PRODUCTION OF A TOPOGRAPHIC MAP AND THE CREATION OF A SIX-LAYER GEOGRAPHIC INFORMATION SYSTEM (GIS) FOR A FIFTEEN SQUARE-KILOMETRE (15 KM^2) AREAL EXTENT OF THE GIDAN KWANO CAMPUS OF THE FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGER STATE, NIGERIA

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Abstract
This work was designed in order that proper surveying, topographic, and Geographic Information System information for a defined fifteen square-kilometer (15km^2) gridded area was executed. The objectives of this project are the creation of a detailed topographic map for the area of study so as to reduce ambiguities in future geoscientific studies at the study area, the implementation of georeferencing protocol at the area of study, the creation of a GIS database for the area of study, and the creation of specific GIS layers for the area of study. These GIS layers define the outcrop, arboreal, economic resource, land use, as well as squatters' settlements profile of the area of study. The area selected for this study is located at the following co-ordinate grids: N09^{0}30'25.20", E006^{0}26'11.34"; N09^{0}33'07.20", E006^{0}26'11.34" and N09^{0}30'25.20", E006^{0}24'34.14"; N09^{0}33'07.20", E006^{0}24'34.14". Latitude, longitude, elevation (i.e. x, y, z) information using the Etrex hand-held Global Positioning System (GPS) units were collected every 100m along every N-S and E-W axes at the area of study, thus forming a grid of 1581 georeferenced stations of interest for the topographic map generation. X, y, z information-gathering sequence for the GIS layers was a non-gridded, spatial-oriented exercise. The site-specific topographic map for this project work was generated using the Golden Surfer 8 software. In addition, the ArcView GIS was used to create a six-layer Geographic Information System (GIS) for the area of study. The topographic map and GIS database can be considered as a suite of very important reference materials that can be assessed by researchers engaged in future surface and subsurface formation studies in the area of study.

Keywords: Topographic, georeferencing, GIS, geosciences, survey, latitude, longitude, elevation

Introduction
It is now desirable, more than ever before, that geological or geophysical surveys must be tied in to an existing Geographic Information System (GIS) platform. Moreso, georeferencing of survey stations should be the acceptable norm and data analysis and presentation must be aided by tie-ins to the GIS database. It is as a result of these facts that this work was designed in order that proper surveying, topographic, and GIS information for a three-kilometre by five-kilometre (i.e. a fifteen square-kilometer) gridded area was generated.

Geoscientific investigations must necessarily be tied-in to existing topographic maps and Geographic Information System (GIS) database of any area of study. Where no such information exist, result presentations are likely to be fraught with ambiguities.

The objectives of this study are the following:
(i) The creation of a detailed topographic map for the area of study.
(ii) The creation of a Geographic Information System (GIS) database for the area of study.

This GIS database is made up of layers that define the outcrop, arboreal, economic resource, land use, and squatters' settlements profile of the area of study.

According to the published literature (ABEM, 1999), any geoscientific survey must be tied-in to existing topographic, geologic, and suchlike (e.g. GIS) maps of the area of interest. Thus this project work has provided a platform by means of which these targets could be met.

The total extent of survey for this project work was 15km^2. Georeferenced data were collected at 100m intervals. Owing to financial and time constraints, only 15km^2 of the total 100km^2 landmass of the Gidan Kwano Campus could be covered.

The area of study is a 15km^2 areal extent within the Gidan Kwano Campus (GKC) of the Federal University of Technology, Minna, Nigeria. The GKC is about 10,650 hectares or 106.5 km^2 in size. The georeferenced indicators of the area of study are N09^{0}30'25.20'', E006^{0}26'11.34''; N09^{0}33'07.20'', E006^{0}26'11.34'' and N09^{0}30'25.20'', E006^{0}24'34.14''; N09^{0}33'07.20'', E006^{0}24'34.14''.

Graph drawing and cartography interact when graphs that already have an embedding (i.e. geometric networks) have to be visualized. Examples of such networks are street, subway, river, or cable networks. Often it helps to visualize the underlying network for analyzing the quantity under consideration. For example, traffic on a road network can be visualized by drawing each road as a rectangle whose width is proportional to the amount of traffic in that road (Wolff, 2004). One of the main problems in map production is a process called *generalization*. Given cartographic data that has been collected at large scale, this data must be simplified in order to produce maps at small scale. In order to obtain readable maps, detail must be reduced and spacing must be enlarged. Traditionally this has been done manually by cartographers, but increasingly semi-automated and even automated methods are in use, particularly in conjunction with Geographic Information Systems, GIS. The esthetic constraints that govern the process of drawing geometric networks can be seen as an example of generalization: usually vertices must keep a certain minimum distance and edges are restricted to polygonal lines that use few directions and have few bends. Note that general graph-drawing algorithms cannot be used ad hoc for drawing geometric networks since they do not respect the given embedding. A good drawing of a geometric network must reflect geometry in a certain way since a user typically has some intuitive notion of the underlying geometry, a *mental map* in other words. For example, the user of a metro system expects stations in the north to appear on the top of maps that depict the metro system. Thus the aim of drawing geometric networks is to find a good compromise between distorting geometry and maximizing aesthetics (Eades et al., 1991).

The term “topographic surveying” encompasses a broad range of surveying and mapping products, ranging from aerial mapping to ground and underground surveys (www.140.194.76.129.org). “Control surveying” is a survey which provides horizontal or vertical position data for the support or control of subordinate surveys or for mapping (www.140.194.76.129.org). Topographic surveys have been defined as follows: “A topographic map shows, through the use of suitable symbols, (1) the spatial characteristics of the earth’s surface, with such features as hills and valleys, vegetation and rivers, and (2) constructed features such as buildings, roads, canals, and cultivation. The distinguishing characteristic of a topographic map, as compared with other maps, is the representation of the terrain relief.”

According to Wikipedia (2011), a contour line (also *isoline* or *isarithm*) of a function of two variables is a curve along which the function has a constant value (also Courant et al., 1996). In cartography, a contour line (often just called a "contour") joins points of equal elevation (height) above a given level, such as mean sea level. A contour map is a map illustrated with contour lines, for example a topographic map, which thus shows valleys and hills, and the steepness of slopes. The contour interval of a contour map is the difference in elevation between successive contour lines (Tracy, 1907). More generally, a contour line for a function of two variables is a curve connecting points where the function has the same particular value. The gradient of the function is always perpendicular to the contour lines. When the lines are close together the magnitude of the gradient is large: the variation is steep. A level set is a generalization of a contour line for functions of any number of variables. Contour lines are curved or straight lines on a map describing the intersection of a real or hypothetical surface with one or more horizontal planes. The configuration of these contours allows map readers to infer relative gradient of a parameter and estimate that parameter at specific places. Contour lines may be either traced on a visible three-dimensional model of the surface, as when a photogrammetrist viewing a stereo-model plots elevation contours, or interpolated from estimated surface elevations, as when a computer program threads contours through a network of observation points of area centroids. In the latter case, the method of interpolation affects the reliability of individual isolines and their portrayal of slope, pits and peaks (Davis, 1986).

According to Wikipedia (2010), Geographic Information System (GIS) represents a new paradigm for the organization of information and design information system, the essential aspect of which is use of the concept of location as the basis for the structuring of information system. The main advantage of using GIS is its ability to access and analyze spatially distributed data with respect to its actual spatial location overlaid on a base map of the area of coverage that allows analysis not possible with the other data base management systems. The main benefit of using the GIS is not merely the user friendly visual access and display, but also the spatial analysis capability and the applicability to apply standard GIS functionalities such as simultaneous access to several layers of data and the overlay of some, as well as the ability to interface with external programs and software for decision supper data management, and user specific functions. A Geographic Information System (GIS) or geospatial information system is a system designed to capture, store, manipulate, analyze, manage, and present all types of geographically referenced data. In the simplest terms, GIS is the merging of cartography, statistical analysis, and database technology. A GIS can be thought of as a system — it digitally creates and "manipulates" spatial areas that may be jurisdictional, purpose or application-oriented for which a specific GIS is developed. Hence, a GIS developed for an application, jurisdiction, enterprise or purpose may not be necessarily interoperable or compatible with a GIS that has been developed for some other application, jurisdiction, enterprise, or purpose. What goes beyond a GIS is a spatial data infrastructure (SDI), a concept that has no such restrictive boundaries.

Methodology

The process of data acquisition for this study was accomplished in various stages discussed hence:

Co-ordinate Mapping: The combination compass-and-rope method enabled the survey party to maintain a straight course in any of the cardinal directions at the commencement of this project work. The use a hand-held Global Positioning System (GPS) units facilitated the determination of latitude and longitude values, as well as elevation values, at each of the stations of interest within the selected study area. The stations of interest are usually fixed at 100m intervals.

Projected Mapping: This is a fast and accurate method of locating the co-ordinates of stations at the 100m point intervals. Knowing the co-ordinates of any one station of interest, the co-ordinates of the remaining stations can be predicted using simple co-ordinate addition and subtraction based on the standard relationship expressed below:

$$100\text{m} \approx 3.24''$$

It is a generally accepted fact that latitude increases due north and decreases due south, whilst longitude increases due east and decreases due west. Thus adding 3.24″ to a reference latitude value represents the next 100m spot along a constant longitude in a northerly direction. Subtracting 3.24″ to a reference latitude value represents the next 100m spot along a constant longitude in a southerly direction. Adding 3.24″ to a reference longitude value represents the next 100m spot along a constant latitude in an easterly direction. Subtracting 3.24″ to a reference longitude value represents the next 100m spot along constant latitude in a westerly direction.

Dataset of Study

Topographic (i.e. x, y, z) Dataset: At 100m spacing between stations of interest for the 15km^2 of the study area, there are 1581 survey points where latitude (x), longitude (y), and elevation (z) information were measured. An abridged x, y, z plus their UTM equivalent dataset is presented in Appendix A.

Economic Resources Georeferenced Dataset: An abridged x, y, z attributes of a recognized economic resource item (in this case the Shea butter tree) in the area of study is presented in Appendix B.

Land Use Georeferenced Dataset: An abridged x, y, z attributes of recognized land use apportionement in the area of study is presented in Appendix C.

Arboreal Georeferenced Dataset: An abridged x, y, z attributes of prominent arboreal resource item (i.e. trees greater 10m in height) in the area of study is presented in Appendix D.

Outcrops-on-Land Georeferenced Dataset: An abridged x, y, z attributes of outcrops-on-land in the area of study is presented in Appendix E.

Outcrops-in-Stream-Channels Georeferenced Dataset: The x, y, z attributes of outcrops-in-stream-channels in the area of study is presented in Appendix F.

Squatter Settlements Georeferenced Dataset: The x, y, z attributes of squatter settlements in the area of study is presented in Appendix G.

Data Analysis and Result Presentation

Conversion of Latitude and Longitude to the Universal Traverse Mercator (UTM) System: The data collected from the field where all longitude and latitude representation, which in this case are in degree (^{0}), minute (‘) and seconds (“). These data was acquired by means of the hand-held e-Trex Garmin GPS device. In using the TatukGIS coordinator calculator, the following properties were considered. The original datum was set as WGS 84 (World Geodetic System 1984) with the projection being Geodetic (unprojected) and the output projection being in UTM, the datum used was Minna, Nigeria Zone 32. The TatukGIS coordinate calculator was used in the data conversion in this study. By convention, the WGS 84 geoid describe Earth as an ellipsoid along North-South axis with an equatorial radius of a = 6378.137*km* and an orbital eccentricity of e = 0.0818192. The resulting UTM values corresponding to the conventional latitude and longitude values are as shown in the various Appendices.

Production of Site-Specific Topographic Map

The site-specific topographic map for this project work was generated using the Golden Surfer 8 software. Initially, the Co-ordinate Calculator software was used to convert the 1581 georeferenced stations of interest of the 15km^2 area from their conventional latitude, longitude, elevation (x, y, z) attributes to their equivalent UTM attributes. These UTM values were exported to Golden Surfer 8.

When in Golden Surfer 8 work mode, click on “Map” to show a dialogue, and then click on “Contour Map”, then “New Contour Map.” Upon assessing the exported UTM dataset, the Golden Surfer 8 generates a topographic map of the designated study area. Fig.1 is the resulting contour map of the study area. The contour map of Fig.1 was produced at an interval of 10m. It is observed in Fig.1 that, overall, terrain elevation trends generally vary between 175m and 215m. The lower terrain elevations are observed in the southern portion of the map whilst the higher terrain elevations are observed in the northern portion of the map of Fig.1. Thus, elevation increases (i.e. topography becomes more steep) as one moves due north along the study area. This fact corroborates the observations of Adesoye (1986). Intense contour closures in the northeastern sector of Fig.1 are indicators of the presence of numerous depressions and prominences whereas the scattered contour signatures in the southerly portion of Fig.1 are indicators of flat lowlands. The twin contour closures between UTM 1054500 and 1055000 on the western edge of the survey area is a prominent stream channel that flows out of the study area. A prominent water hole can be seen at UTM 217500 in the deep south of the survey area. Another water hole is also observed at the northeast of the survey area.

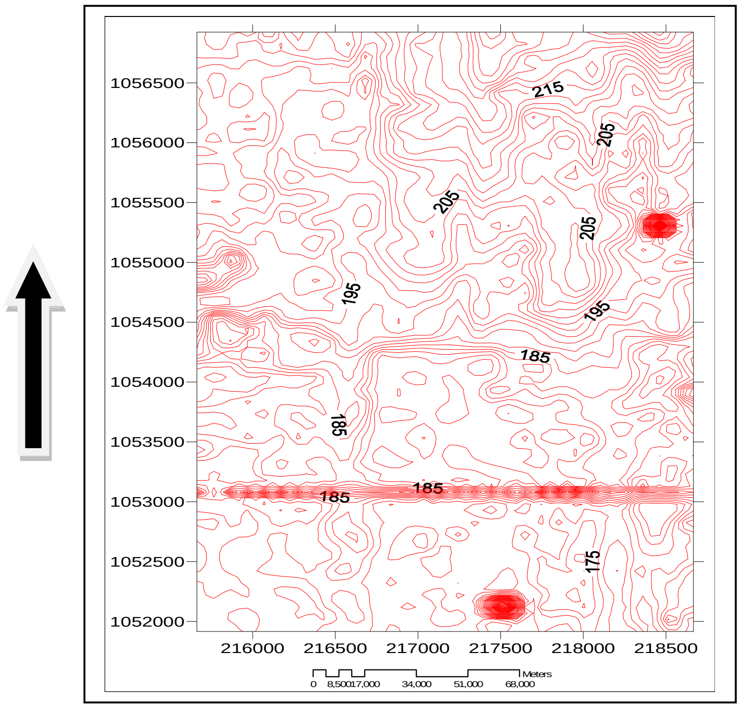

Fig.1: Topographic map of the 15km^2 area of study

Creation of a Geographic Information System (GIS) for the Area of Study

Initially, the database showing all the attributes of field data was created conventionally with a Management Information System (MIS) database application, Microsoft Excel. Later, the database was exported to the ArcView GIS platform. The GIS application has the potential of creating a database which shows the spatial information of any geographical locations on a digital map. The multiple field creation enables the GIS application to function with better user interphase coordination in terms of interactive abilities. After these fields were created in correspondence to each data point, then, the data was inputted into the database progressively such as to create a precise database showing the attributes of the spatial points located on the map. The various columns for the recording of the different attributes of these sources were created afterwards before the data were inputted into these fields. Fig.2 shows the composite GIS map of the area of study with all the GIS layers shown in the ArcView environment.

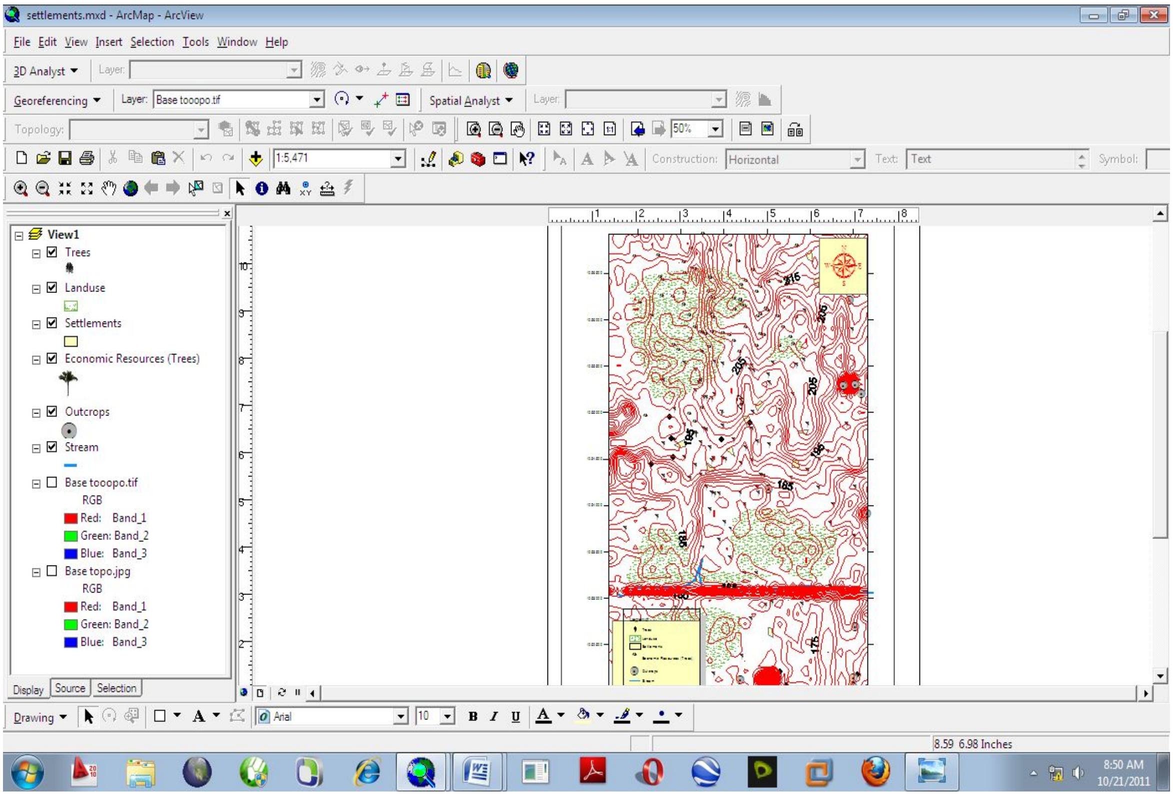

Fig.2: Composite GIS map of the area of study in ArcView

Discussion

For the topographic map creation, data were acquired at 1,581 points of interest within the 15 km^2 gridded area. At 100m spacing between stations, this was considered sufficiently detailed for this study. An improvement over the "rope-and-compass" station-fixing process was the "projected mapping" approach incorporated during this study. Georeferencing economic resources, land use, arboreal, outcrops-on-land, outcrops-in-stream-channels, and squatter settlements information was not necessarily a function of the 100m station spacing. The major economic resource item identified in the area of study was the Shea butter tree and about 118 Shea butter trees were duly identified in the study area. Land use information in the area of study concerns the portions that were "active" farmlands (i.e. evidence of cultivation seen) and arboreal information concerns georeferencing trees that were at least 10m tall; about 131 trees were thus identified. Outcrops seen on land and in stream beds were considered important geological markers for subsequent detailed studies. For this study, squatter settlements were not considered under the land use concept, so a separate information profile was created for it; about 17 different squatter settlements were identified in the area of study. All of the x,y,z dataset collected during the course of this exercise were converted to their corresponding UTM equivalent whilst production of the site-specific topographic map was aided by the Golden Surfer 8 software. The composite GIS map and the specific GIS layers of the study area were produced by use of the Arcview GIS software and the results are as shown in Figs1and 2. In the ArcView GIS environment, distribution of the economic resource item identified for this study (i.e. the Shea butter tree) at the study area can be viewed by highlighting only the icon or legend corresponding to "Economic Resource (Shea butter tree)". It is also observed that all of the Shea butter trees identified during the course of this study were found at the northern portion of the study area.

Conclusion

The area identified as N09^{0}30'25.20'', E006^{0}26'11.34''; N09^{0}33'07.20'', E006^{0}26'11.34'' and N09^{0}30'25.20'', E006^{0}24'34.14''; N09^{0}33'07.20'', E006^{0}24'34.14'' at the Gidan Kwano Campus of the Federal University of Technology, Minna, can now be represented by the detailed topographic map of Fig.1. This map should form an integral component of the database of the Federal University of Technology's Physical Planning and Development Unit (PPDU). Though the horizontal and vertical axes of Fig.1 are given in UTM values, the TatukGIS coordinate calculator can be used to determine the corresponding x and y values at the appropriate locations on the map. Following on the heels of the creation of the topographic map for the study area, a composite GIS map made up of six different layers has now been created for the study area as can be seen in Fig.2.

Recommendation

Detailed topographic map creation for a 15km^2 area of the Gidan Kwano Campus of the Federal University of Technology, Minna, was only a pioneering effort in this regard. It is recommended that further and expanded studies targeting the whole of the Gidan Kwano Campus be carried out. As well as this requirement, a comprehensive and versatile GIS database for the whole of the Gidan Kwano Campus should be produced and archived.

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APPENDICES

Appendix A: Abridged Latitude (x), Longitude (y), Elevation (x), UTM Information for the $15km^2$ Areal Extent

REFERENCED LINE 1: LATITUDE: N09^0 30’25.20”

PROFILE	LONGITUDE	ELEVETIONS	UTM (X)	UTM (Y)	UTM (Z)
P1	E006^0 26’11.34"	199 Metres	218629.1642	1051916.178	176.66
P2	E006^0 26’08.01"	201 Metres	218527.5441	1051916.93	178.66
P3	E006^0 26’04.86"	195 Metres	218416.9521	1051917.748	172.65
P4	E006^0 26’01.62"	202 Metres	218332.5431	1051918.373	179.65
P5	E006^0 25’58.38"	202 Metres	218233.6693	1051919.105	179.65
P6	E006^0 25’55.14"	201 Metres	218134.7954	1051919.837	178.65
P7	E006^0 25’51.09"	198 Metres	218011.2029	1051920.753	175.65
P8	E006^0 25’48.66"	202 Metres	217937.0474	1051921.302	179.65
P9	E006^0 25’45.42"	202 Metres	217838.1733	1051922.035	179.65
P10	E006^0 25’42.18"	201 Metres	217739.2991	1051922.769	178.65
P11	E006^0 25’38.94"	202 Metres	217640.4249	1051923.502	179.64
P12	E006^0 25’35.07"	203 Metres	217522.325	1051924.379	180.64
P13	E006^0 25’32.46"	204 Metres	217442.6762	1051924.97	181.64
P14	E006^0 25’29.22"	200 Metres	217343.8018	1051925.705	177.64
P15	E006^0 25’25.98"	201 Metres	217244.9273	1051926.439	178.64
P16	E006^0 25’22.74"	200 Metres	217146.0527	1051927.174	177.64
P17	E006^0 25’19.05"	200 Metres	217033.4455	1051928.011	177.64
P18	E006^0 25’16.26"	201 Metres	216948.3034	1051928.645	178.64
P19	E006^{0}25'13.02 "	198 Metres	216849.4287	1051929.38	175.63
P20	E006^0 25’09.78"	201 Metres	216750.5538	1051930.116	178.63
P21	E006^0 25’06.54"	202 Metres	216651.6789	1051930.852	179.63
P22	E006^0 25’03.03"	202 Metres	216544.5643	1051931.65	179.63

P23	E006^0 25'00.06"	204 Metres	216453.9289	1051932.326	181.63
P24	E006^0 24'56.82"	200 Metres	216355.0538	1051933.062	177.63
P25	E006^0 24'53.58"	201 Metres	216256.1786	1051933.8	178.63
P26	E006^0 24'50.34"	200 Metres	216157.3034	1051934.537	177.63
P27	E006^0 24'47.01"	201 Metres	216055.6816	1051935.295	178.62
P28	E006^0 24'43.86"	202 Metres	215959.5527	1051936.013	179.62
P29	E006^0 24'40.62"	200 Metres	215860.6773	1051936.751	177.62
P30	E006^0 24'37.38"	200 Metres	215761.8018	1051937.49	177.62
P31	E006^0 24'34.14"	201 Metres	215662.9262	1051938.228	178.62

Appendix B: Abridged Georeferenced dataset for Shea butter tree (i.e. principal economic resource) in the area of study

LONGITUDE	LATITUDE	ELEVATION	UTM (X)	UTM (Y)	UTM (Z)
006^{0}26'01.38"	009^{0}30'37.80"	202 metres	218328.1282	1052311.3267	179.65 metres
006^{0}26'02.40"	009^{0}30'40.26"	201 metres	218359.8148	1052386.7248	178.65 metres
006^{0}26'08.40"	009^{0}30'49.20"	199 metres	218544.9463	1052660.2144	176.65 metres
006^{0}26'02.10"	009^{0}30'49.44"	200 metres	218352.7502	1052669.0164	177.65 metres
006^{0}26'02.52"	009^{0}30'57.06"	200 metres	218367.3024	1052903.1858	177.65 metres
006^{0}26'05.70"	009^{0}31'14.28"	203 metres	218468.2643	1053431.8670	180.65 metres
006^{0}26'07.68"	009^{0}31'27.22"	199 metres	218531.6325	1053829.2379	176.65 metres
006^{0}26'08.40"	009^{0}31'30.54"	204 metres	218554.3596	1053931.1429	181.65 metres
006^{0}26'05.70"	009^{0}31'47.64"	199 metres	218370.5924	1054457.4647	176.65 metres
006^{0}26'02.52"	009^{0}32'45.66"	234 metres	218392.0764	1056241.9152	211.64 metres

Appendix C: Abridged x, y, z attributes of recognized land use apportionement in the area of study

LONGITUDE	LATITUDE	ELEVATIONS	UTM (X)	UTM (Y)	UTM (Z)
006^{0}26'10.08"	009^{0}30'27.12"	202metres	218591.1908	1051981.0232	179.66
006^{0}26'08.10"	009^{0}30'33.78"	201 metres	218532.2830	1052186.2205	178.65
006^{0}26'04.86"	009^{0}30'30.06"	196 metres	218432.5636	1052072.5871	173.65
006^{0}26'03.78"	009^{0}30'42.84"	201 metres	218402.5145	1052465.7307	178.65
006^{0}25'58.38"	009^{0}30'04.14"	199 metres	218228.9172	1051277.1834	176.65
006^{0}25'55.14"	009^{0}30'31.68"	201 metres	218136.3123	1052124.5878	178.65
006^{0}25'52.14"	009^{0}30'29.64"	199 metres	218044.2980	1052062.5497	176.65
006^{0}25'52.14"	009^{0}30'25.20"	203 metres	218043.2864	1051926.0490	180.65
006^{0}25'51.24"	009^{0}30'45.06"	201 metres	218020.3475	1052536.8166	178.65
006^{0}25'40.98"	009^{0}30'41.64"	201 metres	217706.4708	1052433.9969	178.64
006^{0}25'33.72"	009^{0}30'41.64"	200 metres	217484.9221	1052435.6420	177.64
006^{0}25'47.82"	009^{0}30'51.12"	200 metres	217917.3643	1052723.8958	177.64
006^{0}26'08.70"	009^{0}30'40.12"	201 metres	218552.0351	1052380.9975	178.65
006^{0}26'10.20"	009^{0}30'52.26"	203 metres	218600.5712	1052753.8824	180.65

006^{0}26’08.10”	009^{0}31’00.06”	201 metres	218538.2634	1052994.1545	178.65
006^{0}26’06.72”	009^{0}31’02.52”	199 metres	218496.7118	1053070.0949	176.65
006^{0}26’11.34”	009^{0}30’01.44”	198 metres	218623.8054	1051191.2516	175.66
006^{0}26’09.84”	009^{0}31’08.10”	203 metres	218593.1908	1053240.9375	180.65
006^{0}26’01.62”	009^{0}31’09.36”	209 metres	218342.6403	1053281.5325	186.65
006^{0}26’50.66”	009^{0}30’58.80”	201 metres	219836.7203	1052945.8235	178.67

Appendix D: Abridged x, y, z attributes of prominent arboreal resource item (i.e. trees greater 10m in height) in the area of study

	Longitude	Latitude	Elevation	UTM (X)	UTM (Y)	UTM (Z)
1	006^{0}26’01.38”	009^{0}30’37.80”	202 metres	218328.1282	1052311.3267	179.65
2	006^{0}26’02.40”	009^{0}30’40.26”	201 metres	218359.8148	1052386.7248	178.65
3	006^{0}26’08.40”	009^{0}30’49.20”	199 metres	218544.9463	1052660.2144	176.65
4	006^{0}26’02.10”	009^{0}30’49.44”	200 metres	218352.7502	1052669.0164	177.65
5	006^{0}26’02.52”	009^{0}30’57.06”	200 metres	218367.3024	1052903.1858	177.65
6	006^{0}26’05.70”	009^{0}31’14.28”	203 metres	218468.2643	1053431.8670	180.65
7	006^{0}26’07.68”	009^{0}31’27.22”	199 metres	218531.6325	1053829.2379	176.65
8	006^{0}26’08.40”	009^{0}31’30.54”	204 metres	218554.3596	1053931.1429	181.65
9	006^{0}26’05.70”	009^{0}31’47.64”	199 metres	218370.5924	1054457.4647	176.65
10	006^{0}26’02.52”	009^{0}32’45.66”	234 metres	218392.0764	1056241.9152	211.64
11	006^{0}25’57.00”	009^{0}30’28.86”	210 metres	218192.4306	1052037.4710	187.65
12	006^{0}25’57.00”	009^{0}30’44.04”	202 metres	218195.8882	1052504.1554	179.65
13	006^{0}25’57.00”	009^{0}30’56.58”	202 metres	218198.7456	1052889.6773	179.65
14	006^{0}25’57.00”	009^{0}32’45.18”	223 metres	218223.5346	1056228.4103	220.64
15	006^{0}25’54.66”	009^{0}32’17.88”	231 metres	218145.8930	1055389.6459	208.64
16	006^{0}26’01.38”	009^{0}32’41.52”	220 metres	218356.3456	1056114.8960	197.64
17	006^{0}26’01.38”	009^{0}32’59.52”	232 metres	218360.4593	1056668.2771	209.64
18	006^{0}25’56.52”	009^{0}30’32.04”	204 metres	218178.5069	1052135.3434	181.65
19	006^{0}25’55.86”	009^{0}30’41.52”	201 metres	218160.5256	1054271.5433	178.65
20	006^{0}25’55.44”	009^{0}30.58.44”	200 metres	218151.5648	1052947.2129	177.65
21	006^{0}25’54.66”	009^{0}31’38.46”	214 metres	218136.8910	1054177.7404	191.64
22	006^{0}25’52.98”	009^{0}31’08.16”	220 metres	218078.7123	1053246.5956	197.65

Appendix E: Abridged x, y, z attributes of outcrops-on-land in the area of study

LONGITUDE	LATITUDE	ELEVATION	UTM (X)	UTM (Y)	UTM (Z)
E06^{0}26’ 08.88”	N09^{0}31’ 55.86”	216 Metres	218567.1290	1054718.3985	183.03
E06^{0}26’ 09.42”	N09^{0}31’ 56.58”	218 Metres	218583.7709	1054740.4116	185.03
E06^{0}25’ 51.54”	N09^{0}30’ 30.30”	194 Metres	218026.1385	1052082.9760	171.65
E06^{0}26’ 07.86”	N09^{0}32’ 27.30”	223 Metres	218550.8251	1055676.2567	200.64
E06^{0}26’ 01.68”	N09^{0}32’ 07.08”	217 Metres	218357.6348	1055056.0259	194.64
E06^{0}26’ 07.56”	N09^{0}33’ 00.03”	243 Metres	218549.1445	1056682.5546	220.64
E06^{0}26’ 00.06”	N09^{0}32’ 07.80”	221 Metres	218308.3663	1055078.5282	198.64
E06^{0}26’ 08.22”	N09^{0}33’ 03.00”	250 Metres	218569.9613	1056773.7127	227.64
E06^{0}26’ 01.62”	N09^{0}32’ 00.60”	214 Metres	218354.3250	1054856.8224	191.64
E06^{0}26’ 04.74”	N09^{0}33’ 08.22”	262 Metres	218464.9702	1056934.9824	239.64
E06^{0}26’ 01.80”	N09^{0}33’ 03.42”	245 Metres	218374.1660	1056788.0811	222.64
E06^{0}26’ 00.48”	N09^{0}31’ 57.24”	218 Metres	218318.7719	1054753.7829	195.64

E06^{0}26’ 02.64”	N09^{0}33’ 03.48”	247 Metres	218399.8104	1056789.7351	224.64
E06^{0}25’ 58.32”	N09^{0}32’ 56.76”	230 Metres	218266.4590	1056584.1197	207.63
E06^{0}25’ 58.74”	N09^{0}32’ 20.40”	219 Metres	218270.9652	1055466.1941	196.64
E06^{0}25’ 59.22”	N09^{0}32’ 09.18”	220 Metres	218283.0496	1055121.1444	197.64
E06^{0}25’ 53.88”	N09^{0}33’ 06.48”	247 Metres	218133.2056	1056883.9539	224.63
E06^{0}25’ 58.38”	N09^{0}32’ 19.08”	220 Metres	218259.6787	1055425.6944	197.64
E06^{0}25’ 54.54”	N09^{0}32’ 07.68”	218 Metres	218139.9011	1055076.0901	195.64
E06^{0}25’ 52.62”	N09^{0}32’ 17.76”	229 Metres	218083.6173	1055386.4194	206.64
E06^{0}25’ 58.56”	N09^{0}32’ 15.42”	221 Metres	218264.3353	1055313.1328	198.64
E06^{0}25’ 25.02”	N09^{0}32’ 13.68”	222 Metres	217240.4969	1055267.2555	199.63

Appendix F: Full x, y, z attributes of outcrops-in-stream-channels in the area of study

Latitude	Longitude	Elevation	X	Y	Z
N09°30 38.22"	E006°25 48.84"	194	217945.5	1052327	171.65
N09°30 37.44"	E006°25 49.26"	194	217958.2	1052303	171.65
N09°30 32.40"	E006°25 48.54"	193	217935.1	1052148	170.65
N09°32 51.36"	E006°25 06.18"	200	216674.3	1056430	177.61
N09°32 57.72"	E006°25 06.84"	213	216695.9	1056625	190.61
N09°32 02.40"	E006°25 09.24"	213	216756.4	1054924	190.62
N09°32 47.04"	E006°25 30.00"	210	217400.1	1056292	187.62
N09°32 44.10"	E006°24 55.92"	210	216359.5	1056209	187.61
N09°32 36.06"	E006°24 53.04"	211	216269.8	1055963	188.61
N09°32 28.20"	E006°24 49.08"	210	216147.2	1055722	187.61
N09°32 12.66"	E006°24 46.32"	209	216059.4	1055245	186.61
N09°32 08.10"	E006°24 43.44"	209	215970.4	1055105	186.61
N09°32 01.50"	E006°24 43.80"	209	215979.9	1054902	186.61
N09°32 55.80"	E006°24 41.88"	209	215933.8	1056572	186.6

Appendix G: Full x, y, z attributes of squatter settlements in the area of study

Latitude	Longitude	Elevation	X	Y	Z
N09 32 17.64	E006 25 57.96	225	218246.53	1055381.52	202.64
N09 32 13.92	E006 25 57.24	221	218223.71	1055267.32	198.64
N09 32 12.84	E006 25 55.56	223	218172.2	1055234.49	200.64
N09 32 15.00	E006 25 51.72	226	218055.52	1055301.77	203.64
N09 32 11.28	E006 25 50.34	225	218012.56	1055187.72	202.64
N09 32 06.54	E006 25 49.92	229	217998.67	1055042.09	206.64
N09 32 35.58	E006 25 13.02	232	216879.35	1055943.27	209.62
N09 32 40.62	E006 25 18.18	238	217037.96	1056097.05	215.62
N09 32 15.06	E006 25 16.08	228	216968.02	1055311.72	205.62
N09 32 07.80	E006 25 19.26	227	217063.39	1055087.79	204.63
N09 30 58.56	E006 25 57.36	205	218237.58	1056639.68	182.63
N09 32 38.10	E006 25 13.14	234	216883.59	1056020.72	211.62
N09 32 43.38	E006 25 12.00	233	216850.02	1056183.31	210.62
N09 32 02.46	E006 25 05.04	220	216628.25	1054926.86	197.62
N09 32 16.62	E006 25 36.12	225	217579.88	1055355.12	202.63
N09 32 41.34	E006 25 15.06	236	216942.92	1056119.89	213.62
N09 32 43.80	E006 25 14.58	236	216928.84	1056195.63	213.62