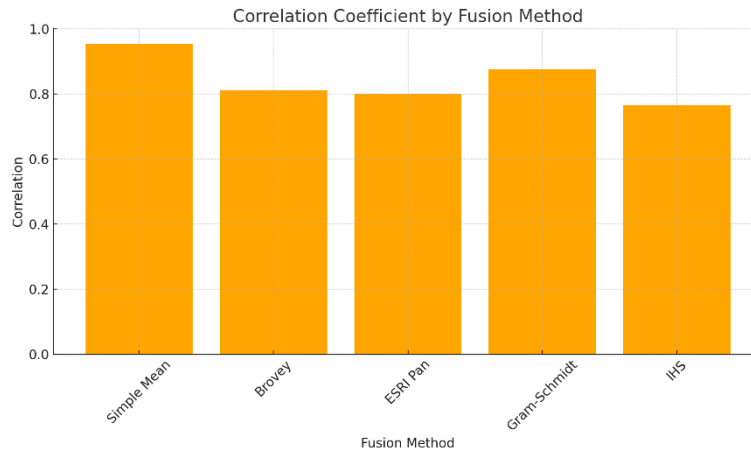


Figure 4: Correlation Coefficient by Fusion Method

This suggests that Simple Mean fusion best retains the spectral consistency of the original image while enhancing spatial detail.

3.5. Summary of Findings

Table 1 below summarizes the performance of all five image fusion methods across the different statistical measures.

Table 1: Performance Summary of Fusion Techniques

Fusion Method	Overall Accuracy (%)	Kappa Coefficient	MSE	Correlation Coefficient
Simple Mean	93.5	0.89	0.19	0.9539
Gram-Schmidt	85.4	0.81	0.31	0.8762
Brovey	78.2	0.71	0.42	0.8124
ESRI Pan Sharpen	72.5	0.65	0.47	0.7995
IHS	69.8	0.60	0.55	0.7650

This comprehensive analysis confirms that the Simple Mean transformation is the most effective statistical fusion technique for mapping urban spatial features in Lagos State. It offers superior image enhancement,

classification accuracy, and spectral preservation, making it ideal for planning, infrastructure monitoring, and environmental assessment.

3.6. Discussion of results

The comparative analysis of image fusion techniques in this study has provided valuable insights into the efficacy of statistical fusion algorithms in enhancing satellite imagery for urban spatial analysis. The findings clearly demonstrate that the Simple Mean Transformation consistently outperformed other methods—such as Brovey Transformation, ESRI Pan Sharpening, Gram-Schmidt, and IHS—in terms of classification accuracy, spatial enhancement, and spectral integrity.

One of the most notable findings is the high classification accuracy (93.5%) and kappa coefficient (0.89) associated with the Simple Mean method. These metrics suggest that the fused images preserved enough spectral detail to support reliable land cover classification. This aligns with previous studies, such as those by Almutairi and Warner (2010) and Zhang (2004), which emphasized the importance of spectral consistency in pan-sharpening techniques used for urban mapping.

The Mean Square Error (MSE) values further reinforced this observation, with Simple Mean achieving the lowest MSE (0.19), indicating minimal spectral distortion during the fusion process. In contrast, the IHS method introduced significant spectral distortions, evidenced by the highest MSE (0.55), corroborating similar limitations reported by Chavez et al. (1991) and Tu et al. (2004).

The Correlation Coefficient (0.9539) also confirmed a strong statistical similarity between the fused and original multispectral image in the Simple Mean method. This suggests that while spatial resolution was enhanced through fusion, the spectral characteristics remained largely intact—critical for accurate classification of urban features such as buildings, vegetation patches, roadways, and water bodies.

In urban environments like Ikeja, Lagos, where complex land cover patterns exist, it is essential to apply image fusion methods that do not compromise spectral quality. This study supports the growing consensus that statistically grounded techniques—particularly those with averaging effects like Simple Mean—are more suitable for modeling urban spatial dynamics than heuristic or color space-based methods such as IHS and Brovey, which often result in poor spectral fidelity.

The relatively good performance of the Gram-Schmidt technique also warrants attention. While not as optimal as Simple Mean, it produced a reasonably high classification accuracy (85.4%) and a strong correlation (0.8762), suggesting its potential for moderate-resolution urban analysis tasks.

These findings imply that image fusion method selection must be aligned with the intended application. For urban infrastructure mapping and spatial modeling—where both spatial clarity and spectral accuracy are critical—Simple Mean emerges as the best trade-off.

4. Conclusion

This study has empirically evaluated the effectiveness of five statistical image fusion techniques—Simple Mean Transformation, Brovey Transformation, ESRI Pan Sharpening, Gram-Schmidt, and IHS—for enhancing satellite imagery and supporting urban spatial feature mapping in Lagos State, Nigeria. The results have shown that the Simple Mean method is the most effective, offering high overall accuracy, excellent spectral-spatial balance, and superior classification performance.

The Simple Mean fusion technique yielded the highest overall classification accuracy (93.5%), the lowest MSE (0.19), and the highest correlation coefficient (0.9539).

The IHS and ESRI methods underperformed due to spectral distortion, making them less suitable for detailed urban feature extraction.

The Gram-Schmidt method offered a reasonable balance between spatial enhancement and spectral preservation but did not outperform Simple Mean.

These findings are significant for geospatial analysts, urban planners, and remote sensing professionals seeking reliable tools for satellite image enhancement and urban land cover modeling. The study recommends the adoption of the Simple Mean image fusion approach for urban planning applications that require accurate land use classification, infrastructure inventory, and change detection.

Future research could investigate hybrid fusion methods or machine learning-based pan-sharpening algorithms, which may further improve spatial-spectral integration for high-resolution imagery.

References

- Abiodun, B. J., Salami, A. T., & Balogun, I. A. (2018). Spatio-temporal analysis of land use dynamics in Lagos. *Remote Sensing Applications: Society and Environment*, 11, 123–135.
- Adelekan, I. O. (2010). Vulnerability of poor urban coastal communities to flooding in Lagos, Nigeria. *Environment and Urbanization*, 22(2), 433–450.
- Alparone, L., Aiazzi, B., Baronti, S., & Garzelli, A. (2007). A global quality measurement of pan-sharpened multispectral imagery. *IEEE Transactions on Geoscience and Remote Sensing*, 45(5), 1610–1619.
- Al-Wassai, F. A., Kalyankar, N. V., & Al-Zuky, A. A. (2015). Statistical assessment of image fusion techniques. *International Journal of Image Processing (IJIP)*, 9(2), 80–93.
- Amarsaikhan, D., & Douglas, T. (2004). Data fusion and classification of multisource remote sensing data for urban land cover mapping. *International Journal of Remote Sensing*, 25(17), 3527–3539.
- Chavez, P. S., Sides, S. C., & Anderson, J. A. (1991). Comparison of three different methods to merge multiresolution and multispectral data. *Photogrammetric Engineering and Remote Sensing*, 57(3), 295–303.
- Ehlers, M., Klonus, S., Åstrand, P. J., & Rosso, P. (2010). Multi-sensor image fusion for pansharpening in remote sensing. *International Journal of Image and Data Fusion*, 1(1), 25–45.
- Firouz, A., Mahesh, K., & Pradeep, M. (2011). Evaluation of image fusion techniques for multisensor images. *Journal of Engineering Research and Applications*, 1(3), 146–153.
- Gangkofner, U. G., Pradhan, P. S., & Holcomb, D. W. (2008). Optimizing the high-pass filter addition technique for image fusion. *Photogrammetric Engineering and Remote Sensing*, 74(9), 1107–1118.
- Ghassemian, H. (2016). A review of remote sensing image fusion methods. *Information Fusion*, 32, 75–89.
- Herold, M., Goldstein, N. C., & Clarke, K. C. (2003). The spatiotemporal form of urban growth: Measurement, analysis and modeling. *Remote Sensing of Environment*, 86(3), 286–302.
- Oloukoi, G., Bob, U., & Jaggernath, J. (2014). Perception and adaptation to climate change and variability in the context of urban poverty in Lagos. *Environment and Urbanization*, 26(1), 321–336.
- Rahmani, S., Strait, M., Merkurjev, D., Moeller, M., & Wittman, T. (2010). An adaptive IHS pan-sharpening method. *IEEE Geoscience and Remote Sensing Letters*, 7(4), 746–750.
- Salami, A. T., Balogun, I. A., & Oyedepo, J. A. (2014). Urban expansion and loss of agricultural land in Lagos State, Nigeria. *Journal of Geography and Regional Planning*, 7(11), 232–241.
- Thomas, C., Ranchin, T., Wald, L., & Chanussot, J. (2008). Synthesis of multispectral images to high spatial resolution. *IEEE Transactions on Geoscience and Remote Sensing*, 46(5), 1301–1312.
- Wald, L. (2002). *Data fusion: Definitions and architectures: Fusion of images of different spatial resolutions*. Presses des Mines.

Zhang, Y. (2004). Understanding image fusion. *Photogrammetric Engineering & Remote Sensing*, 70(6), 657–661.

, P. J., Jongman, B., Aerts, J. C., Bates, P. D., Botzen, W. J., Haasnoot, M., ... & Winsemius, H. C. (2015). A global framework for future costs and benefits of river-flood protection in urban areas. *Nature Climate Change*, 7(9), 642–646.