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Development of methods of peri-urban natural resource information collection, storage, access and management DFID Project R6880

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Estimating the Datum Transformation Parameters Associated with the Ghana National Mapping System

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Relates to: Integration of GPS and remote sensing survey data within GIS	

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1. Background

A fundamental requirement of many research projects that involve the collection of natural resource data is that the data are developed in a form suitable for incorporation into a GIS. GIS (denoting Geographic Information System) is a general term used to describe any computer based system that has capabilities for the input, storage, manipulation and presentation of data that are geographically referenced. Ideally, geographic referencing would be undertaken with respect to a single geodetic datum such as the World Geographic Reference System of 1972 or 1984 (i.e. WGS72 or WGS84). Global datums provide the best approximate model of the Geoid (i.e. the true earth shape) on a global basis, but are of relatively recent origin. On a regional basis, deviations between the Geoid and the global datums become significant for large scale mapping and therefore local horizontal and vertical datums are still required to satisfy mapping and navigation requirements for specific regions of the globe. Many such local geodetic datums are in existence although only a relatively limited number are in current use.

In recent years the increasing availability of GPS (Global Positioning System) has resulted in many natural resource surveys using either WGS84 or UTM (Universal Transverse Mercator) for geo-referencing of the collected data. Both WGS84 and UTM are defined for all positions on the globe and are standard to virtually all GPS systems. However, much existing data for specific countries exists in the form of topographic maps that often use local geodetic datums in the geo-referencing system. The digitisation of map data for combination in a GIS with more recent survey data is commonplace in natural resources projects and provides a general requirement for procedures to convert between geodetic datums. In essence a geodetic datum transformation converts the three dimensional geographic co-ordinates of latitude, longitude and height (above the spheroid rather than the datum) between datums. The resultant geographic co-ordinates are normally then projected into a graticule of eastings and northings.

The majority of image processing and GIS software now in current use for resource surveys contain a formidable list of available projection systems, with associated spheroids and datums. Conversion of map co-ordinates (i.e. eastings and northings) between projection systems that are explicitly represented in the software are based upon use of exact mathematical formulae. These result in precise co-ordinate conversions since in many cases the projection parameters are normally readily available and are not specific to localised areas. A datum transformation may be required as part of a projection transformation or may be independently required. Datums are inherently regionally specific and often the parameters are not readily available since they form part of a national geodetic survey. Consequently, it is not unusual when working in some countries to find that the local geodetic datums in use in the country have not been referenced to more recent global referencing systems and are not defined in the software. In this situation it is necessary to make use of an approximate method of conversion.

There exist several different methods of accomplishing a datum transformation. For general application globally these include the standard and abridged Molodensky method, the 7-parameter Bursa Wolfe formula and locally developed regression equations. Additional methods have been derived specifically for application in the US. The Molodensky method is precise to about 5-10 m. Methods based on locally derived regressions may generate more precise results.

Not all of these methods are necessarily available in any specific software. Additionally, it is necessary to obtain the necessary parametric information to apply a specific method. There are various potential sources of the required parameters, including the host country's national geodetic survey and the US Defence Mapping Agency that provides a comprehensive list of such information. However, occasionally the parameters are not available for reasons of security or have not been calculated. In this situation it is necessary to make estimates of the necessary parameters.

In this report the results of an investigation to determine the parameters necessary to apply the abridged Molodensky datum transformation method for use in Ghana are presented. The next section presents some general information pertaining to mapping systems, while Section 3 details the mapping system used in Ghana. The method of estimation of the abridged Molodensky parameters is explained in Section 4. The application of this method is described in Section 5.

2. Mapping Systems

A mapping system is designed to provide a consistent co-ordinate framework for referencing geographic locations in two-dimensions. It is important to understand the following principal elements involved in the definition of a mapping system: geographic grid, map projection, geoid, spheroid, datum and graticule.

The geographic grid comprises lines of latitude (parallels) and longitude (meridians) defined for a spherical Earth. The geographic grid, or graticule, is not a map projection.

A map possesses two referencing systems: latitude and longitude and eastings and northings. Map co-ordinates are defined by the grid of eastings and northings, with a prime characteristic that the grid is rectangular or planar. In two-dimensions the geographic grid or graticule as defined by latitude and longitude is not planar. Depending upon the required levels of precision it may sometimes be approximated as such when working with large scale maps.

The map projection provides the method of translating the geographic grid or graticule from a spherical Earth onto a two-dimensional map. There is a definite relationship between the grid and the graticule so that a corresponding geographic position can be determined for each grid position. To undertake this transformation, it is necessary to model the shape of the earth. The spheroid defines the modelled shape and size of the Earth. The true shape of the earth is called the geoid. A geodetic datum is defined by the spheroid and the position and orientation relationship of the spheroid to a reference mathematical model of the earth, usually WGS84.

The simplest datum, is therefore, one which has its origin at the centre of the earth, i.e. is geocentric. WGS84 is an example of a global geocentric datum with a spheroidal shape defined by semi-major axis a=6378137m and flattening f=1/298.257223563. Within specific geographic regions, a more accurate mapping system is defined by a local datum that may be subject to an offset, rotation and scale change measured from the centre of mass of the Earth.

It should be apparent from the above that two mapping systems in use in a specific country may use different spheroids and datums or the same spheroid with different datums. In each case the latitude and longitude of a fixed point on the (real) earth will be different for each combination.

3. Mapping Systems used in Ghana

The two mapping systems in use in Ghana are both based on the Transverse Mercator projection. Details of these two systems are provided in Table 1.

Table 1. Parameter description of the Ghana National Mapping System

Projection: Transverse Mercator						
Pre-1977 Datum: Accra						
Spheroid	Semi-Major Axis (a) m	Flattening (1/f)	Origin of grid	False Northing	False Easting	Scale factor
War Office 1924	6378300.58	296.0	N 04° 40′ W 01° 00′	0.0 feet	900000 feet	0.99975
Post-1977 Datum: Leigon						
Clarke 1880	6378249.145	293.465	N 04° 40′ W 01° 00′	0.0 feet	900000 feet	0.99975

Within Ghana topographic maps at 1:50 000 scale prepared jointly by the Government of Ghana and the Government of Canada are available for the region surrounding the city of Kumasi. These maps, produced from aerial photographs dating from 1972, use the Ghana National grid and are in the Transverse Mercator projection based on the War Office spheroid and Accra datum. The maps provide a source of topographic data, as well as transport and built environment data appropriate to the early 1970s period. In addition, further natural resource data are currently being collected as part of a number of national and international government and non-government funded research. These include airborne digital photographic surveys, interpretation of satellite data and socio-economic appraisals. These data are typically geo-referenced to WGS84 or the Universal Transverse Mercator projection system (zone 30 and WGS84 datum).

In order to be able to combine data digitised from the topographic maps with newer data in WGS84 or UTM, it is necessary to undertake a local (Accra) datum to global

(WGS84) datum transformation. The image processing and GIS software available to the authors did not include the Accra datum applicable to Ghana and an initial search did not reveal a source for the necessary parameters. Consequently it was necessary to estimate the required parameters. Subsequently the parameters were obtained from the UK Military Survey. These provide an independent basis of comparison.

4. Estimating the Datum Transformation Parameters for the Accra Datum

The most frequently applied datum transformation is probably the Molodensky method. The abridged method requires cartesian X, Y and Z offsets between the local datum and a reference system (usually WGS84), the latitude and longitude on the local datum, and the semi-major and semi-minor axis (or flattening) of the associated spheroids. The standard method also requires the geoid height and the spheroid/geoid separation. Since this latter information is generally more difficult to obtain, most applications apply the Molodensky method in its abridged form.

The determination of the Molodensky parameters for datum transformation requires that the geographic co-ordinates and height above the spheroid of a series of points are known in both WGS84 and the local datum. A geodetic control point referenced to UTM and WGS84 exists at Kumasi airport. The details of this control point are given in Table 2. The precision of this control point is approximately a few centimetres. The height information is the height above the spheroid.

Table 2. Geodetic Control Point Information

WGS84	UTM (Zone 30)
6 deg 42 min 52.53750 sec North	655535.08423 m E
1 deg 35 min 34.06153 sec West	742421.74146 m N
316.981m Altitude	316.981m Altitude

The geographic grid co-ordinates appropriate to the Accra datum at this same point were derived by use of a SPOT image geo-corrected to the Ghana National Grid (GNG) using available 1:50 000 topographic map sheets. The details of the processing of the SPOT image are available in an associated R6880 report. The image was geo-corrected to a level of precision of approximately 15m. The map co-ordinate position of the geodetic control point was determined by visual inspection of the SPOT image as shown in Figure 1. These co-ordinates were used to determine the geographic grid co-ordinates appropriate to the Accra datum by overlaying a transparency of the SPOT image on the appropriate topographic map sheet and digitising directly in latitude and longitude. The altitude of the point was also estimated by interpolation between the height contours. This height is most likely the height above mean sea level. These data are presented in Table 3.

Table 3. Ghana National Mapping System Co-ordinates for Kumasi Airport Geodetic Control Point

Geographic (Accra datum)	Grid (Transverse Mercator)
6deg 42min 43.3332 sec North	684940 m E
1deg 35min 34.9008 sec West	741930 m N
289.56 m Altitude	289.56 m Altitude

The geographic grid co-ordinates were then converted to earth centred cartesian co-ordinates from knowledge of the spheroid definitions of WGS84 and the War Office spheroid. From these data an estimate of the three components of the datum shift were determined. These estimates are presented in Table 4, together with the data from the Military Survey.

Table 4. Kumasi Airport Geodetic Control Point Cartesian Co-ordinates and Calculated Offsets

	WGS84	Accra Datum	Difference	Military Survey
X	6,332,545.685	6,332,714.821	-169	-199
Y	-176,087.060	-176,117.551	30	32
Z	740,833.987	740,531.145	303	322

5. Application to Road Survey Data

The estimated parameters were used to translate a series of points recorded using a differential GPS in WGS84 to GNG co-ordinates. The data relate to a road survey undertaken along the main ring road in Kumasi. Figure 2 shows the road survey data overlaying the SPOT Panchromatic image of central Kumasi at a scale of 1:100000. The white line represents the data transformed to GNG using our derived parameters. The black line represents data converted to GNG in which the datum shift is ignored and demonstrates the typical magnitude of error (~ 30m in easting and 290m in northing in this instance) that can be encountered when datum transformations are incorrectly applied. The spatial equivalence of the transformed road survey data and the SPOT panchromatic image is difficult to determine at this scale. Figure 3 compares the spatial equivalence of the road survey data transformed using our parameters (white dots) and the Military Survey parameters (black triangles) with the SPOT image. The RMS error between the two sets of transformed co-ordinates (Table 5) is less than 1m in easting but more than 20m in northing. The data transformed using our parameters are greater in magnitude in both easting and northing.

The expected precision of the Molodensky method is 5-10m. However, this is not achievable by the procedures applied in this work due to the following constraints. The height information associated with the control point is the height above the spheroid, while the height estimated from the topographic map sheets is most likely the height above mean sea level. The method requires both heights as the height above the respective spheroid. This will undoubtedly introduce some error in the estimation process. In addition the precision in geo-referencing of the SPOT image is of the order of 15m, with an equivalent uncertainty associated with the map co-ordinates determined for the control point, and consequently in the digitised grid co-ordinates. It is not clear which of these sources of error is most likely to result in significant differences in the northings noted above.

Table 5 RMS errors using the Military Survey and locally derived Molodensky parameters

Number of Points	Easting (m)	Northing (m)	Overall (m)
2355	0.18	22.36	22.36

6. Conclusions

The methodology applied to the data for Kumasi Ghana and reported in this paper is not new. However, the details of the application of such methods do not appear widely reported in the literature and therefore may be relatively inaccessible to the non-specialist. The problem of incompatible projections and conversion between projection systems is of general concern to those involved in the collection of natural resources data. It is not uncommon when working in some parts of the world to be faced with combining data that are mapped using a local geodetic datum with data recorded using GPS. Often it is possible to undertake the necessary datum transformation directly using software, or by use of an approximate method. However, in situations where the available parametric information for a specific method is not available, it may be necessary to make an estimate independently.

This report details the results of deriving the required parametric information for application of the abridged Molodensky method. The parameters are applied to the case of combining road survey data with a SPOT Pan image that has been geo-referenced to the Ghana National Grid (Accra datum) using control point information from available 1:50 000 topographic maps. The most precise piece of information is a geodetic control point located at Kumasi airport reported to cm accuracy. In order to estimate the Molodensky parameters it is necessary to have the geographic co-ordinates reported for the same point and for each datum, as well as the height of the point above the spheroid. The geographic co-ordinates appropriate to the Accra datum were derived from the 1:50 000 topographic maps. Unfortunately the control point is not marked on the map sheets. Consequently, an estimate of the position of the control point was derived by visual inspection of an available geo-referenced SPOT image (geo-referenced to a precision of about 60 feet) and transferred to the map sheets. Subsequently the geographic co-ordinates were digitised from the topographic map. An estimate of the altitude of the point above sea level was also made. No allowance was made for the height of the control point on the airport building where it is physically situated.

Despite these uncertainties, when compared against official estimates of the datum transformation parameters, this relatively simple procedure resulted in estimates that appear acceptable in regard to combining data sets at a nominal scale of 1:50 000.

Figure 1 Determination of Ghana National Grid geographic co-ordinates of Kumasi airport geodetic control point (map scale 1:50000)

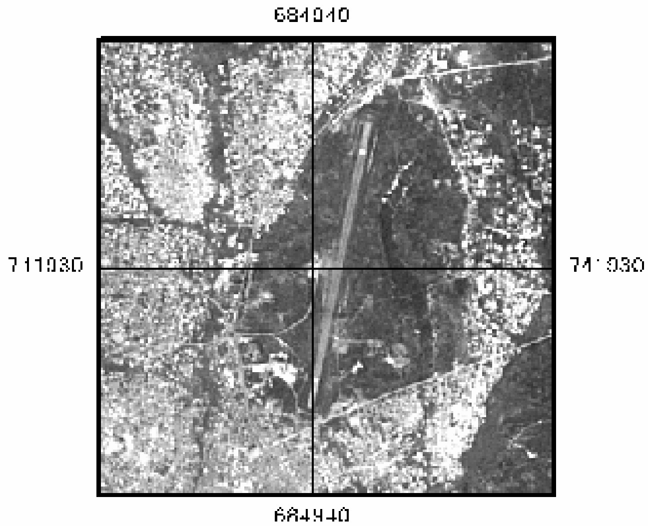

Figure 2 Overlay of road survey data on geo-corrected SPOT image map at scale 1:100000 (white line are data transformed to GNG using estimated parameters, black line are data transformed to GNG without the required datum shift)

Figure 3 Offset in transformed co-ordinates using locally derived (white dots) and Military Survey (black triangles) datum transformation parameters (map scale 1:5000)