# PERFORMANCE LEVEL OF ACCURACY MEASURING METHODS IN CLASSIFIED REMOTE SENSING IMAGES AS APPLIED TO THE BUILT ENVIRONMENT

**Zubayr Alhaji-Taihid Suleyman[1], Ifeanyi Chukwudi Onuigbo[2], Joseph Olayemi Odumosu[3], Oluibukun Gbenga Ajayi[4] and Nanpon Zitta[5]**

*Department of Surveying and Geoinformatics, Federal University of Technology, Minna, Nigeria*

Assessing the accuracy of a classified image is an essential task that gives the user apriori information of the overall reliability of subsequent analysis performed with such classification methods. This research seeks to carry out an assessment of the accuracy measure for evaluating the integrity of the result of image classification using the overall accuracy and the Confusion Matrix. The effect of the size of the defined training site on the accuracy of the resulting classified image has also been examined. LandSAT image of part of South Western Nigeria was used in this study with three different classification methods (Maximum Likelihood, Mahalanobis distance and minimum distance Classifiers). The results obtained shows that the use of the confusion matrix gives a better analysis of the level of reliability of the classification than the use of chance adjusted indices or overall accuracy.

Keywords: accuracy measure, confusion matrix, image classification, spectral class, training site

## INTRODUCTION

Generally, Image classification involves computer based techniques for separating multiple features within an image into distinct classes each with homogeneous characteristics. It group pixels into different land spectral classes to represent different land cover features. It is primarily aimed at enhancing the ability to discriminate multiple objects from each other within an image, based on earlier assigned similarity levels to features with homogeneous characteristics. Image classification is

1091

1 zubayrs@yahoo.com
2 anyionuigbo2006@yahoo.com
3 odumossu4life@yahoo.com
4 ogbajayi@gmail.com
5 bawazitta@gmail.com

Suleyman, Z. A., Onuigbo, I. C., Odumosu, J. O., Ajayi, O. G. and Zitta, N. (2015) Performance level of accuracy measuring methods in classified remote sensing images as applied to the built environment *In:* Laryea, S. and Leiringer R. (Eds) *Procs 6th West Africa Built Environment Research (WABER) Conference,* 10-12 August 2015, Accra, Ghana, 887-900.

classified into Supervised Image Classification, Unsupervised Image Classification and Object-based image analysis.

Image classification is used by professionals within the built environment as a fundamental operation prior to such applications which range from Urban Sprawl investigation, Modeling land use dynamics, investigating crop health/yield in largely forested areas (Francesco et al, 2014, Jones et al, 2008), change detection etc.

Considering therefore the enormous areas of application to which image classification serves as basis (Campbell, 2002) and the many classification techniques available for such operations (Liu et al 2002, Ozesmi and Bauer 2002, Dean and Smith 2003, Pal and Mather 2003,); the need for assessment of the accuracy of the entire classification process cannot be over emphasized Lu and Weng (2007) Jipsa and Karunakaran (2012) and Pooja et al, (2013) gave a survey of existing image classification approaches and techniques while Nur et al (2015) compared image classification techniques using CalTech 101 Dataset.

Conventionally, Pixel based image classification accuracy assessment is done using either chance adjusted indices (such as the kappa co-efficient, tau co-efficient etc.), the overall accuracy measure or the confusion matrix (user and producer accuracies). In recent times however, despite its universal patronage, the use of chance-adjusted indices as accuracy measure in image classification has been greatly criticized as the degree of chance agreement may be over-estimated (Shiguo and Desheng 2011).

The overall accuracy on the other hand also suffers defect in the event when multiple classes are being classified as the accuracy in classification of various classes differ one from another. This has therefore raised much research interest in the need for more reliable indicators of accuracy estimate of which the confusion matrix appears to be a preferred option. Another research concern in recent times is determining the effect of choice of classifier technique (Akgun et al, 2004) and size of defined training site on the result of image classification.

In this paper, three different image classification techniques (Maximum likelihood, Mahalanobis distance and Minimum distance) were used to classify a Landsat Image covering part of South West Nigeria. The level of accuracy of the classification results was then assessed using three methods (Kappa co-efficient, the overall accuracy, the confusion matrix). Also, an attempt has been made to investigate the effect of the size of defined training sites on the resultant accuracy of the image classification.

## BACKGROUND OF THE STUDY

A brief and concise description of the underlying mathematical algorithms or models behind the image classification techniques and accuracy assessments used in this research are herein presented. Though not mathematically exhaustive, the basic formulae are stated and further references given:

**Maximum likelihood classifier**

The maximum likelihood classifier is a supervised classifier that assumes that the distribution of data within a given class "i" obeys a multivariate Gaussian distribution. Derived from the Bayes theorem which states that the a posteriori distribution ($P(i|\omega)$) i.e the probability that a pixel with feature vector $\omega$ belongs to class i is given by (Asmala and Shaun 2012) in (1):

$$P(i|\omega) = \frac{P(\omega|i)\,P(i)}{P(\omega)} \quad (1)$$

**Mahalanobis distance classifier**

The Mahalanobis distance classifier is best used in cases where there is no correlation between the axes in feature space. The mahalanobis distance with variance-covariance matrix is given as (2):

$$d_k^{\,2} = (X - \mu_k)^t . \Sigma_k^{-1} (X - \mu_k) \quad (2)$$

*where:*

$X = Vector\ of\ image\ data\ (n\ bands)$ $\quad X = [x_1, x_2, \ldots\ldots, x_n]$

$\mu_k = mean\ of\ kth\ class$ $\quad \mu = [\mu_1, \mu_2, \ldots\ldots, \mu_n]$

$\sum_k = Variance - covariance\ matrix$

$$\Sigma_k = \begin{bmatrix} \sigma_{11} & \sigma_{12} & \cdots & \sigma_{1n} \\ \sigma_{21} & \sigma_{22} & \cdots & \sigma_{2n} \\ \vdots & & \ddots & \vdots \\ \sigma_{n1} & \sigma_{n2} & \cdots & \sigma_{nn} \end{bmatrix}$$

**Minimum distance classifier**

Generally, minimum distance classifiers are used to classify unknown image data to classes which minimize the distance between the image data and the class in the multi feature space. The mahalanobis distance classifier is a variant form of the minimum distance.

$$d_k^{\,2} = (X - \mu_k)^t . (X - \mu_k) \quad (3)$$

**Accuracy assessment algorithms**

The accuracy of a classification is usually assessed by comparing the classification with some reference data that is believed to accurately reflect the true land-cover. Sources of reference data include among other things ground truth, higher resolution satellite images, and maps derived from aerial photo interpretation (http//:www.yale.edu). Once an error matrix is generated, the elements of the matrix could be used for computation of accuracy assessment parameters as given by (Asmala and Shaun 2012) in (4), (5) and (6)

Kappa Co-efficient (k) = $\frac{\sum_{a=1}^{U}\frac{C_{aa}}{Q}-\sum_{a=1}^{U}\frac{C_{*i}C_{*a}}{Q^2}}{1-\sum_{a=1}^{U}\frac{C_{a*}C_{*a}}{Q^2}}$ (4)

Where: $C_{aa} = element\ at\ position\ ath\ row\ and\ ath\ column$

$C_{*a} = Column\ Sum$

$C_{i*} = Row\ Sum$

Overall Accuracy = $\frac{\sum_{a=1}^{U} C_{aa}}{Q}$ (5)

User Accuracy = $\frac{C_{ii}}{C_{i*}} * 100\%$

Producer Accuracy = $\frac{C_{aa}}{C_{*a}} * 100\%$ (6)

## STUDY AREA

The study area is part of south western Nigeria comprising of Lagos State, Ogun State and Part of Oyo State. The area studied covers an area of about 34,000 Sq.Km extending across various natural and artificial features such as to allow for analysis of the behavior of different classifiers for different earth surface feature class.

## RESEARCH METHOD

Landsat image of the study area was obtained and classified using three different image classification techniques (maximum likelihood classifier, mahalanobis distance classifier and the minimum distance classifier). After the acquisition of the Landsat imageries and prior to the image classification, a true colour composite was first generated from the image bands 1, 2 and 3 to aid easy identification of the feature classes. This true colour composite map was then used in defining the training sites that was used for the image classification.

Five feature classes were identified and created namely:

Vegetation (2) Water Body (3) Bare Ground (4) Built Up and (5) Mangroove.

In order to assess the effect of the size of training site, two classifications were done with each of the earlier stated classifiers herein grouped as classification 1 and classification 2.

The training site region specified for classification 1 being smaller than that specified for classification 2. After the image classifications have been done, the ground truth regions were then identified on the true composite and saved as a separate region of interest ensuring that the ground truth sites were completely independent of the training site used for either classification 1 or 2 respectively.

The results obtained from the classifications were then compared with ground truth region of interest in a post classification process via the

generation of a confusion matrix (error matrix) from where all the accuracy measure used in this research was extracted.

The ENVI 4.7 Image processing software was used for the image classification and analysis and the results obtained are as presented in section 6.0 and further discussed in section 7.0

A sequence of the steps followed are as listed:

(a) Acquire LandSat Image bands 1, 2 and 3

(b) With the image bands, develop a True Colour composite

(c) Define training sites for each feature class

(d) Perform image classification using the three (3) different image classifiers

(e) Perform a post classification analysis and generate the confusion matrix.

## RESULTS

Shown in Figure 2(a – d) is the true composite map of the study area and the results obtained from the three different classification approaches using a small – sized training site hereafter called classification 1. Figure 3(a – d) however presents same results but with a larger sized training site hereafter called classification 2. Tables 1(a and b) presents a summarized analysis of the accuracy level of the three (3) classifiers using the two specified training site sizes (Classification 1 and 2). The full confusion matrixes for each of the classifier technique used in the two (2) classifications are presented in the appendix.

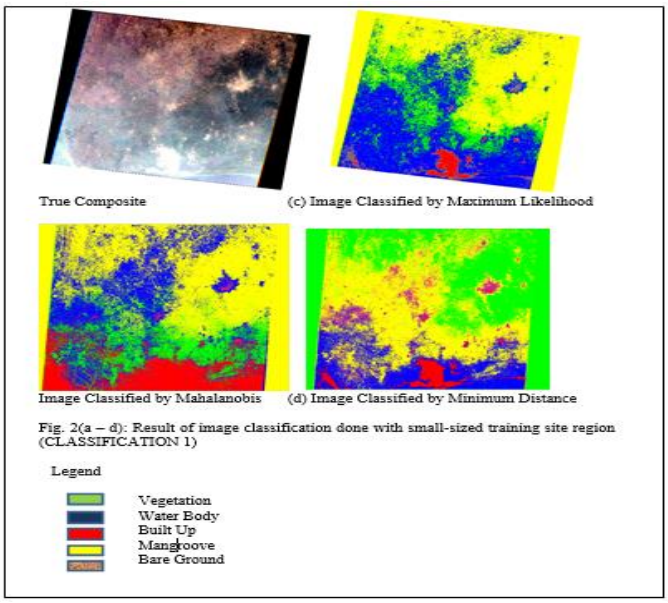


Fig. 2(a – d): Result of image classification done with small-sized training site region (CLASSIFICATION 1)

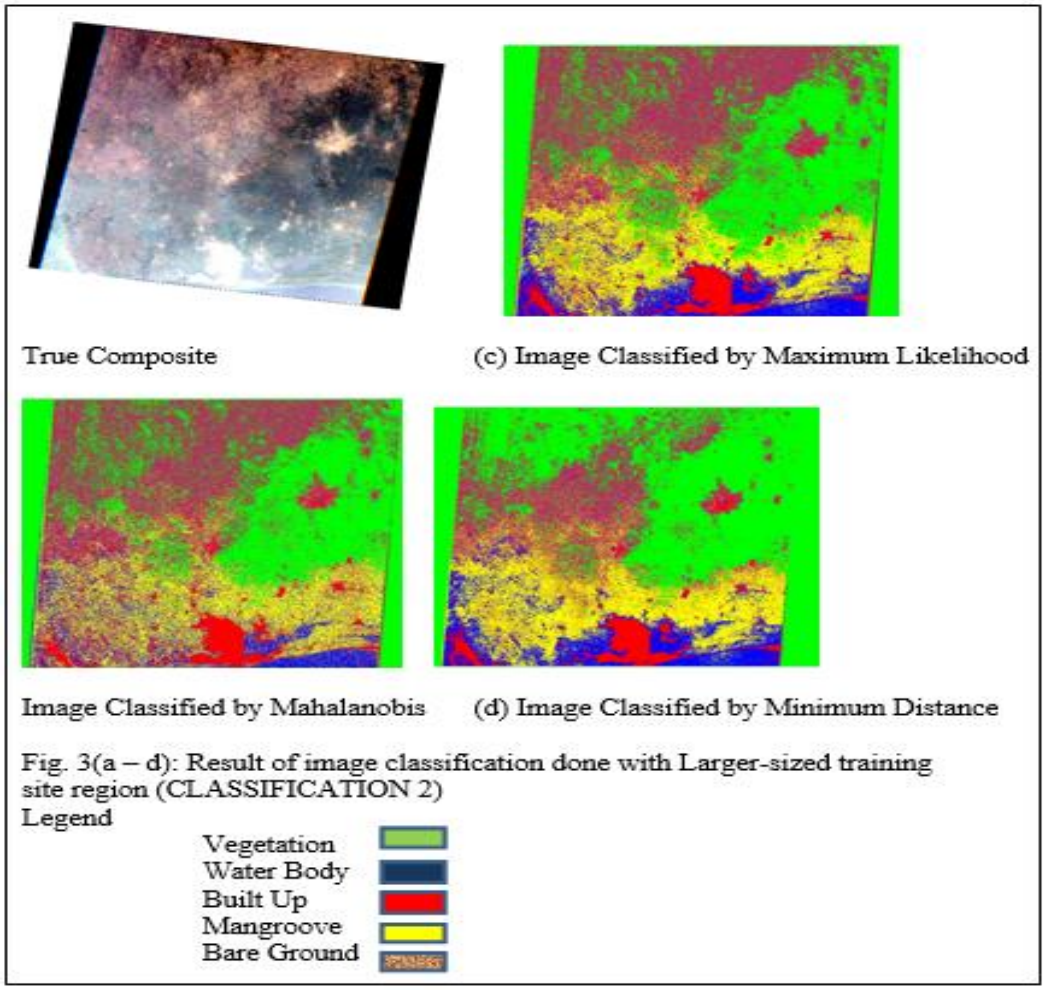


Fig. 3(a – d): Result of image classification done with Larger-sized training site region (CLASSIFICATION 2)

Table 1(a): Summary of accuracy Level obtained From the Three (3) Classifiers when a small Training Site region was used (CLASSIFICATION 1) showing the Kappa co-efficient, Overall Accuracy and User accuracy (Per class).

**Minimal Training Site Specified (CLASSIFICATION 1)**

| CLASSIFICATION TYPE / Accuracy Parameters | Kappa Co-efficent | Overall Accuracy | Vegetation | Bare Ground | Mangroove | Built Up | Water |
|---|---|---|---|---|---|---|---|
| Maximum Likelihood | 0.57% | 69.97% | 1.03% | 14.38% | 2.18% | 92.51% | 92.30% |
| Mahalanobis | 0.17% | 45.15% | 15.74% | 21.36% | 2.72% | 58.54% | 41.72% |
| Minimum Distance | 0.81% | 87.29% | 97.57% | 61.59% | 26.89% | 87.21% | 99.06% |

Table 1(b): Summary of accuracy Level obtained From the Three (3) Classifiers when a large Training Site region was used

(CLASSIFICATION 2) ) showing the Kappa co-efficient, Overall Accuracy and User accuracy (Per class).

**Increased Training Site Specified (CLASSIFICATION 2)**

| CLASSIFICATION TYPE / Accuracy Parameters | Kappa Co-efficent | Overall Accuracy | Vegetation | Bare Ground | Mangroove | Built U | Water |
|---|---|---|---|---|---|---|---|
| Maximum Likelihood | 0.81% | 87.34% | 95.73% | 51.05% | 25.29% | 88.20% | 99.60% |
| Mahalanobis | 0.79% | 85.98% | 97.58% | 58.88% | 21.12% | 87.85% | 98.07% |
| Minimum Distance | 0.88% | 91.86% | 98.08% | 75.42% | 63.81% | 88.50% | 98.65% |

# DISCUSSION OF RESULTS

Visual examination of Figures 1(b – d) in comparison to Figure 1(a) reveasl that the minimum distance classifier gave the closest result to the true ground situation when a small size training site is used for the classification. The next in accuracy being the maximum likelihood while the mahalanobis distance classifier gave the least visually appealing output. Similarly, visual examination of the results of classification 2 also follow similar trend. These visually ascertainable results are further supported by the values obtained from the accuracy assessment results excerpts presented in tables 1 (a and b).

However, Tables 1 (a and b) justified the advantage of the use of the error matrix derived User accuracies over the conventional Kappa co-efficient and overall accuracy as the user is able to ascertain to a reasonable extent the confidence interval of the accuracy of a particular feature over other classes before using the image for further analysis.

For instance, in classification 1 and 2, although the overall accuracy and kappa co-efficient of maximum likelihood is more than that of mahalanobis distance classifier, the accuracy of the latter in classifying vegetation and bare ground exceeds that of the former. Therefore though the overall accuracy is lower, a user of such a classified image who is interested in vegetation or bare ground class would prefer to use the mahalanobis classifier rather than the maximum likelihood.

As it is seen from the user accuracy assessment that the accuracy of mahalanobis in classifying Vegetation and Bare Ground feature classes is consistently higher than that of the maximum likelihood in both classifications, it may be possible to further infer that the Mahalanobis distance is a better classifier for these classes than the Maximum likelihood. Further research is however recommended to validate this finding.

Finally, the summarized results presented above also shows that the accuracy of any classification technique is improved by large sized training

sites therefore the "Larger the size of the training site, the better the classification Results"

## CONCLUSION

From the discoveries made in this research, it can be affirmed that using kappa-coefficient and its overall accuracy alone as a means of evaluating accuracy measure of remote sensing image classification may not be absolutely reliable. Also, it has been identified that the larger the size of the training site, the better the resulting classified image obtained and that the mahalanobis classifier is better suited for vegetation and bare ground classes than the maximum likelihood classifier.

It is therefore recommended that image classification result assessment should be based on the use of confusion matrix results (Producer and User accuracy) rather than solely depending on the overall accuracy or the kappa co-efficient.

## REFERENCES

AKGÜN A, Eronat A. H and Turk N (2004); Comparing different satellite image classification methods: An application in Ayvalik District, Western Turkey.

Asmala, A and Shaun, Q (2012); Analysis of Maximum Likelihood Classification on multispectral data. Applied Mathematical Sciences. Vol 6 (No. 129) Pg. 6425 – 6436.

Campbell, J. B (2002); Introduction to remote Sensing, Taylors and Francis, London.

Dean, A. M and Smith, G. M (2003); An evaluation of per parcel land cover mapping using maximum likelihood class probabilities. International Journal of Remote Sensing, 24 (14), pp 2905 – 2920.

Francesco Holecz, Tri Setiyomo and Andrew Nelson (2014); Remote Sensing based Crop Yield Monitoring and Forecasting. A paper presented at an Expert Meeting on Crop Monitoring for Improved Food Security on 17th Februarty, 2014 at Vientiane, Lao PDR.

H. G. Jones and P. Schofield (2008): Thermal and other remote sensing of plant stress. Gen. Appl. Plant Physiology, 2008, Special Issue, 34(1-2), 19-32

Jipsa Kurian and V karunakaran (2012); A survey on Image Classification Methods. International Journal of Advanced research in electronics and communication engineering, Vol. 1, Issue 4, Oct 2012.

Liu, X. H, Skidmore, A. K and Oosten, V. H (2002); Integration of classification methods for improvement of land cover map accuracy. ISPRS Journal of Photogrammetry and Remote Sensing, 56, pp 257 – 268.

Lu. D and Weng. Q (2007); A Survey of Image Classification methods and techniques for improving classification performance, International Journal of Remote Sensing, Volume 28, Issue 5.

Nur Shazwani Kamarudin, Mokhairi Makhtar, Syed Abdullah Fadzli, Mumtazimah Mohamad, Fatma Susilawati Mohamad, Mohd Fadzil Abdulkadir (2015), Comparison of Image Classification Techniques using CALTECH 101 Dataset, Journal of Theorectical and Applied Information Technology, vol. 71, No 1. January 10, 2015.

Ozesmi, S. L and Bauer, M (2002); Satellite Remote Sensing of wetlands, Wetland Ecology and Management, 10, pp 381 – 402.

Pal, M. and Mather, P. M. (2003); "An assessment of the effectiveness of decision tree methods for land cover classification" Remote Sensing of Environment, 86, 554 – 565

Pooja kamavisdar, Sonam Saluja and Sonu Agrawal (2013); A Survey of Image Classification Approaches and Techniques. International Journal of Advanced research in Computer and Communication Engineering, Vol. 2, Issue 1, January 2013.

Shiguo and Desheng 2011; On chance - adjusted measures for accuracy assessment in remote sensing image classification. Proceedings of the American Society of Photogrammetry and Remote Sensing Annual Conference, Milwaukee, Wisconsin, May 1 - 5, 2011. http://www.yale.edu/ceo/OEFS/Accuracy_Assessment.pdf

# APPENDIX (ERROR MATRIX)

## (Classification 1)

### (a) MAXIMUM LIKELIHOOD CLASSIFIER:

Overall Accuracy = (83870/119973) 69.9074%
Kappa Coefficient = 0.5670

**Ground Truth (Percent) (Confusion Matrix)**

**Ground Truth (Percent)**

| Class | Vegetation | Mangroove | Built Up | Water | Bare Ground |
|---|---|---|---|---|---|
| Unclassified | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Vegetation [G] | 0.09 | 40.94 | 0.00 | 1.21 | 0.57 |
| Mangroove [Ye] | 99.91 | 14.13 | 0.00 | 0.00 | 0.00 |
| Built Up [Red] | 0.00 | 0.00 | 96.56 | 10.40 | 0.42 |
| Water [Blue] | 0.00 | 44.93 | 0.06 | 79.78 | 53.57 |
| Bare Ground [Ma] | 0.00 | 0.00 | 3.38 | 8.61 | 45.44 |
| Total | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |

**PERCENTAGE ERROR**

| Class | Commission (Percent) | Omission (Percent) | Commission (Pixels) | Omission (Pixels) |
|---|---|---|---|---|
| Vegetation [G] | 98.97 | 99.91 | 1924/1944 | 22231/22251 |
| Mangroove [Ye] | 97.82 | 85.87 | 22231/22726 | 3008/3503 |
| Built Up [Red] | 7.49 | 3.44 | 4123/55042 | 1816/52735 |
| Water [Blue] | 7.70 | 20.22 | 2634/34198 | 8001/39565 |
| Bare Ground [Ma] | 85.62 | 54.56 | 5191/6063 | 1047/1919 |

**ACCURACY ASSESSMENT**

| Class | Prod. Acc. (Percent) | User Acc. (Percent) | Prod. Acc. (Pixels) | User Acc. (Pixels) |
|---|---|---|---|---|
| Vegetation [G] | 0.09 | 1.03 | 20/22251 | 20/1944 |
| Mangroove [Ye] | 14.13 | 2.18 | 495/3503 | 495/22726 |
| Built Up [Red] | 96.56 | 92.51 | | 50919/52735 |
| 50919/55042 | | | | |
| Water [Blue] | 79.78 | 92.30 | | 31564/39565 |
| 31564/34198 | | | | |
| Bare Ground [Ma] | 45.44 | 14.38 | 872/1919 | |
| 872/6063 | | | | |

### (b) MAHALANOBIS CLASSIFIER:

Overall Accuracy = (54163/119973) 45.1460%

Kappa Coefficient = 0.1681

**Ground Truth (Percent) (Confusion Matrix)**

| Class | Water | Bare Ground | Mangroove | Built Up | Vegetation |
|---|---|---|---|---|---|
| Unclassified | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Water [Blue] | 3.71 | 69.15 | 20.44 | 0.01 | 0.00 |
| Bare Ground [Ma] | 0.30 | 30.12 | 0.03 | 3.81 | 0.00 |
| Mangroove [Ye] | 0.00 | 0.10 | 17.16 | 0.00 | 96.42 |
| Built Up [Red] | 90.35 | 0.47 | 4.60 | 96.18 | 0.00 |
| Vegetation [G] | 5.63 | 0.16 | 57.78 | 0.00 | 3.57 |
| Total | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |

**PERCENTAGE ERROR**

| Class | Commission (Percent) | Omission (Percent) | Commission (Pixels) | Omission (Pixels) |
|---|---|---|---|---|
| Water [Blue] | 58.28 | 96.29 | 2051/3519 | 38097/39565 |
| Bare Ground [Ma] | 78.64 | 69.88 | 2128/2706 | 1341/1919 |
| Mangroove [Ye | 97.28 | 82.84 | 21457/22058 | 2902/3503 |
| Built Up [Red | 41.46 | 3.82 | 35918/86639 | 2014/52735 |
| Vegetation [G | 84.26 | 96.43 | 4256/5051 | 21456/22251 |

**ACCURACY ASSESSMENT**

| Class | Prod. Acc. (Percent) | User Acc. (Percent) | Prod. Acc. (Pixels) | User Acc. (Pixels) |
|---|---|---|---|---|
| Water [Blue] | 3.71 | 41.72 | 1468/39565 | 1468/3519 |
| Bare Ground [Ma] | 30.12 | 21.36 | 578/1919 | 578/2706 |
| Mangroove [Ye] | 17.16 | 2.72 | 601/3503 | 601/22058 |
| Built Up [Red] | 96.18 | 58.54 | 50721/52735 | 50721/86639 |
| Vegetation [G] | 3.57 | 15.74 | 795/22251 | 795/5051 |

**(c) MINIMUM DISTANCE CLASSSIFIER**

Overall Accuracy = (104726/119973) 87.2913%
Kappa Coefficient = 0.8097

**Ground Truth (Percent) (Confusion Matrix)**

| Class | Vegetation | Water | Bare Ground | Mangroove | Built Up |
|---|---|---|---|---|---|
| Unclassified | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Vegetation [G] | 99.98 | 0.00 | 0.00 | 15.82 | 0.00 |
| Water [Blue] | 0.00 | 66.82 | 6.93 | 1.60 | 0.12 |
| Bare Ground [Ma] | 0.02 | 0.08 | 60.66 | 19.70 | 0.00 |
| Mangroove [Ye] | 0.00 | 15.09 | 0.94 | 62.89 | 0.00 |
| Built Up [Red] | 0.00 | 18.01 | 31.47 | 0.00 | 99.88 |
| Total | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |

**PERCENTAGE ERROR**

| Class | Commission (Percent) | Omission (Percent) | Commission (Pixels) | Omission (Pixels) |
|---|---|---|---|---|
| Vegetation [G] | 2.43 | 0.02 | 554/22801 | 4/22251 |
| Water [Blue] | 0.94 | 33.18 | 250/26689 | 13126/39565 |
| Bare Ground [Ma] | 38.41 | 39.34 | 726/1890 | 755/1919 |
| Mangroove [Ye] | 73.11 | 37.11 | 5989/8192 | 300/3503 |
| Built Up [Red] | 12.79 | 0.12 | 7728/60401 | 62/52735 |

**ACCURACY ACCESSMENT**

| Class | Prod. Acc. (Percent) | User Acc. (Percent) | Prod. Acc. (Pixels) | User Acc. (Pixels) |
|---|---|---|---|---|
| Vegetation [G] | 99.98 | 97.57 | 22247/22251 | 22247/22801 |
| Water [Blue] | 66.82 | 99.06 | 26439/39565 | 26439/26689 |
| Bare Ground [Ma] | 60.66 | 61.59 | 1164/1919 | 1164/1890 |
| Mangroove [Ye] | 62.89 | 26.89 | 2203/3503 | 2203/8192 |
| Built Up [Red] | 99.88 | 87.21 | 52673/52735 | 52673/60401 |

**(CLASSIFICATION 2)**

**(a) MAXIMUM LIKELIHOOD CLASSIFIER:**

Overall Accuracy = (104786/119973) 87.3413%
Kappa Coefficient = 0.8113

**Ground Truth (Percent) (Confusion Matrix)**

| Class | Built Up | Vegetation | Bare Ground | Mangroove | Water |
|---|---|---|---|---|---|
| Unclassified | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Built Up [Red] | 99.17 | 0.00 | 7.71 | 0.00 | 17.31 |
| Vegetation [G] | 0.00 | 99.23 | 0.16 | 28.06 | 0.00 |
| Bare Ground [Ma] | 0.75 | 0.77 | 91.56 | 17.98 | 1.24 |
| Mangroove [Ye] | 0.00 | 0.00 | 0.36 | 52.30 | 13.66 |
| Water [Blue] | 0.09 | 0.00 | 0.21 | 1.66 | 67.79 |
| Total | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |

**PERCENTAGE ERROR**

| Class | Commission | Omission | Commission | Omission |
|---|---|---|---|---|

| | (Percent) | (Percent) | (Pixels) | (Pixels) |
|---|---|---|---|---|
| Built Up [Red] | 11.80 | 0.83 | 6996/59291 | 440/52735 |
| Vegetation [G] | 4.27 | 0.77 | 986/23066 | 171/22251 |
| Bare Ground [Ma] | 48.95 | 8.44 | 1685/3442 | 162/1919 |
| Mangroove [Ye] | 74.71 | 47.70 | 5413/7245 | 1671/3503 |
| Water [Blue] | 0.40 | 32.21 | 107/26929 | 12743/39565 |

**ACCURACY ACCESSMENT**

| Class | Prod. Acc. (Percent) | User Acc. (Percent) | Prod. Acc. (Pixels) | User Acc. (Pixels) |
|---|---|---|---|---|
| Built Up [Red] | 99.17 | 88.20 | 52295/52735 | 52295/59291 |
| Vegetation [G] | 99.23 | 95.73 | 22080/22251 | 22080/23066 |
| Bare Ground [Ma] | 91.56 | 51.05 | 1757/1919 | 1757/3442 |
| Mangroove [Ye] | 52.30 | 25.29 | 1832/3503 | 1832/7245 |
| Water [Blue] | 67.79 | 99.60 | 26822/39565 | 26822/26929 |

**(b) MAHALANOBIS CLASSIFIER:**

Overall Accuracy = (103158/119973) 85.9843%

Kappa Coefficient = 0.7919

**Ground Truth (Percent) (Confusion Matrix)**

| Class | Vegetation | Water | Bare Ground | Mangroove | Built Up |
|---|---|---|---|---|---|
| Unclassified | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Vegetation [G] | 99.05 | 0.00 | 0.05 | 15.56 | 0.00 |
| Water [Blue] | 0.06 | 63.08 | 0.05 | 12.30 | 0.09 |
| Bare Ground [Ma] | 0.86 | 0.64 | 89.68 | 15.90 | 0.38 |
| Mangroove [Ye] | 0.03 | 18.43 | 0.73 | 55.95 | 0.02 |
| Built Up [Red | 0.00 | 17.86 | 9.48 | 0.29 | 99.51 |
| Total | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |

**PERCENTAGE ERROR**

| Class | Commission (Percent) | Omission (Percent) | Commission (Pixels) | Omission (Pixels) |
|---|---|---|---|---|
| Vegetation [G] | 2.42 | 0.95 | 546/22586 | 211/22251 |
| Water [Blue] | 1.93 | 36.92 | 491/25449 | 14607/39565 |
| Bare Ground [Ma] | 41.12 | 10.32 | 1202/2923 | 198/1919 |
| Mangroove [Ye] | 78.88 | 44.05 | 7319/9279 | 1543/3503 |
| Built Up [Red] | 12.15 | 0.49 | 7257/59736 | 256/52735 |

**ACCURACY ACCESSMENT**

| Class | Prod. Acc. | User Acc. | Prod. Acc. | User Acc. |
|---|---|---|---|---|

| | (Percent) | (Percent) | (Pixels) | (Pixels) |
|---|---|---|---|---|
| Vegetation [G] | 99.05 | 97.58 | 22040/22251 | 22040/22586 |
| Water [Blue] | 63.08 | 98.07 | 24958/39565 | 24958/25449 |
| Bare Ground [Ma] | 89.68 | 58.88 | 1721/1919 | 1721/2923 |
| Mangroove [Ye] | 55.95 | 21.12 | 1960/3503 | 1960/9279 |
| Built Up [Red] | 99.51 | 87.85 | 52479/52735 | 52479/59736 |

**(c) MINIMUM DISTANCE CLASSSIFIER**

Overall Accuracy = (110210/119973) 91.8623%

Kappa Coefficient = 0.8767

**Ground Truth (Percent) (Confusion Matrix)**

| Class | Vegetation | Bare Ground | Mangroove | Built Up | Water |
|---|---|---|---|---|---|
| Unclassified | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Vegetation [G] | 98.99 | 0.00 | 12.30 | 0.00 | 0.00 |
| Bare Ground [Ma] | 0.00 | 94.16 | 1.86 | 0.74 | 0.34 |
| Mangroove [Ye] | 1.01 | 1.62 | 76.62 | 0.00 | 3.20 |
| Built Up [Red] | 0.00 | 3.34 | 0.00 | 99.09 | 17.00 |
| Water [Blue] | 0.00 | 0.89 | 9.22 | 0.17 | 79.45 |
| Total | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |

**PERCENTAGE ERROR**

| Class | Commission (Percent) | Omission (Percent) | Commission (Pixels) | Omission (Pixels) |
|---|---|---|---|---|
| Vegetation [G] | 1.92 | 1.01 | 431/22458 | 224/22251 |
| Bare Ground [Ma] | 24.58 | 5.84 | 589/2396 | 112/1919 |
| Mangroove [Ye] | 36.19 | 23.38 | 1522/4206 | 819/3503 |
| Built Up [Red] | 11.50 | 0.91 | 6790/59046 | 479/52735 |
| Water [Blue] | 1.35 | 20.55 | 431/31867 | 8129/39565 |

**ACCURACY ASSESSMENT**

| Class | Prod. Acc. (Percent) | User Acc. (Percent) | Prod. Acc. (Pixels) | User Acc. (Pixels) |
|---|---|---|---|---|
| Vegetation [G] | 98.99 | 98.08 | 22027/22251 | 22027/22458 |
| Bare Ground [Ma] | 94.16 | 75.42 | 1807/1919 | 1807/2396 |
| Mangroove [Ye] | 76.62 | 63.81 | 2684/3503 | 2684/4206 |
| Built Up [Red] | 99.09 | 88.50 | 52256/52735 | 52256/59046 |
| Water [Blue] | 79.45 | 98.65 | 31436/39565 | 31436/31867 |