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ARTICLE

Wavelet Transform Technique Applied to Satellite Image Denoising

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ABSTRACT

Satellite images either digital or analog must have certain elements that are accidentally introduced during the processing of capturing as a result of weather or system sensor known as electronic noise. However, several attempts and advances have been made by academicians, industries and intelligent security agencies to remove this noise. It has been a nagging problem in the area of computer vision, image processing and artificial intelligence to denoise satellite images and noise removal is among the significant components in satellite image analysis. The aim of this research work was to denoise the satellite image of Sambisa forest using the wavelet transform technique. Satellite images of Sambisa forest captured by Landsat satellite in 2007, 2013, 2014, 2019 and 2021 respectively with their associated Geo-referenced 11.2503° N Longitude and 13.4167° E Latitude were downloaded from the United States Geological Survey (USGS) website. The images are acquired as Zipped Geo-referenced Tagged Image File Format (GeoTIFF). Color Composite bands of natural colors (bands 2, 3 and 4) are combined using the ArcGIS software and RGB image were obtained. Wavelet transforms denoising technique was used to filter noise from the images, which was implemented using the wdenoise2() function in MATLAB 2021.

Keywords: Landsat; Color composite; Image denoising; Image enhancement; Sambisa forest

1. Introduction

Noise is an inevitable element in satellite images due to the distortion, distance, interference, nature of the sensor, weather, and transmission media in the process of acquisition are the fundamental factors leading to obtained images with so much noise. The main purpose of this research work was to de-

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noise Landsat images of the Sambisa forest using wavelet transform with the following objectives: To composite bands 2, 3 and 4 using ArcGIS, and to denoise the images using wavelet transform. This forest attracted the attention of media and academia since 2009 when Bokoharam started in Borno state, Northeastern Nigeria. There is a large amount of literature is available on the internet regarding the situation. However, to the best of our knowledge, no single paper has addressed any of our objectives or even attempted to use any advanced techniques in computational intelligence, image processing or artificial intelligence to hamper the menace of insecurity in the region. In this research, we have attempted to showcase and visualize a particular region in the forest with a specific Geo-reference to enable the security and intelligence agencies to know the nature of the forest from a remote.

Digital or analog images are represented mathematically using a function $f(x,y)$ that x *and* y represent the coordinate and the altitude of f at any point (x,y) if the images are monochrome (x,y) represent the grey level but if the images are digital the altitude values of f will be finite and discrete. Moreover, the fusion of red, green and blue colors is perfectly arranged in a matrix format or array of numerical values at certain rows and columns, every numeric value here representing a specific pixel value in an image is two dimensions [1].

Mathematically, image is represented by a function: $(x,y)\, f(x,y)$ such that the value of f at the spatial domain (x,y) are mostly positive values from the natural source of the image therefore $f(x,y) \neq 0$ and finite:

$$0 < f(x,y) < \infty \quad (1)$$

Such that the image f has two main properties:

$f\, i < (x,y)$ *and* $r\,(x,y)$ *hence*

$$f(x,y) = 1\,(x,y)\, r\,(x,y) \quad (2)$$

Such that $0 < i\,(x,y) < \infty$ *and* $0 < (x,y) < 1$.

Hence $i\,(x,y)$ primarily depends on the main source of the image r (x,y) rely on the characteristics of the image.

Therefore, if the image sources are from via transmission media, then the equation will become:

$$L_{min} \leq 1 = f(x,y) \leq L_{max} \quad (3)$$

Such that $I = f(x,y)$ is the grey level at coordinate (x,y).

Satellite images are either captured in two ways passive or active, but vary in resolution of spatial, temporal or spectral due to their different reflection modes and wavelengths, which can be captured using optical sensors or microwaves. Optical sensor uses light radiation which is reflected by the earthy object optical sensor are used to understand the nature of objects such as "forest, mountains, trees, water bodies and sea" etc. Microwave sensors are used to capture information about the environment with water bodies, mountains and ice [2]. Satellite images are captured as a result of various sensors and scanners operating with a variety of electromagnet spectrums. Using many spectral bands provides clear information about an object. But it required more storage capability with much transmission complexity. In satellite imaging, the higher the width of the spectral band, the stronger the signal would be [3].

Noise is normally present in an image in either two ways additive or multiplicative [1], mathematically expresses as:

$$w(x,y) = s(x,y) \times n(x,y) \quad (4)$$

where $s(x,y)$ is the signal, $n(x,y)$ is the noise introduce $w(x,y)$ is corrupted image and (x,y) is the pixel location.

Satellite images suffered from different form of noise such as Gaussian Noise and speckle noise, mathematically represented by William [4] as:

$$f(g) = \frac{1}{\sqrt{2\pi\sigma 2}}\, e^{-2(g-m)2/2\sigma^2} \quad (5)$$

where g represents the grey level of the image, M represents the mean and σ represents the standard deviation.

$$f(g) = \frac{g\propto -1}{(\propto -1)!\,a\propto}\, e^{-g/a} \quad (6)$$

where α is the variance and g is the grey level.

Different forms of techniques and methodologies have recently been applied in satellite image denoising. Such as wavelet transform, which also has different methods like Nasir and Nazamabadi [5] proposed an adaptive nonlinear threshold function with three parameters using a threshold neural network. The method has yielded good results despite the number of datasets used in the experiment not much expressed as:

$$f(u,t,x,y,z) = \begin{cases} u - 0.5\,\frac{tx\times z}{wx-1} + (z-1)t,\ u > t \\ 0.5\,\frac{z\times|u|y}{ty-1}\,Sgn\,(u), \qquad u \leq t \\ u + 0.5\,\frac{(-t)x\times z}{Wx-1} - (z-1)t, u <- t \end{cases} \tag{7}$$

Such that u represents the wavelet coefficient, *x and y* are also turning parameters and z calculate the asymptotic of the function [5].

Another similar method was implemented by Zhang [6] in this research work, Thresholding Neural Network (TNN) was developed for adaptive noise reduction. New types of soft and hard thresholding functions were created to serve as the activation functions for the TNN, not similar to the standard thresholding functions, the new thresholding functions are infinitely differentiable. By using the new thresholding functions, some gradient-based learning algorithms become possible or more effective. The optimal solution of the TNN in a Mean Square Error (MSE) sense was addressed and discussed. It is proved that there is at most one optimal solution for the soft-thresholding TNN. General optimal performances of both soft and hard thresholding TNNs are analyzed and compared to the linear noise reduction method. Gradient-based adaptive learning algorithms are presented to seek the optimal solution for noise reduction. The algorithms include supervised and unsupervised batch learning as well as supervised and unsupervised stochastic learning. It is indicated that the TNN with the Stochastic Learning algorithms can be used as a novel nonlinear adaptive filter and it is also proved that the Stochastic Learning algorithm is convergent in a certain statistical sense in ideal conditions. The function is represented in Equation (9):

$$E\,soft\,(w,t)w + \frac{1}{2}\,(\sqrt{(w-t)2} + x - \sqrt{(w+t)2} + x) \tag{8}$$

where *E soft* represents the improved threshold function.

$$E_{HARD}\quad (w,t) = (\frac{1}{1+\exp\frac{-w+t}{u}]} - \frac{1}{1+\exp[\frac{-w-t}{u}} + 1)w \tag{9}$$

where E_{HARD} represents the improved held threshold function, w represents the wavelet, $u > 0$ is a user defined function [6].

This research [7] introduced a new enhanced Adaptive Generalized Gaussian Distribution (AGGD) threshold for satellite and Hyper Spectral Image (HSI) de-noising. This function is data-driven, non-linear, and it can be fitted to any image. Applying this function provides us with an optimum threshold value without using any Least Mean Square (LMS) learning or optimization algorithms. Thus, it is possible to save processing time as well. The proposed function contains two main parts. There is an AGGD threshold in the interval and a new non-linear function behind the interval. These combined functions can tune the wavelet coefficients properly. They have used hyper spectral remote sensing images from AVIRIS, HYDICE, and ROSIS sensors for experimental analysis and validation process and applied Peak Signal-to-Noise Ratio (PSNR) and Mean Structural Similarity Index (MSSI) to measure and evaluate the performance analysis of different de-noising techniques. The results show the superiority of the developed method as compared with the previous TNN and optimization-based noise suppression methods. This improved function is shown in Equation (10).

$$S(w) = \begin{cases} \left(\frac{1}{1+ew+t}\right) \mathcal{W}t\left(\frac{t}{2} - c(t) - c(0)\right), \mathcal{W} <- t \\ c(\mathcal{W}) - C(0), \qquad |\mathcal{W}| \leq t \\ \frac{1}{1+e-w+1})w - \left(\frac{t}{2} - \left(c(t) - c(0)\right)\right), \mathcal{W} > t \end{cases} \tag{10}$$

Non-Local means of image denoising was implemented in the work of Noorbarkhsh A. et al. [7]. This algorithm takes the advantage of redundancy of natural image. They implement the following equations using C program:

$$NL\,(V) = \frac{1}{C(x)} \int e^{\frac{Ga*|V(x+.)-V(y+.)|)(0)}{h2}} \tag{11}$$

Such that *Ga* represents the Gaussian Kernel with standard deviation, h as a denoising parameter.

$$C\,(x) = \int e^{\frac{(Ga*|V(x+.)-V(y+.)|)(0)}{h2}}\,dz \tag{12}$$

2. Image denoising

Satellite images contain noise that is introduced as a result of system sensors during the processing of capturing. However, different techniques and methods are applied to denoise these images such as radiometric calibration and other advances have been applied to denoised satellite images such as wavelet transform technique. He and Chen [8] proposed a new approach in the method for atmospheric correction noise in an image of turbid coastal water and a case study of Perl River Estuary. The method seems to be a new paradigm for image denoising, but there is a need to improve its performance by adjusting some of its parameters and also providing a theoretical framework for the method.

Golilarz, N.A., Mirmozaffari, M. et al.[9] proposed a robust optimized wavelet based on satellite image denoising technique with multi-population and differential evolution. This method seeks to optimize the wavelet with the assisted Harris Hawks optimization algorithm. In the work of Mohammed, K. et al. [10] , a Thresholding Neural Network (TNN) was developed for adaptive noise reduction. New types of soft and hard thresholding functions are created to serve as the activation function of the TNN. Unlike the standard thresholding functions, the new thresholding functions are infinitely differentiable. By using their new thresholding functions, some gradient-based learning algorithms become possible or more effective. It consists of supervised and unsupervised batch learning as well as supervised and unsupervised stochastic learning. The results show that the TNN with stochastic learning algorithms can be used as a novel nonlinear adaptive filter. It is proved that the stochastic learning algorithm is convergent in a certain statistical sense in ideal conditions. Numerical results show that the TNN is very effective in finding the optimal solutions of thresholding methods in an MSE sense and usually outperforms other noise reduction methods. However, in the work of Nasri M. and H. Nezamabadi [11], some new adaptive learning types are also proposed. Based on these learning methods, the threshold and the thresholding function effects are considered simultaneously. These methods are used to suppress two types of important noises, Gaussian and Speckle, ranging from natural images to ultrasound and SAR pictures. The simulation results show that the proposed thresholding function has superior features compared to conventional methods when used with the proposed adaptive learning types. This makes it an efficient method in image denoising applications. In the work of N. A. Golilarz and H. Demirel [12] , they introduced a new technique for image denoising in wavelet domain which uses soft thresholding function. Denoising based on Un-decimated Wavelet Transform (UWT) using soft threshold function results in acquiring better visual quality and PSNR values in comparison with alternative techniques in the field of image denoising in wavelet domain. A new method was proposed for image denoising by applying a smooth nonlinear soft threshold on high-frequency subbands of the images by N. A. Golilarz, H. Gao, and W. Ali. et al. [13] , after applying 3D un-decimated wavelet transform, the proposed method was compared with de-noising based on 3D-UWT using standard hard and soft thresholding techniques. Results show the superiority of the proposed method over the standard and alternative methods in the literature by means of visual quality and Peak Signal to Noise Ratio (PSNR).

2.1 Mathematical models in image denoising

From the degradation model $g(x,y) = f(x,y) = n(x,y)$ where $f(x,y)$ is the real image and $g(x,y)$ degraded image and $n(x,y)$ is the noise. However, there are different form of noise and are represented mathematically as:

From probability distribution function Gaussian noise can be written as:

$$p(r) = \frac{1}{\sqrt{2\Omega\sigma}} e^{-(r-\mu)/2\sigma} \tag{13}$$

where μ represents the mean and σ is the standard deviation.

From the probability distribution function, uniform noise can be written to complete the references so that the sentences flow smoothly.

$$p(r) = f(x) = \begin{cases} \frac{1}{B-A} If\ A \leq r \leq B \\ 0\ otherwise \end{cases} \quad (14)$$

From probability distribution function impulse noise can be written as:

$$\begin{cases} PA\ if\ r = A \\ PB\ if\ r = B \\ 0\ otherwise \end{cases} \quad (15)$$

2.2 Filters

Let g be the input noisy image and f be the output that is denoised image if also $S(x,y)$ is the neighborhood of the pixel $S(x,y)$ defined as:

$$S(x,y) = \{(x+s, y+t), -a \leq s \leq a, -b \leq t \leq b\} \quad (16)$$

The image size *mn where m* = 2*a* + 1 *and n* = 2*b* + *t and are postive integer.*

Therefore, the arithmetic mean filter can be written as:

$$f(x,y) = \frac{1}{mn}\sum_{(s,t)\epsilon S_{(x,y)}} g(s,t) \quad (17)$$

which is very good in denoising Gaussian noise and uniform noise.

Geometric mean filter is also defined as:

$$f(x,y) = \left(\prod_{(s,t)\epsilon S_{(x,y)}} g(s,t)\right)^{1/min} \quad (18)$$

Contraharmonic mean filter is also defined as:

$$f(x,y) = \frac{\sum_{(s,t)}\epsilon S_{(x,y)}\, g(s,t)^{Q=1}}{\sum_{(s,t)}\epsilon S_{(x,y)} g(s,t)^{Q}} \quad (19)$$

Modern filter is also called order statistics filter where $f(x,y)$ depends on the ordering of the pixel value of the image g in the window $S(x,y)$ which is given as:

$$f = (x,y) = modern\{g(s,t), (s,t)\ \epsilon S(x,y)\} \quad (20)$$

Hybrid filters are also available and applied in denoising image, therefore by combining statistical filters and averaging filters which are very good at denoising Gaussian noise and uniform noise as is given by:

$$f(x,y) = \frac{1}{2}[(s,t)\overset{max}{es(x,y)}\{g(s,t)\} + \overset{min}{es(x,y)}\{g(s,t)\}] \quad (21)$$

2.3 Alpha-trimoned mean filter

From the first order *mn* pixel value of an input image g in the window $S(x,y)$ and then we remove image g in the lowest $d/2$ and then the largest $d/2$ and also we denote the remaining *mn -d* value by gr provided that $d \leq 0$ be an even integer such that $o \leq d \leq mn - 1$. It is given by:

$$f(x,y) = \frac{1}{mn-d} = \sum_{(s,t)} \epsilon S(x,y)\ gr \quad (22)$$

3. Method

Sambisa forest is an area covering 518 km of land, mountains and drainage in Borno state extreme north eastern Nigeria with a coordinate's 11.2503° N Longitude and 13.4167° E Latitude. In early 1958, it was gazette as a reserved area by the colonial administration and after independence in early 1977. Sambisa forest has been re-gazette as a national game reserve center by the Nigerian state. It has a variety of wild animals such as monkeys, elephants, lions, hyenas etc. and 62 different species of birds which attract tourists from different parts of the world to the first republic. However, today Sambisa forest has become no go area zone because is a hidden space for terrorist and also battle ground between terrorist and the Nigerian army [14].

The initial stage of satellite image preprocessing in this work is image acquisition of Sambisa forest with coordinates 11.2503° N Longitude and 13.4167° E Latitude from LandSat satellite of the United States Geological Survey (USGS) at http://earthexplorer.usgs.gov/ from 2007, 2013, 2014, 2017, 2019 and 2021 respectively. The images were acquired in Zipped Geo-referenced Tagged Image File Format (GeoTIFF). Landsat was selected for this research because it is one of the best sources of images for Earth observation, mapping and monitoring, biophysics and geophysics, land cover and land used etc.

3.1 Band composites

LandSat 8 satellite has 11 bands and every band has its own properties and role to play in color composite to enable distinguishing different features on the image. Therefore, in this work, we have focused on vegetation, mountains, buildings, water body, and bare surface natural colors that are bands 4, 3, and 2 were stacked to create a single composite. After the band composite, the images were saved with the Joint Photographic Expert Group (JPEG) file format for further preprocessing. We have used the ArcGIS software to obtain the composite bands. The color composites of satellite images were obtained by combining red, green and blue bands 2, 3, and 4 of Landsat satellite images captured in 2007, 2013, 2014, 2019, and 2021, respectively, using ArcGIS software to enable perform further analysis.

3.2 Denoising

Image denoising is an important component in satellite image preprocessing because the noise in satellite images is inevitable. In this research, wavelet transforms denoising technique was applied to filter our images. From the degradation model:

$$g(x,y) = f(x,y) = n(x,y) \tag{25}$$

where $f(x,y)$ is the real image and $g(x,y)$ de-graded image and $n(x,y)$ is the noise.

3.3 Wavelet transform technique

Wavelet transform is one of the conventional methods for image denoising and signal denoising. Theoretically, wavelet refers to a wave similar to an oscillation whose amplitude start at zero (0) and then increases and decreases back to zero (0) again. This is represented in the mathematical function that is applied in an images or signals according to the scale or resolution. Let us consider the original image $f(x)$ and then the continuous wavelet transform of the image is expressed as:

$$w\varphi(s,t) = \int_{-\infty}^{\infty} f(x)\, \varphi s,t(x)dx \tag{24}$$

where $w\varphi(s,t)$ is the weighted summation of the wavelet.

In this research work we have applied the continuous wavelet transform technique to de-noise our images; therefore Equation (24) was implemented in MATLAB using the “wdenoise2” function.

4. Results

The satellite image denoising of the Sambisa forest captured in 2021 was implemented using the wavelet transform technique and simulated in MATLAB as shown in **Figure 1** below. The output of the simulation shows that noises are removed, the quality and brightness of the image have a significant increase as compared with the original.

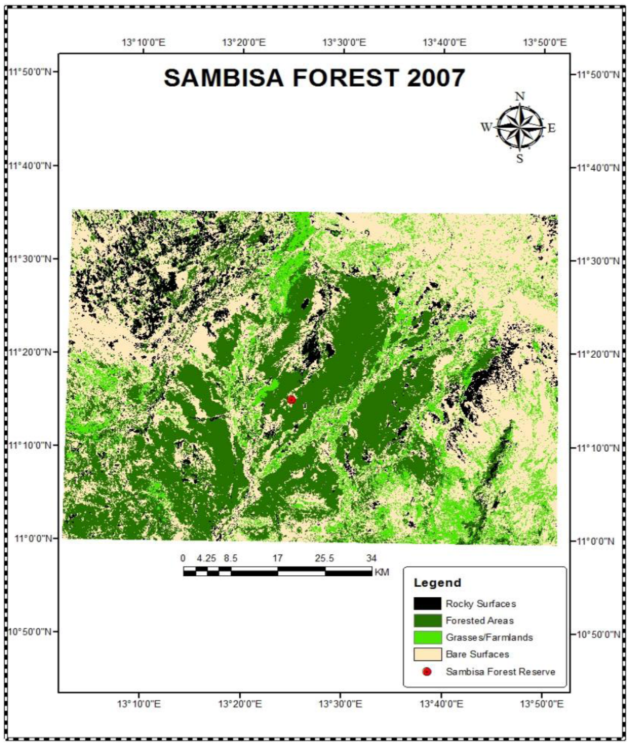

Figure 1. Original and denoised image of Sambisa forest captured in 2007.

The denoising of RGB satellite image of the Sambisa forest captured in 2013 has been implemented using the wavelet transform technique and simulated in MATLAB 2021 as shown in **Figure 2** below. The output of the simulation shows that the denoised image has a significant increase in brightness and the quality of the colors as well as the smoothness of the image has improved.

The denoising of colored satellite image of the Sambisa forest captured by Landsat in 2014 was implemented using the wavelet transform technique. It is implemented in MATLAB as shown in **Figure 3** below the output of the denoised image shows a significantly increased in brightness and the quality of the colors, as well as the smoothness of the image, was improved as compared with the original image.

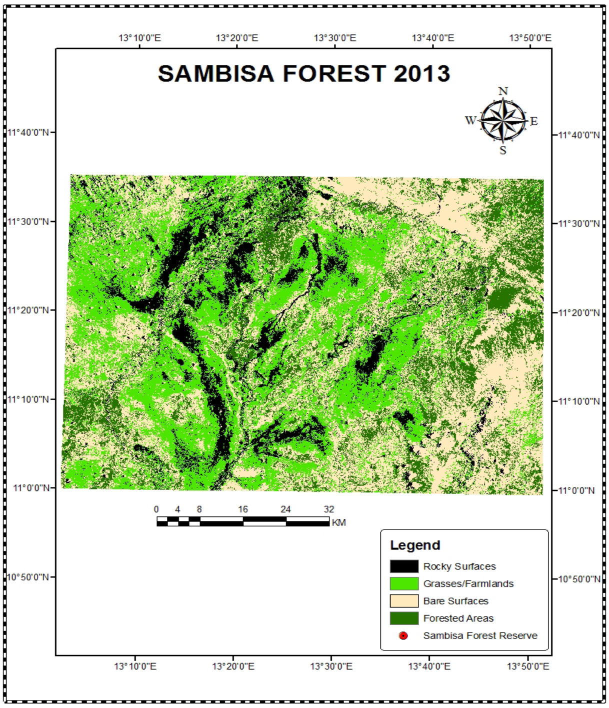

Figure 2. Original and denoised satellite image of Sambisa forest captured in 2013.

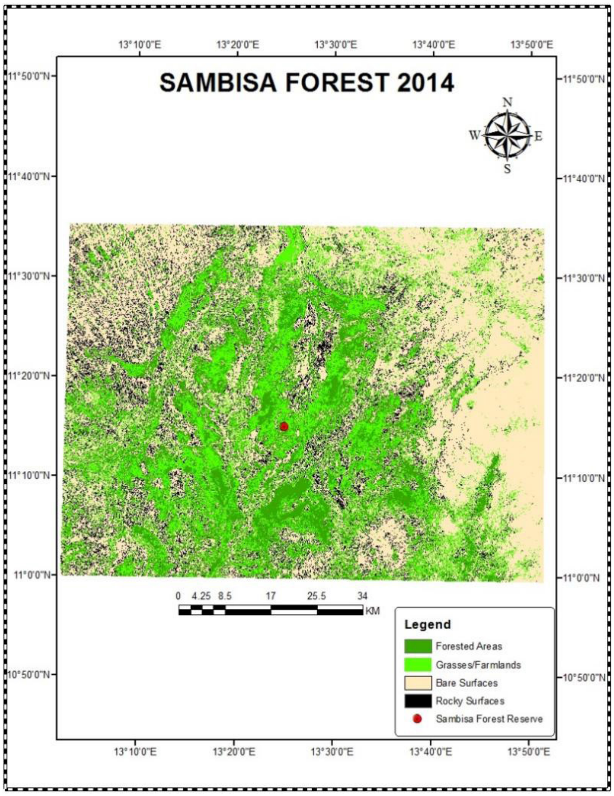

Figure 3. Original and denoised satellite image of Sambisa forest captured in 2014.

The denoising of the satellite image of the Sambisa forest captured in 2021 was implemented using the wavelet transform technique and simulated in MATLAB as shown in **Figure 4** below. The output of the simulation shows that noises are removed, the quality and brightness of the image has a significant increase. This will be easy for segmentation and object detection.

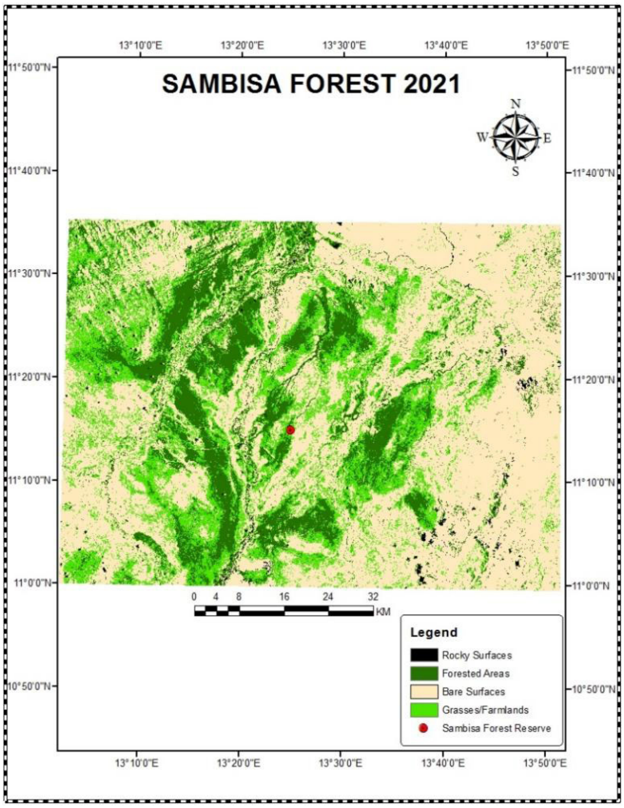

Figure 4. Original and denoised satellite image of Sambisa forest captured in 2021.

5. Conclusions

Noise removal is an important task in satellite image analysis, and discarding noisy elements and restoring substantial parts of the image is the cardinal objective of this work. In this research work, the wavelet transform technique is applied to denoised satellite images of the Sambisa forest captured by Landsat satellite in 2007, 2013, 2014, 2019 and 2021, respectively. This method shows a remarkable performance in terms of clarity compared to the original image and the denoised image.

Author Contributions

Ibrahim Goni designed the framework, Asabe Sandra Ahmadu reviewed the literature and designed the methodology,and Yusuf Musa Malgwi analyzed and interpreted the results.

Conflict of Interest

There is no conflict of interest.

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