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Sudan Geodetic and Geospatial Reference System

Kamal A. A. Sami

Department of Surveying Engineering, University of Khartoum, Khartoum, Sudan

ABSTRACT

The development in information and satellite technologies and geospatial data productions of today, let the Sudan Survey Authority to study all available options for a change from its local datum, Adindan to a global reference frame to be in line with the United Nations Global Geospatial Information (UNGGIM) committee of expert recommendations. Sudan Survey Authority (SSA) finally adopted the ITRF2008 (IGS2008) to be as the official Sudan Reference System (SRS). The SRS shall be an accurate reference system for the unification of Sudan existing many geospatial reference systems and datums, geodetic networks and mapping products and to work closely with the international and regional geospatial communities. The Sudan adopted reference system shall assist the public and private sector institutions for improving their organizational integration, data sharing and data exchange capabilities as well as increasing the ability to link geospatial data infrastructure data sets based on common location data, including Sudan National Basemap, property and building surveys, utility surveys and setting outs, natural resources surveys, roads and infrastructure surveys, map productions and map updatings, as well as all what can be considered as geospatial and survey practices in Sudan. The new Sudan reference system (ITRF2008) will be considered as a national Geodetic Reference Frame (NGRF), which, shall help the geospatial community in Sudan to adopt the best practices in the fields of geomatics and geoinformation by enhancing the existing systems and adopting new technologies associated with common standards and specifications.

The paper overviewed the technical considerations of the adopted Sudan Reference System and outlined the benefits of the unification of previous georeferencing systems and to eliminate the drawbacks of using many datums within the entire boundaries of Sudan.

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1. INTRODUCTION

Technological advancements in GNSS positioning and Geospatial systems, processing's and implementations have necessitated to perform precise georeferencing and to produce high quality spatial data infrastructure for data sharing, data exchange and integration. This ability, together with the prospect applications of continuously operating reference stations (CORS) in Sudan may expanded the use of geodetic control stations in support of Sudan development of spatial information systems, [4], as well as to meet today's demands for the adoption of reliable procedures to support e-government and geomatics activities. The requirement of continuing evolution of GNSS and GIS let the Sudan Survey Authority to focus on the best practices and on the adoption of standards, specifications and methodologies, [9], [13], in all Survey activities and in location-based operations, map production and GIS implementation.

The Sudan Reference System has an impact on the existing geodetic control surveying and shall assist the geomatics communities with a powerful tool for the establishment of precise geodetic control and for unifying georeferencing of geospatial data, [15]. This evolution has brought with it reduction in cost and an increased demand for sharing geomatics and Geospatial services.

The diversity of Sudan datums and reference systems in use today and the technological advancements that have made possible global positioning measurements requires careful reference System selection and careful conversion between coordinates in different datums and reference systems. It is well known that the current, and growing, trend towards the use of satellite positioning systems and global satellite mapping systems to produce position-based products in a global reference frame can introduce serious practical difficulties if the results need to be related to older maps and/or digital data. Special problems arise, for instance, in the fields of updating, map revision, cadastral surveying and geomatics operations to support geospatial data production. The difficulty fundamentally arises because of the need to transform the data into the coordinate systems used to describe the older data. In principle, coordinate transformations are straightforward mathematical procedures but in practice they can cause serious problems due to non-homogeneity of geospatial data and the diversity of geodetic datums.

Here also, the emphasis is that, Sudan Reference System shall implement the International System of Units (SI) as Linear metric units, the angular units are radian and degrees and the gravimetric SI units are $m.s^{-2}$ or the other widely used units are mGals or µGals (100 Gal = 1 $m.s^{-2}$ thus 1 $m.s^{-2}$ = 100 000 mGals).

The number of decimal digits must be chosen so that it is consistent with the required accuracy for that particular quantity. The Sudan Reference System (SRS) or datum should be a consistent reference system that specifies latitude, longitude, height, scale, gravity, and orientation throughout the Sudan territory, as well as how these values change with time. The SRS consisted of the following components:

Sudan Geodetic Control Network, the network of permanently marked geodetic control points based on SRS.

First order vertical control network (benchmark) based on Alexandria and in the near future should be based on Port Sudan vertical datum.

2. Geodetic Surfaces and Models

Geodesy deals with the earth surface and the other surfaces used for computation of control points, [15], [16] and representation of spatial data, namely the ellipsoid and geoid surfaces. These surfaces can be defined as follows.

A. The earth surface is irregular and constantly changing surface. This reflects the reasons behind using the Models of the surface of the earth in navigation, surveying and mapping. Topographic and sea level models attempt to model physical variations of the surface, while gravity models and geoids are used to represent local variations in gravity that change the local definition of a level. The topographical surface of the earth is the actual surface of the land and sea at some moment in time.

B. The ellipsoid is generated by the revolution of an ellipse about its minor axis; the ellipsoid is considered to represent simplified figure of the earth and used as the fundamental reference surface for horizontal coordinates. This figure is flattened towards the earth's poles. The size of the ellipsoid is defined by its semi-major axis (a) and minor axis (b); its geometrical shape is defined by the flattening ($f=1-b/a$). The Sudan Reference system from its definition is adopting the WGS84 as its reference ellipsoid.

C. The geoid is the equipotential surface of the earth's gravity field, which corresponds most closely with mean sea level and extends continuously through the continents and used as zero reference for orthometric heights. However, the geoid is a physically and mathematically complicated surface, which is impractical to use for mapping purposes. The knowledge of the geoid or developing the geoid model, is necessary for automatic transformation of the ellipsoidal heights to orthometric heights as planned by SSA, to be implemented in the near future in Sudan.

A global ellipsoid (such as WGS84) corresponds to a best fit to the geoid over the entire earth, [13], and luckily the WGS84 ellipsoid is fitting Sudan area within few metres level. Furthermore, global ellipsoids are geocentric, which means that their geometrical centre corresponds with the earth's centre of mass. The orientation of the ellipsoid is achieved by aligning its minor axis with the earth's rotation axis at a particular time. The other important internationally recognized global geocentric ellipsoid, which was derived with the inclusion of refined and superseded by the Geodetic Reference System 1980 (GRS80), which is also geocentric, with a=6378137 metres and f=1/298.257222101.

In addition to defining the geometrical size and shape of the earth, [17], physical parameters are associated with global ellipsoids. These are the product of the Newtonian gravitational constant and the mass of the earth (GM), the angular velocity of the earth's rotation, and the dynamical form factor. These additional physical parameters allow a model gravity field to be computed, as widely used in case of the GRS80 ellipsoid, but with flattening (f=1/298.257223563).

Sudan Reference System Parameters

Horizontal Reference System	WGS84 (ITRF2008) Associated ellipsoid: WGS84
Vertical Reference System	Port Sudan (orthometric heights) based on Mean Sea Level observation.
Gravimetric Reference System	IGSN71, Reference Gravity Stations distributed by reference gravity stations.
Projection	Universal Transverse Mercator (UTM) zones, 34, 35, 36 and 37N Easting and Northing in Meters

Table 1: Sudan Reference System

The reference ellipsoid WGS84 is defined as follows:

Parameter	Parameter Values
Semi-major axis (by definition)	a = 6378137.000 meters
Semi-minor axis (calculated)	b = 6356752.31424 meters
Flattening (calculated)	f = 1/298.257223563

Table 2: WGS84 Ellipsoid Parameters

The general UTM parameters in Sudan can be defined as: central meridian λ_0, Latitude of the equator φ_0, Scale factor k_0, false eastings E_0, and false northings N_0.

Zone	34 North	35 North	36 North	37 North
λ_0	21° east of Greenwich	27° east of Greenwich	33° east of Greenwich	39° east of Greenwich
φ_0	0°	0°	0°	0°
k_0	0.9996	0.9996	0.9996	0.9996
E_0	500000 m	500000 m	500000 m	500000 m
N_0	0 m	0 m	0 m	0 m

Table 3: parameters for UTM zones in Sudan

3. Geodetic Datum, Reference Frame and Coordinate Systems

As geodesy is interested in positioning points on the surface of the earth. For this task a well-defined coordinate system should be used. Many coordinate systems are being used today, but with the interventions of GNSS technology, mainly geocentric coordinate systems are to be adopted. The Sudan reference system uses both 3D Cartesian and geographical coordinates. The geocentric systems have their z-axis aligned with the instantaneous spin axis of the earth and became more useful, with the advent of satellite positioning. The non-geocentric systems are used for local coordinate systems (such as Adindan); in such case their origin would be located at a point on the surface of the earth.

Both the geocentric and local geodetic coordinate systems are used together with reference ellipsoids. These reference ellipsoids are taken to be geocentric or near geocentric, [8], with the axis of revolution coinciding with the z-axis of the coordinate system. The basic idea behind using the reference ellipsoids is that they fit the real shape of the earth, as described by the geoid. Basically, reference ellipsoids are the horizontal surfaces to which the geodetic latitude and longitude are referred. As well the ellipsoid is associated with the Cartesian coordinate system, and must be fixed with respect to the earth Geodetic Survey Division (1996). Such an ellipsoid is often classically called a horizontal datum. The horizontal geodetic coordinates (Latitude, ϕ, and longitude, λ), together with the ellipsoidal height, H, make the basic curvi-linear coordinates system. They are related to their associated 3D Cartesian coordinates X, Y and Z by the following well-known expression:

$$
\begin{aligned}
X &= (\nu + H)\cos\phi\cos\lambda \\
Y &= (\nu + H)\cos\phi\sin\lambda \qquad (2) \\
Z &= (\nu(1 - e^2) + H)\sin\phi
\end{aligned}
$$

and

$$\lambda = \arctan\left(\frac{Y}{X}\right)$$

$$\phi = \arctan\left(\frac{Z + e^2\nu\sin\phi}{\sqrt{X^2 + Y^2}}\right) \qquad (3)$$

$$H = \frac{X}{(\cos\phi\cos\lambda)}$$
$$= \frac{Y}{(\cos\phi\sin\lambda)}$$

$$v_1 = \frac{a}{\left(1 = e^2 \sin^2 \phi_1\right)^{\frac{1}{2}}} \qquad (4)$$

Where
ν: The radius of curvature of reference ellipsoid,
a: Semi major axis of the reference ellipsoid.
e: the eccentricity. And
H: the ellipsoidal height.

In recent decades, the International Terrestrial Reference System (ITRS), is fixed to the earth through several permanent stations whose horizontal velocities are monitored and recorded. The fixing is done at realization of the ITRS by means of coordinates of some selected points is called the International Terrestrial Reference Frame (ITRF), [1]. Transformation parameters needed for transforming coordinates from one epoch to the next are produced by International Earth Rotation Service (IERS), which keep track of the time evolution of the positions (Table.4).

Due to non-homogeneity of Adindan datum information throughout Sudan, SSA recommended that the use of ITRF2008 as a reference frame for the Republic of Sudan, and it's well known that the ITRF2008 is adopting the WGS84 as a reference ellipsoid.

Modern geodetic datums, range from flat-earth models used for plane surveying to complex models used for international applications that completely describe the size, shape, orientation, gravity field, and angular velocity of the earth. Referencing geodetic coordinates to the wrong datum can result in position errors. Different nations and agencies use different datums as the basis for coordinate systems used to identify positions in geographic information systems and for precise positioning systems. International GPS Service, IGS, was established in 1994 by the International Association of Geodesy, IAG, to support the international earth Rotation Service (IERS) by collecting GNSS observations from global networks of continuously operating reference stations, [1]. The IERS maintains two primary reference systems: celestial and terrestrial. The celestial reference system provides the context for the Earth-Centered, Earth-Fixed terrestrial reference system. Realization of this system is made by three technologies in addition to GPS: Very Long Baseline Interferometry (VLBI), Doppler Orbitography by Radiopositioning Integrated on Satellite (DORIS), and Satellite Laser Ranging. The International GNSS Service (IGS) network of GNSS reference stations form global baselines which are periodically least squares adjusted to a set of coordinates and reported annually as the International Terrestrial Reference Frame, ITRF. However, since there are tools to convert data between the ITRF and other coordinate systems, geospatial data can be pre-processed for conformance with ITRF.

Solution	Tx	Ty	Tz	D	Rx	Ry	Rz	EPOCH
Units	mm	Mm	mm	ppb	.001"	.001"	.001"	
Rates	Tx	Ty	Tz	D	Rx	Ry	Rz	
Units	mm/y	mm/y	mm/y	Ppb/y	.001"/y	.001"/y	.001"/y	
ITRF2005	-2.0	-0.9	-4.7	0.94	0.00	0.00	0.00	2000.0
Rates	0.3	0.0	0.0	0.00	0.00	0.00	0.00	
ITRF2000	-1.9	-1.7	-10.5	1.34	0.00	0.00	0.00	2000.0
Rates	0.1	0.1	-1.8	0.08	0.00	0.00	0.00	
ITRF97	4.8	2.6	-33.2	2.92	0.00	0.00	0.06	2000.0
Rates	0.1	-0.5	-3.2	0.09	0.00	0.00	0.02	
ITRF96	4.8	2.6	-33.2	2.92	0.00	0.00	0.06	2000.0
Rates	0.1	-0.5	-3.2	0.09	0.00	0.00	0.02	
ITRF94	4.8	2.6	-33.2	2.92	0.00	0.00	0.06	2000.0
Rates	0.1	-0.5	-3.2	0.09	0.00	0.00	0.02	
ITRF93	-24.0	2.4	-38.6	3.41	-1.71	-1.48	-0.30	2000.0

Rates	-2.8	-0.1	-2.4	0.09	-0.11	-0.19	0.07	
ITRF92	12.8	4.6	-41.2	2.21	0.00	0.00	0.06	2000.0
Rates	0.1	-0.5	-3.2	0.09	0.00	0.00	0.02	
ITRF91	24.8	18.6	-47.2	3.61	0.00	0.00	0.06	2000.0
Rates	0.1	-0.5	-3.2	0.09	0.00	0.00	0.02	
ITRF90	22.8	14.6	-63.2	3.91	0.00	0.00	0.06	2000.0
Rates	0.1	-0.5	-3.2	0.09	0.00	0.00	0.02	
ITRF89	27.8	38.6	-101.2	7.31	0.00	0.00	0.06	2000.0
Rates	0.1	-0.5	-3.2	0.09	0.00	0.00	0.02	
ITRF88	22.8	2.6	-125.2	10.41	0.10	0.00	0.06	2000.0
Rates	0.1	-0.5	-3.2	0.09	0.00	0.00	0.02	

Table (4) Well Known Transformation parameters from ITRF2008 to past ITRFs.

Notes: These parameters are derived from those already published in the IERS Technical Notes and Annual Reports. The transformation parameters should be used with the standard model (eqn. 5) given below and are valid at the indicated epoch.

: XS: : X: : Tx: : D -Rz Ry: : X :

: YS: =: Y: +: Ty: +: Rz D -Rx: : Y: (5)

: ZS: : Z: : Tz: : -Ry Rx D: : Z :

Where X, Y, Z the coordinates in ITRF2008 and XS, YS, ZS are the coordinates in the other frames.

On the other hand, for a given parameter P, its value at any epoch, t is obtained by using equation (6)

P(t) = P(EPOCH) + P*(t – EPOCH) (6)

Where EPOCH is the epoch indicated in the above table (2000.0) and P is the rate of that parameter.

4. Vertical Control

Vertical control networks are a series of points on which precise heights, or elevations, have been established. Vertical control stations are typically called Bench Marks (BM) as part of a vertical information network, the benchmark's elevation is known relative to a vertical datum, usually approximating the mean sea level, Baker (1974). Alexandria vertical datum is historically adopted as a vertical datum for Sudan. This means that the zero surface to which elevations or heights are referred is called a level (MSL). MSL is determined by continuously measuring the rise and fall of the sea at tide gauge stations, [5]. This averages out the highs and lows of the tides caused by the changing effects of the gravitational forces from the sun and moon which produce the tides, [2]. The MSL then is defined as the zero elevation for a local or regional area. MSL is a close approximation to the geoid, which is the true zero surface for measuring elevations. Heights obtained from geodetic leveling are known as orthometric heights, [7]. The orthometric heights are usually reflect local variations in gravity as well as changes in topography which are unknown parameters in Sudan. Due to this, Sudan vertical datum should be shifted from Alexanderia to the Red Sea at Port Sudan area. Hence, Port Sudan vertical datum is proposed to be the Sudan new vertical datum.

In describing a vertical reference datum, [11], the heights are referring to the geoid. Orthometric heights can also be determined through the use of a geoid model. Differences between the geoid model and the vertical datum can indicate any biases that may be present in the vertical datum, [5] and [6]. Effectiveness of the geoid model may be determined by the relatively small geoidal heights exhibited in the region with the use of a particular datum, and obviously the amount of data sourced will have an effect on the accuracy of the geoid, [12]. Here, the SSA is urged to compute the Sudan official gravimetric geoid model.

5. Georeferencing, Projection and GIS Spatial Data

Geospatial Information Systems require georeferencing of spatial data for a variety of reasons, such as: collection and processing of spatial data, establishing of mapping relationship to other existing data, updating, discovering and potentially reconciling discrepancies between conflicting data sets; providing a reference coordinate system for GIS applications, to reduce mapping errors as new data are created, to constrain mapping errors within a geographic area, to improve the spatial accuracy of existing data sets; conversion of maps into digital format for GIS. Georeferencing is fundamental in data sharing and in the integration of spatial data from various sources into a single consistent data set, [10]. This shall be achieved by using the ITRF2008 (IGS2008) as a single common geodetic reference frame, or datum for Sudan. A number of factors have led to an increasing need to georeferencing and to base spatial data products on a common reference frame that extends across the whole globe. These factors include growing reliance on GNSS system and development of satellite-based mapping systems affording increasingly higher resolution images. Another major influence is the trend to spatial data infrastructures across Sudan, such as the Sudan base map which has a complete coverage to Sudan territory.

The most common projection used for Sudan spatial data is the Universal Transverse Mercator projection (UTM), which is usually adopting the required reference system and practically suited to maps of north south extent.

By implementing the ITRF2008 (IGS2008) as the Sudan Reference System, widespread integration between GIS and GNSS will be available, in various activities of GIS applications including mobile GIS, monitoring and tracking activities. Many of these applications require accurate positioning, and, a common requirement is the transformation of GNSS ellipsoidal heights into heights above mean sea level or the geoid. The adoption of Sudan Reference system will enable the production of a homogeneous series of maps and geospatial data that meet Sudan user requirements. However, Sudan Reference System as it deals with positioning which is the fundamental element of GIS base maps and spatial data in terms of usage, analysis, and features location accuracy and the reliability of any information derived from the GIS system. SRS will also, help in ensuring that all maps or layers in GIS database overlay accurately and the data set is georeferenced to a common reference system, [14], and this will be fully complying with the UNGGIM resolutions for implementation of Global Geodetic Reference Frame (GGRF).

6. Conclusions

The Sudan Reference System can be considered as the official unified geodetic and geospatial reference system, which shall be a common reference for all geospatial data, Geomatics and GIS applications and provides key elements for integration and sharing of spatial data and thematic information. The unification and implementation of Sudan reference system will lead to:

* Better accuracy in connection with national and regional datums;

* Enhancing the homogeneity of surveying and map data,

* Converting national and regional data sets to global reference systems.

* Sudan is to comply with the UNGGIM resolutions related to Global Geodetic Reference Frame to integrate the national geospatial data national, regional as well as at the global level.

The paper also recommended that future Sudan Vertical datum should be based on Port Sudan Vertical datum. The Global ITR2008 (IGS 2008) reference system should be adopted to provide Country wise and national framework for geospatial data. It should be characterized by accuracies compatible with modern positioning technologies and facilitate sharing of geospatially referenced data between various governments and spatial data users. The use of the Sudan Reference System shall be highly important as it relate the global reference systems to the time dimension.

Conflict of Interest:

The authors have no conflict of interest to declare that are relevant to this article.

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