# Geometric Accuracy Assessment of Digital Map Derived from QuickBird High Resolution Satellite Imagery

*Nzelibe, I. U., Tata, H. and Nnamani, O. J
Department of Surveying and Geoinformatics, Federal University of Technology Akure, Nigeria
*Correspondence email: iunzelibe@futa.edu.ng

**Abstract**

*The evaluation of the geometric accuracy obtainable from orthorectified QuickBird High-Resolution Satellite Image (HRSI) product with an approximate Ground Sampling Distance (GSD) of 70cm, has been carried out using 49 Independent Check Points (ICPs). The ICPs which were selected on the QuickBird HRSI were represented as distinct point features conducive for high-precision measurement in both the HRSI and on the ground, well spread over the study area. These ICPs were surveyed using South Differential Global Positioning System (DGPS) based on the same coordinate reference and projection as that of the QuickBird HRSI, to obtain their corresponding coordinates of Ground Control Points (GCPs). The results obtained indicated that the differences were of small magnitude and random in nature. The computed Root Mean Square Error ($RMSE_{2D}$ of 0.722481 m) and adjusted $R^2$ (0.999999) indicates that the accuracy obtained, conformed to the resolution of the orthorectified QuickBird HRSI. Hence, the orthorectified QuikBird HRSI could be applied for map creation, change detection, image analysis, and to geolocate features in remote areas without the use of ground control points as well as other relevant mapping applications.*

**Keywords**: Geometric Accuracy, Digital Map, Differential GPS, Ground Control Points, QuickBird

## INTRODUCTION

New possibilities for mapping have been opened due to the availability of High-Resolution Satellite Images (HRSI) (Gupta & Jain, 2005). The increased level of quality that high-resolution satellite images have reached in recent years has demonstrated that these images could be a vital data source for the production of orthophoto images and different mapping products as well. Because of this, it is therefore, necessary to investigate and evaluate the geometric accuracy of these satellite images to comprehend their possible potential applicability and reliability for position determination (Li *et al.*, 2000). Nowadays, the cost of acquiring such mapping products (e.g., Ikonos Pro or QuickBird Orthorectified Imagery) is quite considerable, however, there are methods available for users with the photogrammetric capability to generate high accuracy mapping at the lowest cost from basic products such Ikonos Geo or QuickBird Imagery(Aguilar *et al.*, 2007).

In the past, the improvement in the resolution of satellite images has broadened the applications for satellite images to areas such as urban planning, data fusion with aerial photos and digital terrain models (DTMs), and the integration of cartographic features with GIS data. However, previous HRSI, such as 1-m resolution IKONOS, still could not replace the use of aerial photos, which resolutions as high as 0.2 to 0.3m (Toutin & Cheng, 2002). The successful launch of QuickBird and its high-resolution sensors has narrowed the gap between satellite images and aerial photos. QuickBird's high resolution, high revisit frequency, large area coverage, and the ability to take images over any area, especially hostile areas where airplanes cannot fly (DigitalGlobe, 2020), are certainly the major advantages over the use of aerial photos. The potential uses for QuickBird imagery are only limited by users' imagination (Toutin & Cheng, 2002). Instead of using aerial photos, highly detailed maps of entire countries can be frequently and easily updated using QuickBird's data. In addition, high resolution Digital Terrain Model (DTM) can be extracted automatically from the stereo data. The high-resolution DTM can help in areas such as determination of building heights, prediction of flood damage, and installation of cellular towers to achieve the best coverage. Some of the benefits of the QuickBird HRSI stated by the service providers include its ability to acquire high- quality satellite imagery for map creation, change detection, and image analysis, geolocate features to create maps in remote areas without the use of ground control points, Collect a greater supply of frequently updated global imagery products and extend the range of suitable imaging collection targets and enhance image interpretability sub-meter resolution imagery 61 cm panchromatic at nadir 2.44 m multispectral at nadir (DigitalGlobe, 2020).

Several studies have been carried out in the past, on the assessment of the potentials and accuracy of various satellite image products. Fraser *et al.,* (2002) used different models to process the IKONOS images. The results yielded 3D object-point determination with an accuracy of 0.5 m in plane and 0.7 m in height. Tadono *et al.,* (2004) describe the updated plans for sensor calibration and product validation of the Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM), which is to fly on the Advanced Land Observing Satellite (ALOS). Meguro & Fraser, (2010) evaluated a stereo pair of pansharpened GeoEye-1 Basic images covering the Tsukuba Test field in Japan, which contains more than 100 precisely surveyed and image-identifiable GCPs. It was indicated that the direct georeferenced accuracy was 2 m (CE90, the circular error of above 90% points) in plane and 3 m (LE90, the line error of above 90% points) in height. The use of a few GCPs improved the geopositioning accuracy to around 0.35 m (0.7 pixels) in plane and 0.7 m (1.4 pixels) in height. Dolloff & Settergren (2010) used the Metric Information Network (MIN) method to process all 50WorldView-1 stereo pairs. Statistics based on 101 ICPs (Independent Check Points) showed that the positioning result was 0.5 m in plane and 0.3 m in height.

Agugiaro *et al.,* (2012) evaluated the accuracy of GeoEye-1 andWorldView-2 by control and check data of the Trento test field in Italy. Where, 3D information extraction of the images was mentioned. For reference and validation, a DSM (Digital Surface Model) from airborne LiDAR acquisition was used as a standard for comparison. Wang *et al.,* (2014) validated the use of ZY-3 for the generation of cartographic maps at the 1:50,000 scale and for revision and updating of 1:25,000 scale maps. By detecting and eliminating various kinds of geometric processing errors, such as equipment installation, attitude and orbit measurement, camera distortion, time synchronization.

Li *et al.,* (2016) found that the geometric orientation accuracy of Chinese satellite images could be improved to be better than 1.5 pixels, which is higher than the designed accuracy. Tian *et al.,* (2017) showed that more accurate and reliable assessment results can be obtained by choosing the appropriate evaluation method of geometric positioning accuracy. Taylor *et al.,* (2011) mapped the distribution of an invasive species using Landsat TM, SPOT 5 and Quickbird imagery with the maximum likelihood supervised classification method. The cost-effectiveness of the three different kinds of imagery was also evaluated. Landsat TM multi-spectral (MS) imagery provided an overall accuracy of 85.1 percent and a kappa coefficient of 0.78, while SPOT 5 imagery gave an overall accuracy of 84.9 percent and a kappa value of 0.77. Landsat TM was suitable for detecting dense infestations. Quickbird showed an overall accuracy of 84 percent and a kappa coefficient of 0.76. Zheng *et al.,* (2018) studied the geometric accuracy of HRSI, based on this study, Pleiades reached an accuracy of 0.860 m in plane and 2.654 m in height, although the 0.5 m GSD (Ground Sampling Distance) of Pleiades is the highest among the HRSIs. SPOT6 reached an accuracy of 5.336 m in plane and 4.595 m in height, and also has a superior performance in geometric accuracy without GCP. It was stated that, the block adjustment accuracy without GCP of Pleiades and SPOT6 meet the requirements for 1:50,000 Topographic maps. However, ALOS, ZY-3 and TH-1 cannot reach that level. Nzelibe & Tata, (2018) carried out an evaluation on the potentials of QuickBird HRSI, in determination of encroachment within 30m Right-of-Way on a 1.4km road corridor located at Akure, Nigeria. Results obtained from this evaluation, recorded a mean absolute difference in area of encroachment between QuickBird HRSI and conventional survey as 1.656177 $m^2$ with standard deviation of 0.587613 $m^2$.

The need for mapping on the African continent in recent times is enormous, however, the conventional surveying and mapping technique, may not provide the best solutions in terms of speed and financial resources. Therefore, the HRSI offers an improved alternative. Based on the recent review of literature, several test fields have been established around the world, for evaluating the accuracies of satellite product. There is a need to evaluate the accuracy with which the QuickBird HRSI product represents map features over portions of the African continent. This study is aimed at investigating the geometric accuracy of the orthorectified QuickBird HRSI of the Federal University of Technology, Campus, Akure, Nigeria.

## Study Area

Part of the Federal University of Technology Akure (FUTA) campus, Ondo State Nigeria was selected for the study. The study area was found suitable for the study, based on the fact that, FUTA campus presented distinct point features conducive for high-precision measurement in both the HRSI and on the ground, required for HRSI geometric accuracy assessment. The study area lies geographically between latitudes 07˚ 16’ N and 07˚ 18ˈ N and longitudes 05˚ 09’ E and 05˚ 11ˈ E covering an area of approximately 222.954 hectares. Figure 1 is a map showing the study area.

## METHODOLOGY

The procedure adopted for this study is summarized in Figure 2. This is a schematic representation of the framework of the methodology adopted for this study. The procedure for this study, basically involves, acquisition of orthorectified QuickBird HRSI and ground surveys observation. Processing of data acquired was also carried out involving: identification and measurement of the ICPs on HRSI and processing of conventional ground survey data. Finally, evaluations of positional accuracies based on common points (Conventional survey GCP and HRSI-ICP) using the Root Mean Square Error (RMSE) and coefficient of determination (adjusted $R^2$) metrices.

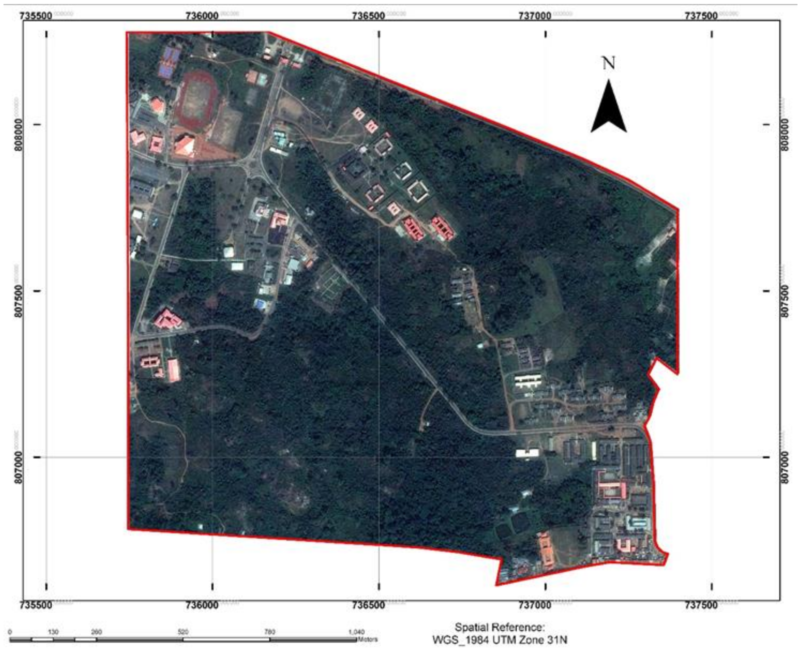


*Figure 1: Satellite Image Indicating the Study Area.*

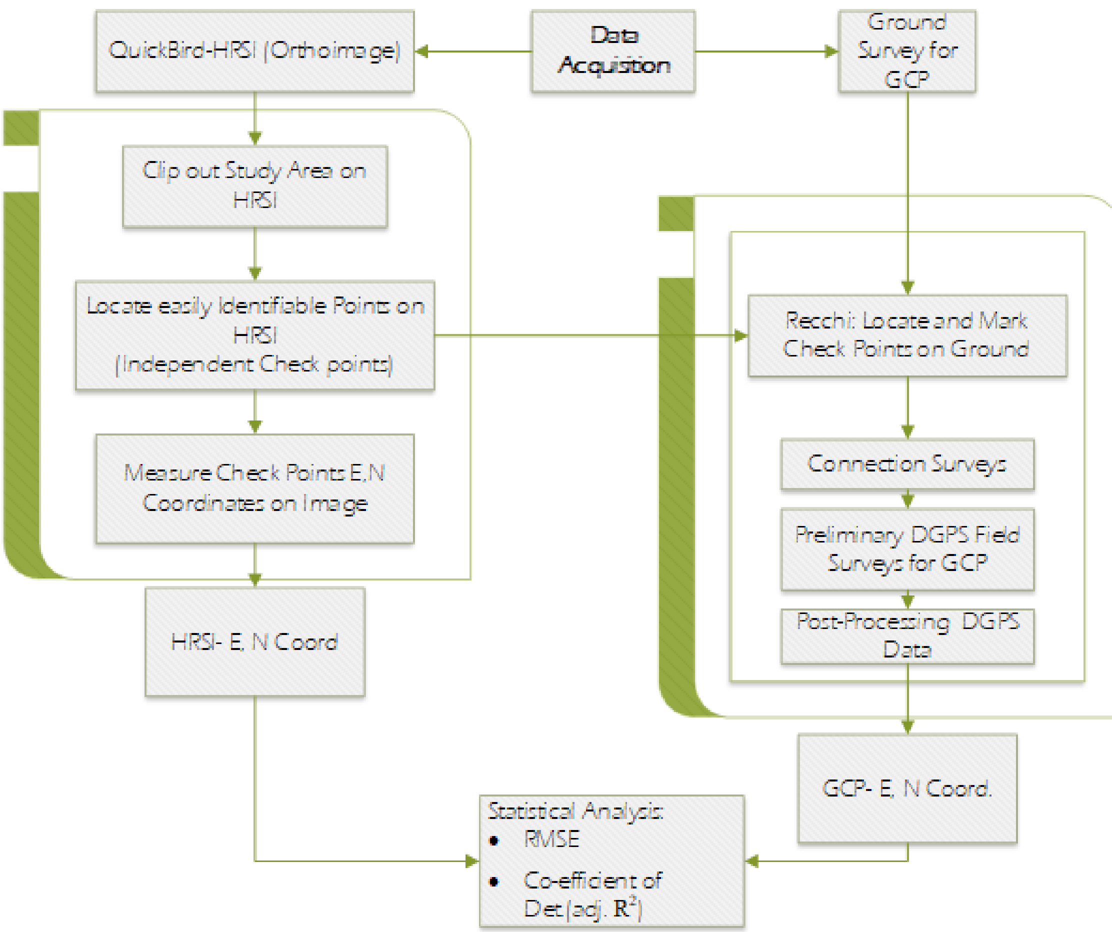


*Figure 2: Framework of methodology*

***Data Acquisition***

Multispectral Orthorectified QuickBird HRSI was obtained from DigitalGlobe, Inc. The HRSI is distributed in three different product forms which include: Basic Imagery, Standard Imagery, and Orthorectified Imagery (DigitalGlobe, 2020). Basic Imagery products are designed for users who have advanced image processing capabilities. It is the least processed image product. The positional accuracy is 23-m (CE 90%) and 14-m (RMSE), which does not include errors due to viewing geometry and terrain relief. Standard Imagery products are designed for users with knowledge of remote sensing applications and image processing tools that require data of modest absolute geometric accuracy and/or large area coverage. Each Standard Image is radiometrically calibrated, corrected for sensor and platform-induced distortions, and is mapped to a cartographic projection. These has similar accuracy as the Basic Imagery product except it only does not include errors due to terrain relief. The Orthorectified Imagery products are designed for users who require GIS-ready imagery products or a high-degree of absolute positioning accuracy for analytical applications. Each Orthorectified Imagery is radiometrically calibrated, corrected for systematic sensor and platform-induced distortions and topographic distortions, and is mapped to a user-specified cartographic projection (Toutin & Cheng, 2002).

To obtain orthorectified images of very high-resolution imagery, regardless of the raw data format, it is necessary to have into account the following: acquisition of image(s) and metadata, coordinates $X$, $Y$, $Z$ of ground points, ground control points (GCPs) and independent check points (ICPs), the image coordinates of these points, unknown parameters of the 3D geometric correction model used, and finally image(s) orthorectification using a digital elevation model (DEM). The resulting orthoimage can then be directly applied in Geographic Information Systems (GIS) or mapping oriented area applications. (Rossi & Volpe, 2005). The QuickBird HRSI used is the Multispectral HRSI, comprising of 4 bands (sub-images). These sub-images were rectified to a previously georeferenced QuickBird panchromatic satellite image bringing the resolution of the QuickBird HRSI used in the study to 0.7m. Table 1 is the metadata of the QuickBird HRSI used in the study.

Table 1: Metadata of the QuickBird HRSI product used

| **Raster Information** | **Value** |
|---|---|
| Number of Bands | 4 |
| Pixel size (x,y) | 0.5m, 0.5m |
| Ground Sample Distance (GSD) | 70.7cm |
| Pixel Depth | 16 Bits |
| Pyramid Level | 4 |
| Resampling | Nearest Neighbour |
| Coordinate System | WGS 1984 UTM Zone 31N |
| Linear Unit | Meter (1.000000) |
| Angular Unit | Degree (0.0174532925199433) |
| False Easting | 500,000 |
| False Northing | 0 |
| Central Meridian | 3 |
| Scale Factor | 0.9996 |
| Latitude of Origin | 0 |
| Datum | D_WGS 1984 |

The imagemap of the HRSI was delivered rectified and georeferenced to a coordinate system, projection and datum of UTM 31N WGS84. Hence, to evaluate accuracy of this orthorectified QuickBird HRSI, Independent Check Points (ICP) were carefully selected well spread over the study area comprising of distinct point features conducive for high-precision measurement in both the HRSI and on the ground. The corresponding GCPs were surveyed using the conventional surveying technique. In order to achieve this, reconnaissance survey was carried out, which involved identification of the GCPs and marking them on the ground using temporary markers. Forty-nine (49) ICP in all were marked on the ground as GCP. For the purpose of the preliminary survey, the South Differential Global Positioning System (DGPS) with a transmission range of 5m, was used in rapid-static positioning mode. For the purpose of the connection surveys, which was to be carried out in order to tie the survey to a first order control, the coordinates of 3 first-order controls were provided thus A72S, A73S, and A74S by the Ondo state Ministry of Lands. The datum of the first-order controls was transformed from Minna into WGS 1984, in order to conform to the datum of the orthorectified QuickBird HRSI. Since the study area was found to be within the range of the DGPS used the base receiver was mounted on A72S while the roving receiver was used to coordinate the 49 GCPs after the instrument and the pillars were checked and found to be in good condition.

### *Data Processing*

The data collected were processed at this stage. ArcGIS 10.6 was used in processing the QuickBird HRSI. The QuickBird HRSI product, which has already been preprocessed (georeferenced and orthorectified) ready for GIS applications before delivery, was imported into the ArcMap environment alongside its embedded coordinate reference and projections. The location of all 49 ICPs were carefully marked with a point marker, by zooming to the largest possible visible pixel resolution. The ICP were labelled serially from 1 - 49 and their X, Y geometry calculated as point feature attribute, which represents Eastings and Northings plane coordinates of the ICP. These ICP coordinates were exported as a text file for further analysis. For the purpose of processing the DGPS field observations, the observed RINEX files were post-processed using GNSS Solutions software. The post processing was carried out based on the coordinates system, projections and datum set the same as that of the QuickBird HRSI (WGS 1984 UTM Zone 31N). At the end of the post processing 2D plane coordinates of the GCPs were obtained.

## RESULTS AND DISCUSSION

Based on the study, the results obtained include a large-scaled digital orthophoto imagemap of the study area showing features with their respective labels as well as the ICP extracted from HRSI and corresponding GCP surveyed using DGPS as shown in Figure 3. Further more a zoomed portion of part of the study area around the “Jibowu Hall” is also represented in Figure 4.

The differences in the Eastings and Northings coordinates between the ICP measured on the QuickBird HRSI and GCP surveyed with DGPS were computed and plotted on a multiple bar chart in Figure 5. Figure 6 represents the differences in the 2D plane of the ICP measure on the HRSI and GCP surveyed with DGPS.

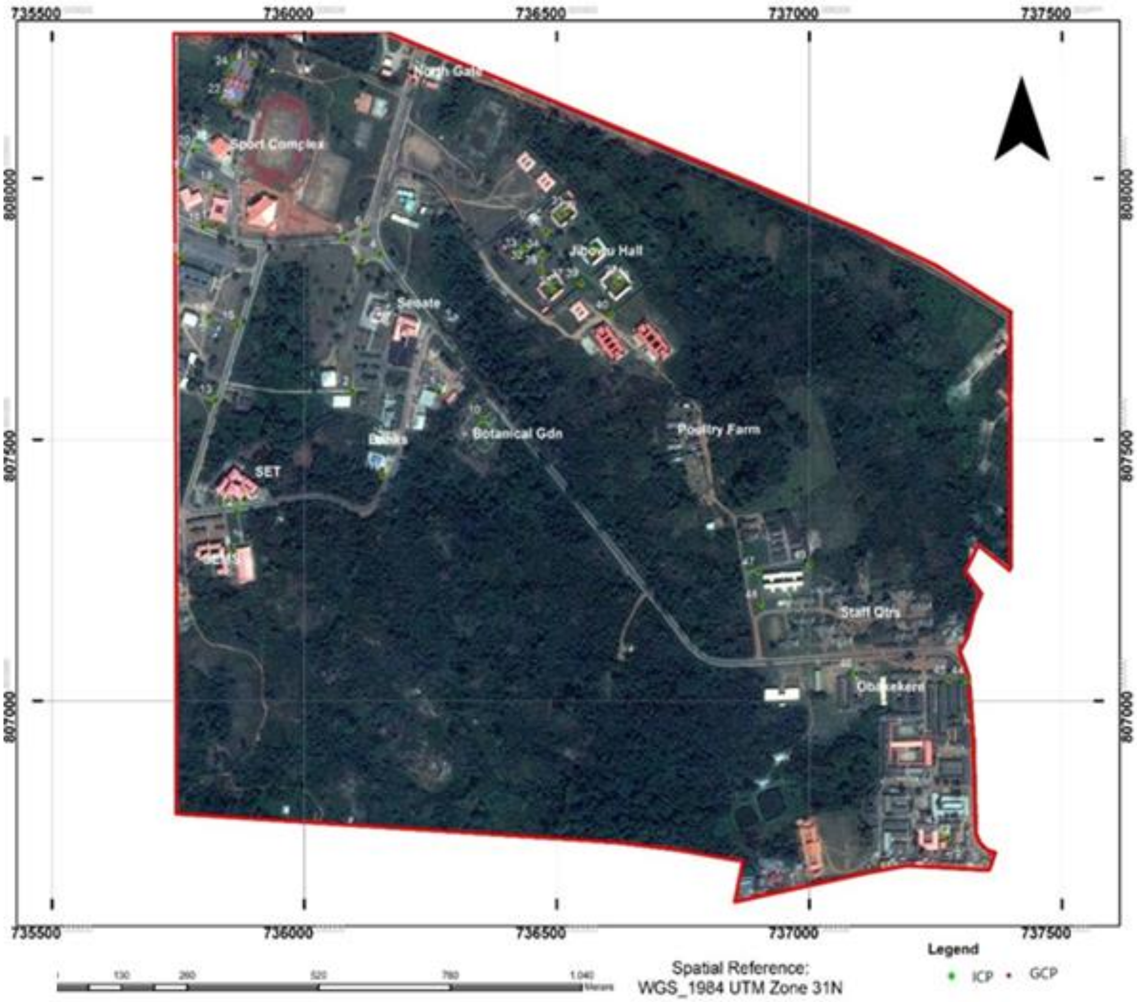


*Figure 3: QuickBird-HRSI Orthorectified image map of part of FUTA showing ICP and GCP*


*Figure 4: Zoomed Sub-image of study area, portraying differences in GCP and ICP*

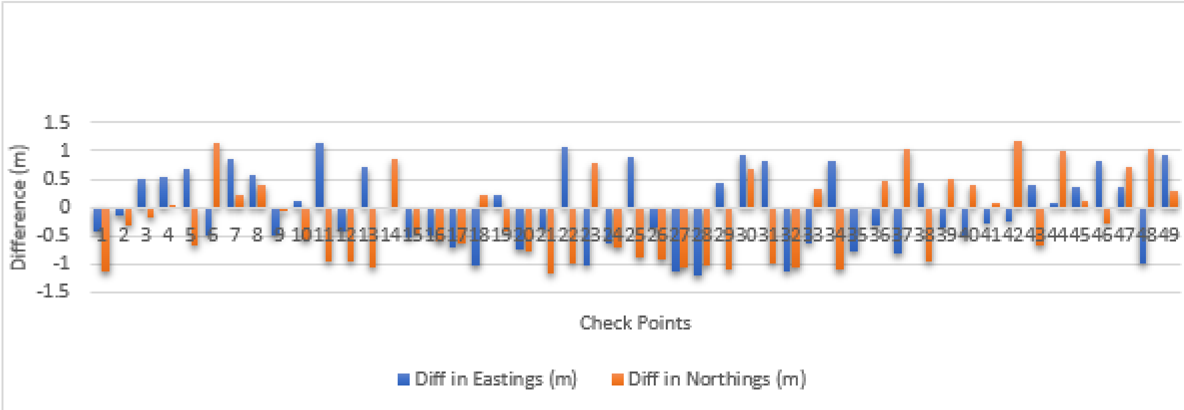


*Figure 5: Chart showing computed differences in coordinates of ICP measured on Orthoimage of QuickBird HRSI and ground surveyed GCP*

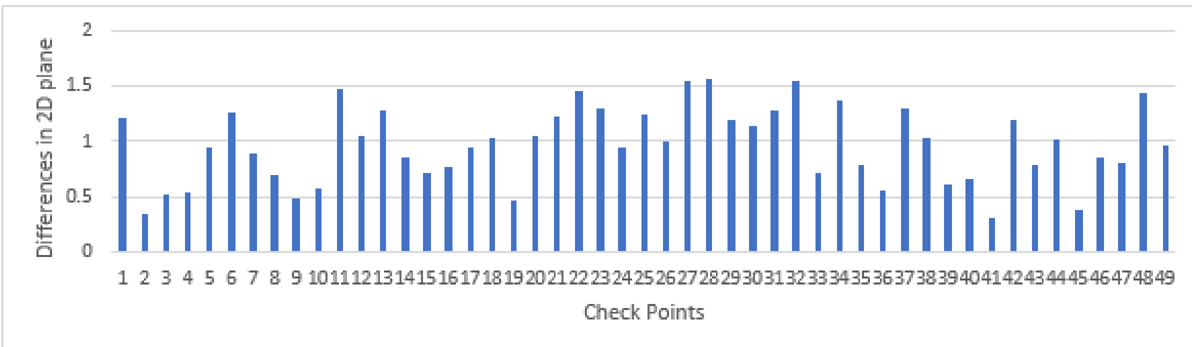


*Figure 6: Chart showing computed differences 2D plane in coordinates of ICP measured on Orthoimage of QuickBird HRSI and ground surveyed GCP*

The Root Mean Square Error (RMSE) and the Coefficient of Determination (adjusted $R^2$) evaluation metrics were also used to analyze the geometric accuracy of the QuickBird HRSI. The RMSE is the standard deviation of the residuals. Residuals are a measure of how far from the regression line data points are; RMSE is a measure of how spread out these residuals are.
The formula is given by Barnston, (1992) as:

$$RMSE_x = [\sum_{i=1}^{N}\left(East_{icp_i} - East_{GCP_i}\right)^2/N]^{1/2} \quad (1)$$

$$RMSE_y = [\sum_{i=1}^{N}\left(North_{icp_i} - North_{GCP_i}\right)^2/N]^{1/2} \quad (2)$$

$$RMSE_{2D} = \sqrt{RMSE_x^2 + RMSE_y^2} \quad (3)$$

Where $RMSE_x\ RMSE_y\ and\ RMSE_{2D}$ are the RMSE in easting, northing and the plane 2D coordinate components respectively, $\left(East_{icp_i} - East_{GCP_i}\right)$ and $(North_{icp_i} - North_{GCP_i})$ are the differences in eastings and northings coordinates between ICP and corresponding GCP for $N$ sample size.

The coefficient of determination, $R^2$, is used to analyze how differences in one variable can be explained by a difference in a second variable. The range is 0 to 1 (i.e. 0% to 100% of the variation in y can be explained by the x-variables). The coefficient of determination, $R^2$, is similar to the correlation coefficient, R. The correlation coefficient formula tells how strong a linear relationship exists between two variables. R Squared is the square of the correlation coefficient, r. The coefficient of determination can be thought of as a percent. It gives you an idea of how many data points fall within the results of the line formed by the regression equation. The higher the coefficient, the higher percentage of points the line passes through when the data points and line are plotted. Values of 1 or 0 would indicate the regression line represents all or none of the data, respectively. A higher coefficient is an indicator of better goodness of fit for the observations. The Adjusted Coefficient of Determination (adjusted R-squared) is an adjustment for the Coefficient of Determination that takes into account the number of variables in a data set. It also penalizes for points that do not fit the model. The adjusted $R^2$ is given by Vogt, (2005) as:

$$R^2_{adj} = 1 - \left(\frac{n-1}{n-p}\right)\frac{SSE}{SST} \tag{4}$$

Where SSE is Sum of Squared Error, SST is the Sum of Squared Total, $p$ is the number of regression coefficient and n is the total Number of observations. Result on Error Evaluation based on the RMSE and CoD metrices for check points and check lines are given on Table 3.

Table 3: Error evaluation metrics for point and linear measurements

| S/N | Error Evaluation matrices | Eastings (m) | Northings (m) | 2D Plane |
|---|---|---|---|---|
| 1 | Root Mean Squared Error (RMSE) | 0.679726385 | 0.762844071 | 0.722481499680 |
| 2 | Coefficient of Determination (adjusted $R^2$) | 0.999997959 | 0.99999631 | 0.99999999960 |

The GCPs measured on the ground and ICPs measured on the HRSI plotted on the image map (Figures 3 & 4), indicated little deviations between the ICP and GCP locational coordinates. The bar chart in Figure 5 indicates that the differences between the ICP and GCP coordinates are random in nature, and are of small magnitude, with positive and negative values approximately equally distributed. This implies that the effect of the systematic and gross error was not found in the 49 ICP used in evaluating the orthorectified QuickBird HRSI. The square root of the sum of the square of differences in easting and northing between ICP and GCP (as in Equation 3) were computed individually for the 49 ICPs, represented as coordinate differences in 2D plane. These differences in the 2D plane were presented in a bar chart in Figure 6. The differences in 2D plane indicated that out of the 49 ICPs, ICP No. 28 gave the largest difference as 1.5613m while the smallest difference at ICP No. 41 was 0.3004m. The $RMSE_{2D}$ having a value of 0.722481m, shows that the HRSI conforms to the 0.707m resolution of the QuickBird HRSI used in this study and also this indicates that the image processing operations carried out by QuickBird HRSI vendors yielded satisfactory a result. The adjusted $R^2$ having value 0.999999 indicates that 99% of the entire 49 data points fall within the results of the line formed by the regression equation. This shows a strong agreement between the HRSI ICP and the ground surveyed GCPs.

## CONCLUSION

The main campus of the Federal University of Technology, Akure, Nigeria, has been applied as a test field for evaluating the geometric accuracy of the 2D plane coordinates derived from orthorectified QuickBird HRSI. The QuickBird HRSI which has been preprocessed led to an improved average image resolution of 70cm. Evaluations carried out using 49 ICPs in this study reveals that the orthorectified QuickBird HRSI produced results which are satisfactory and conforms within the study area to the resolutions of the QuickBird HRSI. Based on this study, it could be stated that the potentials of the QuickBird HRSI can only be limited by the imagination of its users. Further investigations are necessary in the area of evaluating the radiometric accuracy and potentials of QuickBird HRSI in various mapping applications within locally established test fields.

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