International Journal of Innovative Environmental Studies Research 14():125-132, July-Sept, 2026

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DOI:10.5281/zenodo.22022120

A Comparative Investigation into Mapping Techniques: Traditional Land Surveying, GNSS and Satellite Imagery at Federal Polytechnic of Oil and Gas, Bonny, Rivers State, Nigeria

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ABSTRACT

The increasing demand for accurate, efficient, and cost-effective spatial data has intensified the need to evaluate mapping techniques suitable for institutional and coastal environments. This study comparatively assessed Traditional Land Surveying, Real-Time Kinematic (RTK) Global Navigation Satellite System (GNSS) surveying, and satellite imagery-based map extraction at the Federal Polytechnic of Oil and Gas, Bonny, Rivers State, Nigeria. The objective was to evaluate positional agreement, time efficiency, cost-effectiveness, and practical suitability for campus mapping and land management. Spatial data were acquired using conventional ground surveying, a Kolida C6 GNSS receiver operated in RTK mode, and satellite imagery acquired in 2021 at 10 m spatial resolution and referenced to WGS 84/UTM. Traditional survey coordinates were adopted as the reference dataset. Coordinate deviations were calculated from differences in X and Y coordinates, and planimetric errors were obtained using Euclidean distance. Based on the 24-point coordinate set, the Map method recorded a mean positional error of 0.556 m, an RMSE of 0.674 m, and a maximum error of 1.450 m, whereas GNSS recorded a mean positional error of 1.694 m, an RMSE of 2.053 m, and a maximum error of 4.093 m. The Map method therefore showed closer positional agreement with the Traditional reference within the dataset, while requiring less field time. The findings indicate that no single method is optimal for all applications: map extraction is suitable for preliminary planning and spatial analysis, GNSS for rapid field data capture, and Traditional surveying for control and applications requiring rigorous ground verification. An integrated workflow is therefore recommended for institutional mapping in coastal Niger Delta environments.

Keywords: Traditional surveying; RTK-GNSS; satellite imagery; map extraction; positional accuracy; RMSE; campus mapping; Bonny; Niger Delta.

1. INTRODUCTION

Accurate spatial data acquisition is fundamental to infrastructure development, environmental management, land administration, and institutional planning. The reliability of decisions relating to campus development, utility management, construction, and environmental monitoring depends largely on the quality of available geospatial information. Consequently, selecting an appropriate mapping technique requires consideration of positional accuracy, speed, cost, and the operational conditions of the survey environment.

The Federal Polytechnic of Oil and Gas, Bonny, Rivers State, Nigeria, is located within the Niger Delta, a coastal environment characterised by mangrove vegetation, high humidity, waterlogged terrain, and

limited geodetic control infrastructure (Obiefuna et al., 2013; Selemo et al., 2022). These conditions can complicate conventional surveying through restricted access, difficult station occupation, and increased field effort. At the same time, the institution requires reliable geospatial information for campus planning, infrastructure development, utility mapping, research, and land management (Federal Polytechnic of Oil and Gas Bonny, 2020).

Traditional land surveying, particularly total-station traversing, remains widely used for engineering and cadastral applications because of its established precision and suitability for detailed ground measurements.

However, it can be labour-intensive and time-consuming in difficult terrain (Nwankwo & Ogundare, 2019). GNSS has improved the speed of coordinate acquisition by reducing dependence on intervisibility between stations, although performance can be affected by canopy obstruction, multipath, satellite geometry, and other observation conditions (Lykasheva et al., 2020; Onyeogaziri et al., 2021).

Satellite imagery provides broad spatial coverage and can support rapid mapping and preliminary spatial analysis at relatively low operational cost. Its positional usefulness, however, depends on image resolution, georeferencing, acquisition date, and the quality of the source data (Eze & Okeke, 2018; Ogunlade & Akomolafe, 2021).

Although previous studies have examined individual techniques or compared selected approaches in other settings, there is limited empirical evidence from the study area comparing Traditional Surveying, GNSS, and satellite imagery-based mapping using the same set of survey points and environmental conditions. This study addresses that gap by comparing the three approaches within the Federal Polytechnic of Oil and Gas, Bonny.

The study addresses four questions: (1) Which technique provides the closest positional agreement with the Traditional reference under the study conditions? (2) Which method offers the best balance of accuracy, time efficiency, and cost-effectiveness? (3) What are the principal operational strengths and limitations of each technique in the study environment? and (4) How can the methods be combined to support institutional mapping applications?

2. RESEARCH PROBLEM AND OBJECTIVE

2.1 Research Problem

Accurate spatial data acquisition is fundamental to effective mapping, planning, and land management. However, the choice of mapping technique may be influenced by equipment availability, familiarity, or convenience rather than by evidence of comparative performance. Traditional land surveying provides detailed ground observations but may require substantial field time and labour. GNSS and satellite imagery provide faster or broader alternatives, but their positional performance depends on equipment, observation conditions, image characteristics, and processing procedures.

At the Federal Polytechnic of Oil and Gas, Bonny, accurate spatial information is required for infrastructure development, land-use planning, utility management, and surveying-related training. Yet the available study did not provide a direct comparison of Traditional surveying, RTK-GNSS, and satellite imagery-based coordinate extraction under the same local conditions. This creates a practical need to evaluate their relative positional agreement, operational efficiency, and suitability for different mapping tasks.

2.2 Objective of the Study

The objective of this study was to comparatively evaluate Traditional Land Surveying, RTK-GNSS surveying, and satellite imagery-based mapping within the Federal Polytechnic of Oil and Gas, Bonny, Rivers State, Nigeria.

1. Acquire and process spatial data of the study area using Traditional surveying, RTK-GNSS, and satellite imagery.
2. Evaluate the positional agreement and reliability of each mapping approach.
3. Compare the time efficiency and cost-effectiveness of the three approaches.

4. Identify the strengths, limitations, and practical applications of each approach under the study conditions.

2.3 Area of Study

The study was conducted within the premises of the Federal Polytechnic of Oil and Gas, Bonny, located on Bonny Island, Rivers State, Nigeria. Bonny Island lies within the Niger Delta and is characterised by coastal influences, mixed vegetation, low-lying terrain, creeks, mangrove environments, and sandy soils. The study area lies approximately between latitude 4°26′ and 4°28′ N and longitude 7°09′ and 7°13′ E. The local environment provides a useful setting for evaluating mapping approaches under coastal field conditions. The Polytechnic contains academic buildings, hostels, administrative facilities, and open or undeveloped areas suitable for surveying and mapping activities.

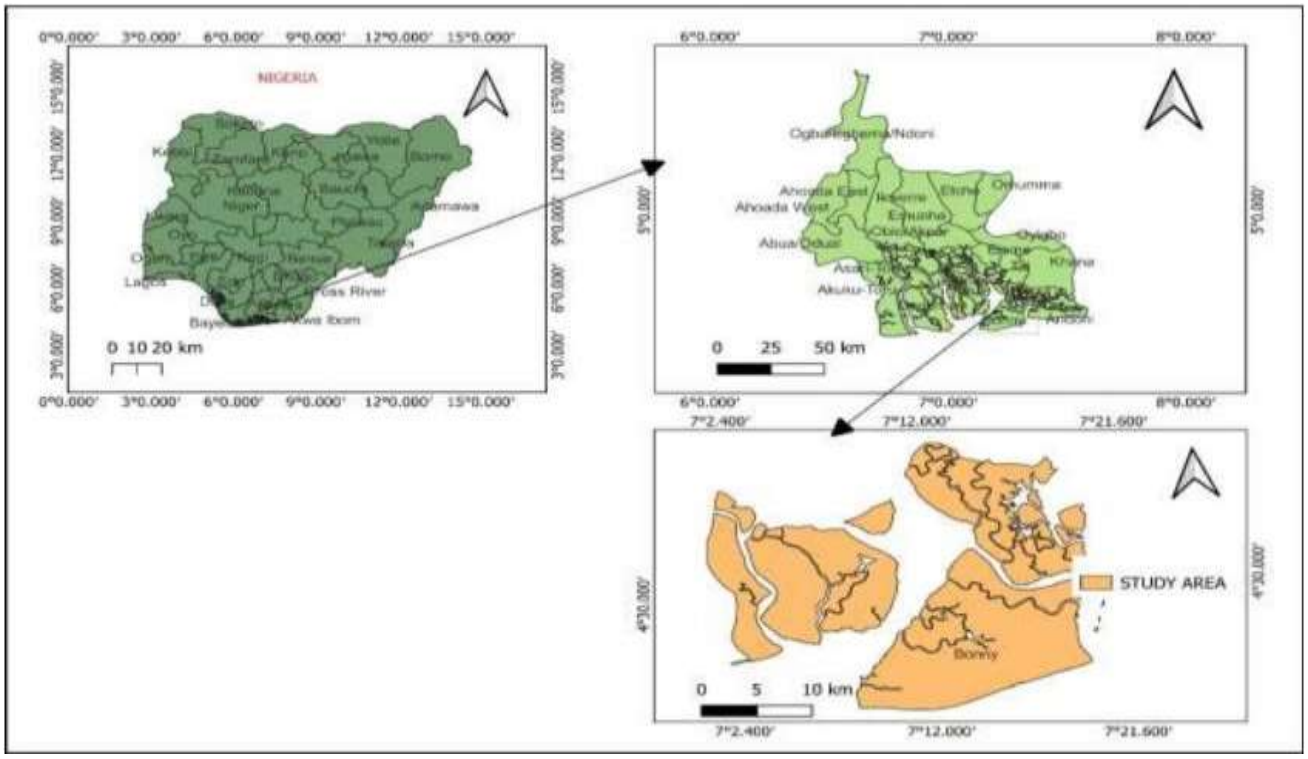
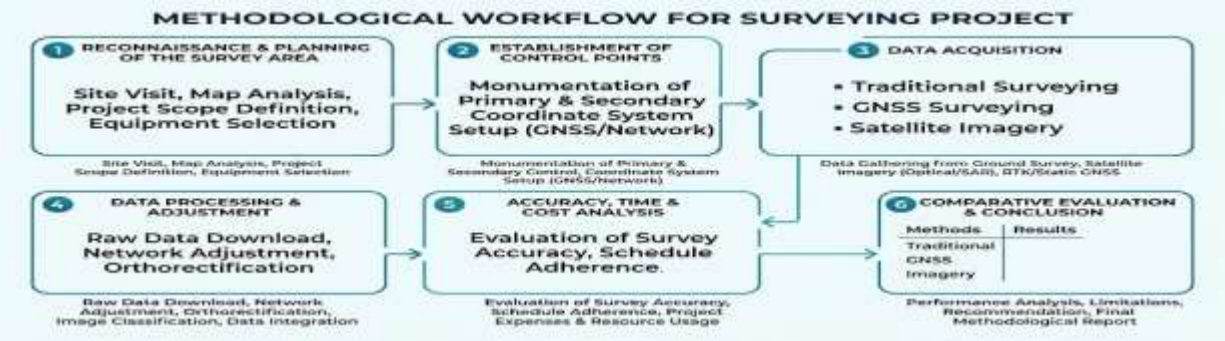


Fig 1: Map of Bonny

3. METHODOLOGY

3.1 Research Design

The study adopted a comparative design in which the same selected points were represented using three mapping approaches: Traditional Land Surveying, RTK-GNSS surveying, and satellite imagery-based mapping. Traditional survey coordinates were adopted as the reference dataset for assessing the positional deviations of the other two methods. The workflow comprised data acquisition, coordinate processing, deviation analysis, area comparison, and comparative assessment of time efficiency, cost-effectiveness, and operational suitability.



3.2 Data Acquisition

3.2.1 Traditional Land Surveying

Traditional surveying was undertaken to establish reference coordinates for the selected points within the study area. Conventional ground-surveying observations were obtained using the survey equipment employed for the field exercise. A graphical method was used for traverse closure, and RPP was adopted as the precision standard for the survey observations. The resulting coordinate dataset served as the reference against which the corresponding GNSS and satellite imagery-derived coordinates were compared.

3.2.2 RTK-GNSS Data Acquisition

GNSS observations were obtained using a Kolida C6 receiver operated in Real-Time Kinematic (RTK) mode. RTK was selected because it enables rapid field coordinate acquisition with high positional precision under suitable observation and correction conditions. The manufacturer-specified accuracy of the Kolida C6 is approximately 2 cm under appropriate conditions. The resulting GNSS coordinates were compared point-bypoint with the Traditional survey coordinates.

3.2.3 Satellite Imagery-Based Mapping

Satellite imagery was used as the third data acquisition approach. The imagery used for the coordinate extraction was acquired in 2021 and had a spatial resolution of 10 m per pixel. The imagery was referenced using the World Geodetic System 1984 (WGS 84) within the Universal Transverse Mercator (UTM) coordinate system. Coordinates corresponding to the selected survey points were extracted from the georeferenced imagery and compared with the Traditional survey coordinates.

Fig 2: Federal Polytechnic of Oil and Gas Bonny imagery

3.3 Data Processing and Analysis

The coordinates from the three approaches were organised and compared on a point-by-point basis. Traditional survey coordinates were treated as the reference values. Deviations for the Map and GNSS methods were calculated as follows:

$\Delta X = X_method - X_traditional$

$\Delta Y = Y_method - Y_traditional$

The resultant planimetric positional error was calculated using the Euclidean distance:

$E = \sqrt{[(\Delta X)^2 + (\Delta Y)^2]}$ where E is the planimetric positional error, ΔX is the difference between the method and Traditional Xcoordinates, and ΔY is the difference between the method and Traditional Y-coordinates.

For each alternative method, the mean positional error, RMSE, and maximum positional error were determined from the 24 corresponding points. RMSE was calculated as the square root of the mean squared point-by-point positional errors. Area was calculated from the coordinate vertices using the coordinate (shoelace) method, treating the listed points as boundary vertices in their stated sequence.

3.4 Comparative Assessment

The approaches were compared in terms of positional agreement, time efficiency, cost-effectiveness, operational requirements, and practical suitability. Positional performance was assessed quantitatively from the deviations relative to the Traditional reference. Time and cost were assessed qualitatively from the operational requirements of each approach, including field observation, equipment, personnel, transportation, processing, and dependence on existing spatial data. Because direct monetary cost records were not available, the cost-effectiveness assessment should be interpreted as a qualitative comparison rather than as a measured economic analysis.

4. RESULTS

4.1 Coordinate Data

S/N	Map X	Map Y	GNSS X	GNSS Y	Traditional X	Traditional Y
1	299526.470	489921.460	299526.9086	489922.4734	299526.730	489920.840
2	299526.090	489912.570	299525.0906	489910.8003	299525.190	489911.780
3	299518.730	489905.630	299518.6020	489905.6093	299518.760	489904.940
4	299443.270	489902.970	299442.8582	489905.0512	299442.570	489903.700
5	299477.770	490158.830	299477.7264	490160.4011	299477.980	490159.080
6	299486.220	490215.460	299485.9525	490214.0461	299486.090	490215.467
7	299537.570	490220.180	299537.1982	490224.0299	299537.070	490220.229
8	299536.260	490261.290	299536.4684	490261.4724	299536.080	490260.980
9	299645.880	490272.760	299646.2515	490267.3533	299646.480	490271.440
10	299648.510	490051.200	299646.2287	490051.0017	299648.870	490051.610
11	299648.110	490049.600	299648.1074	490050.1929	299648.190	490049.650
12	299649.660	490045.500	299648.1719	490045.9384	299649.750	490045.740
13	299648.920	490042.970	299648.5781	490043.2835	299649.110	490043.100
14	299649.060	490039.780	299649.2224	490040.6061	299649.330	490039.970
15	299652.170	490037.680	299650.8071	490038.3691	299651.500	490037.370
16	299642.140	490017.430	299642.0249	490018.1050	299642.060	490017.400
17	299636.660	489967.170	299639.0458	489966.1244	299637.290	489966.940
18	299612.110	489967.600	299616.2768	489966.3483	299612.550	489967.890
19	299583.560	489955.170	299586.1019	489953.3365	299583.670	489955.570
20	299551.840	489954.550	299552.6797	489951.8274	299551.390	489953.980
21	299553.780	489905.490	299552.5085	489907.8731	299553.510	489905.200
22	299549.680	489906.990	299549.5054	489907.6124	299549.480	489906.860
23	299544.180	489912.680	299544.3782	489912.8129	299543.890	489912.550
24	299547.050	489925.420	299544.9356	489925.1897	299545.660	489925.040

4.2 Area Comparison

Method	Calculated Area (m²)	Area (ha)	Difference from Traditional (m²)	Difference (%)
Traditional Survey	56,585.495	5.6585	0.000	0.000
Map	56,472.196	5.6472	-113.299	-0.200
GNSS	56,295.158	5.6295	-290.337	-0.513

Using the coordinate vertices in their listed sequence, the Traditional survey produced the largest calculated area (56,585.495 m²). The Map method differed from the Traditional area by 113.299 m² (0.200%), while

GNSS differed by 290.337 m² (0.513%). Thus, the Map-derived area showed closer agreement with the Traditional area for the coordinate set analysed.

4.3 Positional Deviation and Accuracy

S/N	Map ΔX (m)	Map ΔY (m)	Map Error (m)	GNSS ΔX (m)	GNSS ΔY (m)	GNSS Error (m)
1	-0.260	0.620	0.672	0.179	1.633	1.643
2	0.900	0.790	1.198	-0.099	-0.980	0.985
3	-0.030	0.690	0.691	-0.158	0.669	0.687
4	0.700	-0.730	1.011	0.288	1.351	1.382
5	-0.210	-0.250	0.327	-0.254	1.321	1.345
6	0.130	-0.007	0.130	-0.138	-1.421	1.428
7	0.500	-0.049	0.502	0.128	3.801	3.803
8	0.180	0.310	0.358	0.388	0.492	0.626
9	-0.600	1.320	1.450	-0.229	-4.087	4.093
10	-0.360	-0.410	0.546	-2.641	-0.608	2.710
11	-0.080	-0.050	0.094	-0.083	0.543	0.549
12	-0.090	-0.240	0.256	-1.578	0.198	1.590
13	-0.190	-0.130	0.230	-0.532	0.184	0.563
14	-0.270	-0.190	0.330	-0.108	0.636	0.645
15	0.670	0.310	0.738	-0.693	0.999	1.216
16	0.080	0.030	0.085	-0.035	0.705	0.706
17	-0.630	0.230	0.671	1.756	-0.816	1.936
18	-0.440	-0.290	0.527	3.727	-1.542	4.034
19	-0.110	-0.400	0.415	2.432	-2.233	3.301
20	0.450	0.570	0.726	1.290	-2.153	2.510
21	0.270	0.290	0.396	-1.001	2.673	2.854
22	0.200	0.130	0.239	0.025	0.752	0.753
23	0.290	0.130	0.318	0.488	0.263	0.554
24	1.390	0.380	1.441	-0.724	0.150	0.739

4.4 Summary of Positional Accuracy

Method	Mean Positional Error (m)	RMSE (m)	Maximum Error (m)
Map vs Traditional	0.556	0.674	1.450
GNSS vs Traditional	1.694	2.053	4.093

The Map method produced the smaller mean positional error, RMSE, and maximum error relative to the Traditional reference. This indicates closer positional agreement and lower dispersion within the 24-point dataset. GNSS exhibited larger deviations, particularly at points 7, 9, 18, 19, and 21.

4.5 Time Efficiency and Cost-Effectiveness

Method	Observed/Reported Time	Time Efficiency	Cost-Effectiveness
Traditional Survey	2 weeks	Low	Moderate to Low
Map Extraction	1 day	Very High	Very High
GNSS Survey	3 days	High	Moderate

The time values should be interpreted as the reported duration for the study exercise rather than as universally applicable benchmarks. The Traditional survey required field reconnaissance, instrument setup, observations, booking, computation, and plotting. Map extraction required substantially less field activity once the source imagery was available. GNSS provided a faster field workflow than Traditional surveying but still required field occupation and equipment.

4.6 Strengths, Limitations and Practical Applications

Approach	Major Strength	Major Limitation	Most Suitable Local Application
Traditional Survey	High confidence for detailed ground control and engineering measurements	Labour- and time-intensive	Control, cadastral and engineering surveys
RTK-GNSS	Rapid field coordinate acquisition	Performance depends on observation conditions and equipment/correction availability	Topographic surveys, GIS data capture and reconnaissance
Map Extraction	Rapid, economical and widearea coverage	Dependent on source imagery, resolution and georeferencing quality	Preliminary mapping, planning and feasibility studies

5. DISCUSSION

The comparison demonstrates that the three approaches provide complementary rather than interchangeable capabilities. The Map method produced the closest positional agreement with the Traditional reference for the 24-point dataset, with a mean positional error of 0.556 m and RMSE of 0.674 m. Its maximum error was 1.450 m. The GNSS method produced a higher mean positional error of 1.694 m, an RMSE of 2.053 m, and a maximum error of 4.093 m. Therefore, within this study, the Map method showed lower positional dispersion than the GNSS observations.

The result should not be interpreted as evidence that satellite imagery is inherently more accurate than GNSS. The comparison is relative to the Traditional reference dataset and is specific to the imagery, coordinate extraction procedure, GNSS observation conditions, and 24 points used in this study. The larger GNSS deviations at selected points indicate that field observation conditions and processing may have affected the coordinate agreement.

The area comparison provides a second measure of consistency. The Map-derived area differed from the Traditional area by 0.200%, while the GNSS-derived area differed by 0.513%. The smaller Map difference indicates closer agreement in the computed polygon area for the coordinate set analysed.

Operationally, the methods have distinct advantages. Traditional surveying remains appropriate where detailed ground control and rigorous verification are required, but its field workflow is comparatively demanding. RTK-GNSS can provide rapid field positioning and is particularly useful where intervisibility between stations is inconvenient. Map extraction is highly efficient for preliminary planning and spatial screening, but its usefulness for detailed ground positioning is constrained by the quality and spatial resolution of the source imagery.

These findings support the position that the methods should be selected according to the purpose and required accuracy of a mapping project. Previous studies have similarly identified the efficiency benefits of modern geospatial technologies while noting the influence of environmental and data-quality conditions on positional performance (Lykasheva et al., 2020; Nwankwo & Ogundare, 2019; Ogunlade & Akomolafe, 2021). In the coastal setting of Bonny, an integrated workflow is therefore more defensible than selecting a single technique for all tasks.

6. CONCLUSION

This study comparatively evaluated Traditional Land Surveying, RTK-GNSS, and satellite imagery-based map extraction using a common set of 24 coordinate points at the Federal Polytechnic of Oil and Gas, Bonny. Traditional survey coordinates were used as the reference dataset. The Map method produced a

mean positional error of 0.556 m, RMSE of 0.674 m, and maximum error of 1.450 m, while GNSS produced a mean positional error of 1.694 m, RMSE of 2.053 m, and maximum error of 4.093 m. The Map method also showed closer agreement with the Traditional area, differing by 0.200% compared with 0.513% for GNSS.

The findings indicate that map extraction is particularly useful for preliminary mapping, planning, and rapid spatial assessment; RTK-GNSS is useful for rapid field data acquisition; and Traditional surveying remains appropriate for establishing and verifying detailed ground control. Because the three methods have different strengths and limitations, an integrated workflow—map extraction for preliminary planning, GNSS for rapid field capture, and Traditional surveying for control and final verification—is recommended for institutional mapping applications in coastal Niger Delta environments.

The study is limited by the use of a single institutional study area, a 24-point coordinate dataset, and qualitative rather than measured cost assessment. Future studies should incorporate larger and more diverse control networks, multiple imagery sources and acquisition dates, independently verified ground control, and direct time and cost measurements.

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