Optimal Vertical Datum for Tanzania

Prosper E. Ulotu
Ardhi University, Tanzania.
e-mail: ulotu@aru.ac.tz

Abstract

Review of the advantages and disadvantages of the current Tanzania Tide Gauge (TG) vertical Datum (VD) has revealed that some of the problems cannot be solved to conform to the Satellite geodesy era timely and cost effectively. The current VD is costly and uneconomic. By changing to a Global Navigation Satellite Systems (GNSS) compatible VD, most of the problems of the current Tide Gauge-Vertical Datum (TG-VD will disappear and thus boost greatly economic and social prosperity.

One of the current objectives of the International Association of Geodesy (IAG) is to establish a global homogeneous gravity potential vertical datum, a task assigned to the Global Geodetic Observing System (GGOS). From GGOS, realization of the IAG objective is very much dependent on the unification of compatible local and regional VDs. Hitherto, New Zealand realized a new VD based on a geoid model in 2009, and Canada in 2013. The goal of the USA government is to change from TG-VD to geoid model VD by 2022, similarly a lot more countries and regions are striving for the same, and so should Tanzania.

The data for a reliable gravimetric geoid model for Tanzania is ready. A few but not serious and solvable problems are envisaged if a GNSS compatible geoid model based VD replaces the current TG-VD. The advantages of Tanzania changing from the Tide Gauge VD to geoid model VD in this era of GNSS and other satellite technologies are enormous with long term solutions and surpass the expected problems by far. In addition to meeting the IAG/GGOS objective, it will enable the SPILL project to complete the NSRS which is partly ready with the horizontal component only, i.e. TAREF11.

Keywords: *vertical datum. tide gauge. geoid model. GNSS-position. orthometric height*

1 Introduction

The aim of this paper is to critically analyse the problems facing the current Tanzania vertical datum (VD), look at all the opportunities that have opened up since the current VD became operational, and the ideal requirements for a VD to keep pace with the current national and global developments. Thereafter an optimal VD for Tanzania will be suggested. This paper is timely since it comes when the Surveys and Mapping Division (SMD) of the Ministry of Lands, Housing and Human Settlement Development (MLHHSD), Tanzania, is on the move to establish a new National Spatial Reference System (NSRS). In 2013, SMD inaugurated the horizontal component of the new NSRS, the Horizontal Spatial Reference System (HSRS) named as Tanzania Reference Frame of 2011 (TAREF11). The VD for the Vertical Spatial Reference System (VSRS) has not yet been decided.

1.1 Historical perspective

1.1.1 Vertical datum

By definition, Vertical Datum (VD) is a reference surface of zero elevation relative to which heights or depths are referred to. The Mean Sea Level (MSL) has been used extensively for a long time as VD all over the World. It is realized by averaging sea water levels over a minimum period of 18.6 years at a Tide Gauge (TG) station in a coastal area. By averaging the sea water levels over a long period, seasonal and periodical sea level fluctuations can be reduced to the minimum. Such a Local Mean Sea Level

(LMSL) is a good approximation of the geoid at that particular location. Geoid is an equipotential surface of the Earth's gravity field that approximates the mean sea surface in the least squares sense, and by definition it is the datum for orthometric height system. Therefore, heights referenced to MSL are often referred to as *orthometric heights*. The tidal datum is a local datum. The mean sea level determined at a TG is generally different for different locations, and therefore MSL chosen in this manner for a particular region cannot be used as the reference surface for another region. Usually the elevation of each tidal station is transferred to a number of fixed and stable monuments on the land called benchmarks.

For a long time, VD has been a MSL out of one or more fixed point(s) of tidal station(s). The time fixed MSL of a tidal station is referenced to a firmly monumented land point usually referred to as Tide Gauge Benchmark (TGBM). Sometimes more than one tidal station is involved in the establishment of a VD, if so, the TG levels are adjusted to give the same reading and the respective TGBMs are improved accordingly. Thereafter a network of Fundamental and Intermediate Benchmarks (FBMs and IBMs) is established on the land by geodetic levelling method based on the TGBM(s) reduced height(s), this way the MSL VD is realised on the land. MSL established from tide gauge(s) depart from the geoid by the Mean Dynamic Topography (MDT) and other coastal oceanographic effects. To determine orthometric heights referenced to the TG based VD, a series of profiles of spirit levelling and gravity observations are conducted from the closest datum benchmark(s).

We observe that the TG based VD:

1) Is held stationary, i.e. does not consider time variations, besides, MSL is not an equipotential surface and therefore can differ from the geoid by up to a few metres (Featherstone & Filmer 2012);
2) Consumes time to establish; ideal VD requires continuous sea level observations for a minimum of 18.6 years;
3) Is costly to maintain, update and adjust, and requires a frequent re-adjustment;
4) Height information of a new point cannot be determined at once and directly;
5) Height transfer is relative, often with cumulated biases from given BM;
6) In mountainous and rugged terrain, levelling errors accumulate fast, making it difficult to achieve high accuracies;
7) The gravity information required along the levelling routes to correct the spirit levelled height differences makes orthometric height expensive to obtain;
8) TG-VD departs from the geoid and departure cannot be removed by the sea level observations only;
9) To establish the position of a heighted point, additional horizontal positioning method must be used,
10) TG-VD is spatially realized on the surface by a network of physical markers, although it is established by a combination of spatial tidal observations and differential levelling.

1.1.2 Current VD of Tanzania

Establishment of a National (local) VD commenced in the 1960s. By then a model for the geoid of Tanzania did not exist. Consequently a LMSL was instead established in place of the geoid surface. The LMSL was established using TG measurements for 28 months only that was between August 1962 and November 1964 inclusive at the Tanga harbour; see Dickson (1965). In Tanzania mainland, TG stations are found in Tanga, Dar es Salaam and Mtwara harbours. The said TGs have not officially been unified into one VD. The fundamental reference benchmark is the Tanga TGBM. A dense network of ground datum markers; benchmarks (BM) of differing accuracies were monumented and referred to the Tanga TGBM from 1961 to 1969. Figure 1 illustrates the eight loops (A to H) of Tanzania Primary Levelling Network (TPLN) solely based on the Tanga TG-VD.

The MSL that results from the Tanga TG-VD ought to differ substantially from the geoid in Tanzania. In Tanzania, orthometric height is explained as the official height system, and thus its VD should be the geoid and not the MSL (Hofmann-Wellenhof & Moritz 2005). Knowledge of the geoid of Tanzania is now available; cf. Olliver (2007), Merry (2007), Pavlis et al. (2008), Ulotu (2009) & Forsberg et al. (2013). The four geoid models have been assessed by Olliver (2007), Ntambila (2012) & Ulotu (2009, 2013), with the intention of advising the MLHHSD that Tanzania has a geoid model that could either be used to replace the short-term MSL datum at Tanga or to revise it for a better VD with less datum problems. Most of the FBMs and IBMs of the TPLN were established about 50 years ago and were not provided with horizontal coordinates. The only information that exists for the recovery of a TPLN FBM/IBM is its respective locality sketch of that time. Many times it requires dedicated efforts and skills to recover a marker of the TPLN. The TPLN as documented in 1970s is shown in Figure 1, where we observe that a good part of loop B was proposed but not observed. The rate of investment in loop B and the coast is very high similarly in the southern Tanzania.

1.2 Advantages and problems of the current Tanzania TG based VD

1.2.1 *Advantages*

In spite of inadequacies cited above which are mainly of establishment, densification and maintenance of the TPLN and its TG-VD, there are still a few advantages of the present VD and the TPLN as listed below:

1) High relative accuracies can easily be achieved using precise levelling when complemented by gravity corrections,
2) Levelling instrumentation is affordable, also data validation and processing is not complicated,
3) Error tracing is easy, and formats and procedures are well established to minimize gross and systematic errors,
4) Room for improvement is possible to remove some of the datum observational and establishment deficiencies cited earlier, and
5) GPS levelling is a preferred method in the external quality assessment of a gravimetric geoid/quasi-geoid model as well as global gravity models (GGM). Therefore for such undertaking, FBMs and IBMs of the TPLN, which are tide-gauge based, are necessary.

1.2.2 *Disadvantages*

The disadvantages of the Tanzania TG based VD are many, they include:

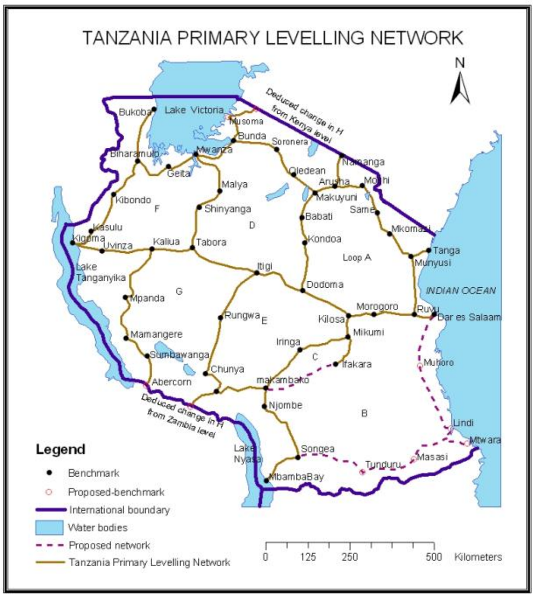
1) Although there are four tidal gauge stations in Tanzania; at Tanga, Dar es Salaam, Mtwara and Zanzibar, the current VD of Tanzania is solely based on the Tanga tide gauge station. Its establishment falls short of the requirements for a tide gauge VD by far. For example:
    a. The LMSL data was observed for 28 months only instead of at least 18.6 years, and this cannot remove short and long term sea level variations which are periodical as well as temporal.
    b. Mean dynamic sea surface topography (MDT) was not accounted for at the Tanga TG station, making it difficult for the VD to coincide with the geoid.
    c. Effects of salinities, sea temperature, ocean currents, ocean wind/tsunamis as well as coastal line configuration were not modelled, and therefore their effects were not removed. The effects displace the tidal VD from the geoid,
2) During spirit levelling, heights of the benchmarks of the TPLN were corrected using normal gravity instead of the actual gravity, cf. John *et al.* (1991), and therefore the height system of Tanzania is normal orthometric and not orthometric height system.
3) There has not been a uniform adjustment of the TPLN. Consequently the network has led to a lot of inconsistencies, which cannot be

explained adequately. Besides, the initial raw data cannot be traced and therefore it is not possible to adjust it rigorously (John & Deus 2009),

4) There is no clear documentation of how heights of trigonometric stations relate to the TPLN. In fact, it is known that some trigonometric stations existed well before TPLN. Moreover, it is not clear in which type of height system are the heights of trigonometric network,
5) If all the TG stations are to be unified, it does not mean that a better tidal VD would be obtained. In fact, the situation could be worse (Filmer & Featherstone 2012). Usually tide gauge stations do not coincide with one another, or regional/global geoid. Investigation conducted in South Africa showed huge discrepancies among its four tide gauge stations at Pretoria, Cape Town, Durban and Lourenco Marques (now Maputo), (Wonnacott & Merry 2012),
6) Re-observation of the entire TPLN so that rigorous adjustment can be conducted, will be very expensive, and very likely not the most relevant option in this GNSS era, and
7) Completion, maintenance and expansion of the TPLN by spirit levelling and actual gravity observations will be costly, time consuming and laborious especially in mountainous and rough terrains of Tanzania.

Advantages of orthometric height system are not fully comprehended in Tanzania. Moreover, errors of the present TPLN cannot be explained confidently and reliably as their causes, which are not fully documented, cannot be inferred practically from the prevailing network. The system could be improved by incorporation of a consistent and reliable gravity network and gravity database. Even then, the system will not qualify to be orthometric as the VD will still be displaced from the geoid.

Figure 1: Tanzania Primary Levelling Network (TPLN)



The TPLN as in 1970's showing the finished loops, Fundamental Benchmarks (FBM), routes and FBMs proposed but not implemented

2 MODERN VERTICAL DATUMS

The current trend in the world is to modernize the TG-VD into a geocentric geoid model VD (Sánchez 2013). Orthometric height is the most preferred height system in the world, whose VD is the geoid (Heiskanen & Moritz 1967). The use of normal heights is also on the rise, but the datum for normal heights (the quasi-geoid) is a bit displaced from the geoid, see Equation (1). Modern VDs which are mainly geoid-model based are explained shortly in the following sections.

2.1 Geoid model or geoid model based vertical datum

2.1.1 Geoid model vertical datum

Geoid is defined as an equipotential surface of the Earth's gravity field that best fits the mean sea surface in a least squares sense, and by definition it is the VD for orthometric height system (*ibid*). The height system is also the official height system in Tanzania. The quality of a geoid model depends much on the data (mainly gravity); quality, density and distribution on the surface of the earth or on the geoid and methodology used. Therefore, the geoid is the most ideal datum for orthometric heights, but problems of replacing a TG-VD with a geoid model exist; these will be explained in a later section. Be it geoid model or TG-VD, both change with time, and thus their updates are necessary. The frequency of update is a function of collective factors which include magnitude of the change of the respective datum, knowledge advancement, as well as policy issues and funds availability, cf. Amos & Featherstone (2009).

2.1.2 *Quasi-geoid model as VD*

Gradually adoption of the normal height instead of orthometric height system is gaining popularity in the world mainly due to its less stringent determination process and closeness of normal heights to orthometric heights. Normal height reference surface is quasi-geoid. Quasi-geoid does not deviate much from the geoid; often it is less than 1m, cf. Equation (1), but the surface has no physical meaning. Quasi-geoid determination is attributed to a Russian geodesist (Molodensky *et al.* 1962). At the moment, improvements and variations of the method exist, one such approach is the Royal Institute of Technology (KTH) of Sweden method called ‘Least Squares Modification of Stokes Method, LSMS’. LSMS method for gravimetric quasi-geoid model determination combines improvement to Stokes method and variation to Molodensky’s method. The relationship between the geoid and the quasi-geoid, i.e. geoidal height N and height anomaly ζ is expressed in Sjöberg (2010, 2012, & 2013) by,

$$N = \zeta + \left(\left(\Delta \mathrm{g} - 2\pi\rho H \right) / \gamma \right) H \tag{1}$$

where:

N	Geoidal height,
ς	Height anomaly from Quasi-geoid model,
Δg	Bouguer gravity anomaly,
ρ	Constant density of topographical masses,
γ	Normal gravity on the telluroid; close to the surface,
H	Elevation of the surface point.

2.1.3 *Hybrid geoid model as VD*

When accurate and fairly well distributed benchmarks referred to appropriately determined TG based VD exist, together with precise gravimetric geoid model, a hybrid VD can be created out of the two using GPS observations on the BMs. Precise GPS observations on the BMs i.e. GPS/levelling enable determination of geometrical geoidal height N_{BM}^{GPS} as below:

$$N_{BM}^{GPS} = h - H \,, \tag{2}$$

where, N_{BM}^{GPS} is the geometrical geoidal height, h is ellipsoidal height from precise GPS positioning and, H is orthometric height based on the TG-VD.

From a gravimetric geoid model we obtain N, that upon combination with N_{BM}^{GPS} over the respective region often in least squares manner, results into hybrid VD. When the above conditions are favourable, hybrid datum combines the advantages of both types of geoidal models, and that is often advantageous to the user.

2.1.4 *Geoid model constrained to TG-VD by a corrector surface*

When ideal TG-VD is in place, the VD can be improved further for time dynamics of the earth that it lacks through a corrector surface. A corrector surface is a surface of small geoidal displacements from the existing TG-VD. Therefore, an up to date precise gravimetric geoid model is needed to create a corrector surface to model the inconsistencies of the BMs of the TG vertical datum and the gravimetric geoid model by holding fixed heights of some of the reference BMs of the TG-VD.

Thereafter, orthometric heights are determined from the geoid model and the corrector surface as if they were referred to the fixed BMs of the TG-VD, for more information see for example Ulotu (2009, 2013) and the references therein. Minor variations to the above geoid model based VDs exist. For example, a regional gravimetric geoid model may be shifted by a factor which constrains the gravimetric geoid model to give say the same height as that of the TGBM. This way height differences between the existing TG-VD and the new VD, i.e. shifted geoid model are minimized. This practice is not bad when both the TG-VD and the geoid model are both in sound conditions. If one is too inferior to the other, then the shift does not bring any meaningful results, as such it lowers the quality of the good surface. Once the decision for a VD has been reached, and the datum is in place, a vertical coordinate system is carefully designed and implemented to address monuments of different accuracies/orders. The type of VD adopted often influences the distribution, densification and the way the ground vertical network is utilized.

2.2 Modernization of VSRS by implementing a geoid model based VD

A few of countries which have succeeded or are one the move to change their TG-VDs to geoid model based VD are cited, please refer to the given references for more insights. The official national VD for New Zealand and its offshore islands based on gravimetric quasi-geoid model is NZVD2009 since 2009 (Amos 2010). As of 2013, the VD for Canadian is CGVD2013 and is a gravimetric geoid model that has replaced the 13-TG based VD of 1928 CGVD28; see NRCan (2011) & Huang *et al.* (2011). Since 2011, the USA National Geodetic Survey (NGS) formed a project to improve Gravity for the redefinition of the American VD (GRAV-D). By 2022 GRAV-D is required to have replaced the current North American VD of 1988 (NAVD 88) by a gravimetric geoid model VD for the whole of the USA; for more details see Roman and Weston (2012) as well as: https://www.ngs.noaa.gov/heightmod/

3 Gravimetric geoid model as the new VD for Tanzania

The reason of opting for the current short duration TG based VD was absence of a better approximation to the geoid of Tanzania at that time. Some of the problems that Tanzania has suffered and continue to suffer due to the use of the current TG-VD were enumerated in Section 1.2.2. Going through the references cited in the preceding sections and especially in Section 2.2, enormous benefits of using a reliable gravimetric geoid model based VD in this era of GNSS and related technologies are perceived. The next section, discusses the readiness of Tanzania to change from TG-VD to gravimetric geoid model VD.

3.1 How ready is Tanzania to change its VD to a geoid model?

3.1.1 Data for geoid model determination

In addition to the global geoid models EGM96 (Lemoine *et al.* 1998) & EGM2008 (Pavlis *et al.* 2008), three full coverage dedicated gravimetric geoid models for Tanzania have been computed since 2007; TZG07 (Olliver 2007), TZG08 (Ulotu 2009) & TZG13 (Forsberg al. 2013), TZG13 is still preliminary. Except for TZG13, partial assessment using GPS levelling showed that TZG08 has a better performance (Ntambila 2012), (Ulotu 2013) & (Willison 2013). Since the computation of TZG08 in 2008, data for geoid computation for Tanzania has changed favourably by many folds as outlined briefly in Table1.

Table 1: Situation of data for geoid model computation at present

Data Type	Condition in 2008	Present improvements	Remark
Terrestrial surface point gravity at 99% confidence level, see Figure 2	39,677 points used with coverage $15^{\circ} S \le \phi \le 4^{\circ} N$ and $26^{\circ} E \le \lambda \le 44^{\circ} E.$	- 4-absolute gravity stations by FG5 in 2008 - About 26 1st and 2nd order relative gravity stations well distributed within Tanzania	The new ground gravity can be used to further clean the old gravity data, before they are combined
Ship tracks gravity on the Indian Ocean	7,843 Marine point ship track data, see Figure 2	No change	The same data to be used after validation
Marine gravity anomaly	KMS02- $2' \times 2'$ mean marine altimetry gravity anomaly grid from KMS Denmark	DTU10, $2' \times 2'$ mean marine gravity anomaly from Danish Space Centre of the University of Copenhagen, Denmark	DTU10 to be used since it is a much improvement of KMS02, see Figure 3
Aerial gravity	Never existed	Tanzania is now fully covered by $5' \times 5'$ surface aerial gravity anomaly of about 5mgal resolution as of Dec. 2013	Aerial and ground point gravity data should improve significantly the geoid quality
		$5' \times 5'$ surface aerial gravity anomaly of about 5mgal resolution outside the boundaries of Tanzania from Mozambique and Malawi.	There is a possibility of more gravity data from Uganda & Kenya also.
Global Gravitational Model (GGM)	Only CHAMP and GRACE pure and combined models were used.	- GOCE GGMs - Variable combinations of CHAMP, GRACE, GOCE, EGM08 and Altimetry models	Regional assessment for best pure and combined GGMs to be conducted
Digital Elevation Model	SRTM 3-arc seconds from the Consultative Group for International Agricultural Research of the Consortium for Spatial Information (CGIAR-CSI) v3.1	- SRTM3 CGIAR-CSI v4.1 - ASTER GDEM v2 is 1-arc second and - ACE2 (3-arc second) DEM - TanDEM-X 0.4 arc second resolution (commercial)	Best DEM to be used. Preferably between SRTM3 *CGIAR-CSI v4.1 and TanDEM-X GDEM,*
Upper crust density	Constant value of $2.67 g.cm^{3}$	A simple model of upper crust lateral density variation for Tanzania, see Maduka (2013)	Maduka density model will be tested for possible use
GPS/levelling data	19 stations	23 stations. Soon the number and quality of the older data is likely to improve.	Important data for external assessment of GGMs and geoid models

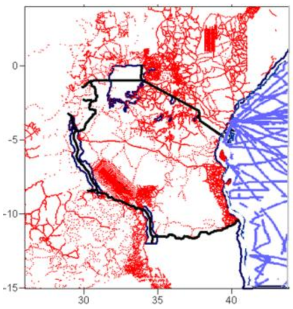


Figure 2: 39,677 land surface point gravity (red dots) and 7,843 Marine point ship track data (blue dots)

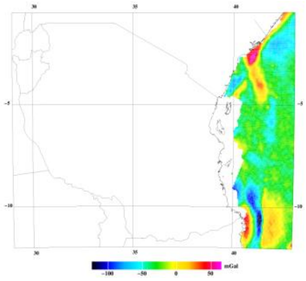


Figure 3:

Satellite altimetry gravity from DTU10 Data deleted in airborne coverage areas.

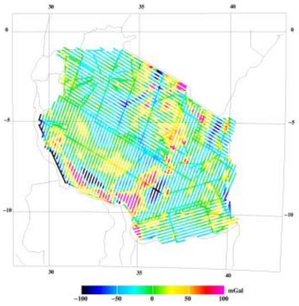


Figure 4a:

Airborne surface free-air gravity anomaly data; unit mGal

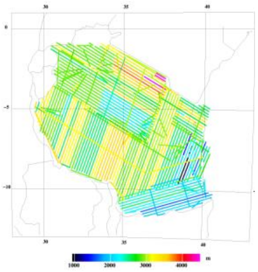


Figure 4b: Airborne free-air gravity anomaly data at flight level; unit mGal

Note: The different elevations of the airborne survey are fully taken into account in the post-processing to come up with airborne surface free-air gravity anomaly data (Forsberg et al. 2013).

3.1.2 Methods and software

The quality of a gravimetric geoid model is mainly a function of gravity and associated data quality, density and distribution as well as reliable methods and software. The methods are such as Sjöberg (2003a-b) & Forsberg (2003).

3.2 Advantages of replacing the current TG-VD with a geoid model

1) The new VD will be an equipotential surface of the Earth's gravity field. Therefore, most of the orthometric height system benefits will be realized,
2) The coverage will no longer be limited to the TPLN limits, but will be available throughout the boundaries of Tanzania (geoid model extent),
3) Orthometric height together with its geocentric position will be obtained directly after obtaining ellipsoidal height from GNSS positioning. That is relative heighting and extra horizontal positioning will no longer be necessary,
4) Orthometric height will be consistent with the GNSS positioning due to the compatibility of reference ellipsoids of geoid model and GNSS positioning,
5) Requirement for gravity along the levelling routes will no longer be needed,
6) TPLN maintenance will be reduced substantially since most of the stations of the TPLN will be updated and augmented by the high precision 3D Tanzania National Geodetic Network
7) Misclosure accumulation along the levelled routes will no longer be a problem,
8) TPLN inconsistencies due to non-rigorous adjustment of TPLN will cease to exist,
9) Since the geoid is defined in relation to a geocentric reference ellipsoid, it makes it compatible with the space-based positioning technologies like GNSS and satellite altimetry,
10) With the right equipment, software and knowledge, the quality of orthometric height will improve and the time to acquire it will generally be much smaller.

3.3 Who really need the new VD in Tanzania?

1) A large number of stakeholders rely on GNSS as their tool of choice for accurate positioning and daily use; a geoid model is required to convert ellipsoidal height to orthometric height.
2) It has been observed that a lot of potential areas for investment are outside the TPLN coverage, see Figure 1. That is, the current VD is not available throughout Tanzania. In such areas, GNSS levelling which requires the new geoid based VD is inevitable.
3) There is no record of update or maintenance of the current VD since its inception in 1960s, therefore it is obsolete and hence a new optimal VD is required to replace it without further delays.
4) The geocentric TNGN is integral part of the TAREF11; its controls are well distributed all over Tanzania, thus a geocentric geoid based VD is inevitable for GNSS levelling.
5) Even without a proper research, it is believed that the government has been losing colossal amounts of money on linear infrastructure development due to poor height system associated with the current VD, which leads to huge levelling misclosures.
6) In addition to the daily uses, there is a large community of GNSS users in Tanzania, and in the region who require accurate geoid-based VD for research and scientific applications.

3.4 Envisaged problems by changing the current VD to geoid model

1) Training: Countrywide educational lectures to all stakeholders during the transition period on such issues as changed VD and the benefits, orthometric height from GNSS ellipsoidal height and its accuracy using approved/gazetted national geoid model, dangers of using a different geoid model and repercussions of continuing the old system,
2) Inevitable preparations: Expertise and instrumentation for GNSS data collection and processing,
3) Limitations of the orthometric height: There will be variable orthometric height quality due to variable gravity data quality in the geoid model,
4) Variable coverage and density of the Tanzania National Geodetic Network controls monuments for efficiency in GNSS ellipsoidal height realization.
5) Matching and merging of maps, plans, charts etc. based on the old and new systems.

3.5 Concluding remarks

The disadvantages of the current TG-VD outweigh substantially its few and weak advantages. Ideally, the Tanzania height system ought to be orthometric, but it is not due to the use of wrong VD and non-use of actual gravity in the whole system. Moreover, the TPLN has not been adjusted rigorously; consequently it leads to unreliable results with big levelling misclosures. The relationship between spirit levelled and trigonometric heights which are the two main sources of heights in Tanzania is not documented anywhere. Markers of the TPLN do not have positional coordinates; as a result most of them cannot be located easily, let alone many that have been vandalised. TPLN is not available in the south-eastern coast and southern Tanzania (see Figure 1); it is not available also in many new urban centres and densely populated and high investment regions.

Advantages of a geoid based VD in this era of GNSS are many; some were cited in Section 3.2. The current move of the whole World as directed by the IAG under the GGOS is to unify all the local and regional geoid model based VD into a homogeneous global vertical datum compatible with the GNSS and satellite related technologies of potential W_0 .

Tanzania is ready for a gravimetric geoid model VD since all the necessary inputs to such a datum as outlined in Section 3.1 exist. Therefore it should not continue to waste colossal amounts of funds due to extended use of the current TG-VD. Choice of a gravimetric geoid model VD will be a timely, viable long term solution with enormous benefits. The envisaged challenges are ordinary and nothing is serious. In addition to meeting the IAG/GGOS objective, it will enable the MLHHSD "Strategic Plan for Implementation of Land Laws in Tanzania" (SPILL) project to complete the NSRS which is partly ready with the horizontal component only, i.e. TAREF11.

Acknowledgement

The author is grateful to Prof. W.E. Featherstone of Curtin University of Technology, Australia for very constructive recommendations also Messrs Eugene H. Silayo, Maenda D.J. Kwimbere and Saburi John all of Ardhi University, Tanzania for proof reading the manuscript carefully.

References

Amos, M 2010, 'New Zealand VD 2009'. *New Zealand Surveyor,* no. 300, 2010.

Amos, MJ & Featherstone, WE 2009, 'Unification of New Zealand's local VDs: iterative gravimetric quasi-geoid computations', *J Geod*, vol. 83, no. 1, pp. 57-68.

Dickson, WL 1965, 'Primary Levelling Heights of Benchmark', *Technical report to the Ministry of Lands, Settlements and Water Supply, Survey and Mapping Division, Dar es Salaam*.

Filmer, MS & Featherstone, WE 2012, 'Three viable options for a new Australian vertical datum', *J Spatial Sci*, vol. 57, no. 1, pp. 19-36, DOI: 10.1080/14498596.2012.679248.

Forsberg, R 2003, *An overview manual for the GRAVSOFT Geodetic Gravity Field Modelling Programs,* KMS - National Survey and Cadastre of Denmark including comments to programs by Tscherning CC (Univ. CPH) and Knudsen P (KMS).

Forsberg, R, Olesen, AV, Mtamakaya, J, Tarimo, C & Ulotu, PE 2013, *Preliminary geoid model for Tanzania from airborne and surface gravity,* Scientific research report submitted to the Surveys and Mapping Division of the Ministry of Lands, Housing and Human Settlements Development, Dar Es Salaam, Tanzania.

Heiskanen, WA & Moritz, H 1967, *Physical geodesy*. WH. Freeman and Company, San Francisco, USA.

Hofmann-Wellenhof, B & Moritz, H 2005, *Physical geodesy*. Springer Wien New York.

Huang, J, Véronneau, M, Henton, J & Héroux, P 2011, 'A Prototype of a Geoid-Based Height System in Canada', *XXV IUGG General Assembly, Earth on the Edge: Science for Sustainable Planet, Melbourne, Australia, IAG G06: Towards a unified World Height System, 28 June-7 July*.

John, S & Deus, D 2009, 'Transformation of the Tanzania national levelling datum to the geoid', *Geophysical Research Abstracts,* vol. 11, EGU2009-11339, EGU General Assembly, 19-24 April, 2009,Vienna, Austria. http://meetings.copernicus.org/egu2009

John, S, Laswai, ZJM, Richard, BK, Stephen, DM & Msemo HO 1991, 'Proposal for rigorous systems of heights for East Africa', *Technical report Department of Land Surveying Ardhi Institute Dar Es Salaam Tanzania*, no. 90-1,

Kotsakis, C, Fotopoulos, G & Sideris, MG 2001, 'Optimal fitting of gravimetric geoid model undulations to GPS/levelling data using an extended similarity transformation model', *Proceedings of the annual scientific meeting of the Canadian Geophysical Union of Ottawa, Canada, May 14-17*.

Lemoine, FG, Kenyon, SC, Factor, JK, Trimmer, RG, Pavlis, NK, Chinn, DS, Cox, CM, Klosko, SM, Luthcke, SB, Torrence, MH, Wang, YM, Williamson, RG, Pavlis, EC, Rapp, RH & Olsen, TR 1998, 'The development of the joint NASA GSFC and NIMA geopotential model EGM96', *NASA Technical Publication.*

Maduka, PR 2013, 'Digital mapping of the lateral density variation of the upper crust in Tanzania', B.Sc. Dissertation, Department of Geomatics, School of Geospatial Sciences and Technology, Ardhi University

Merry, CL 2007, 'AGP07 an updated geoid model for Africa', *Presented, Symposium G2, XXIV General Assembly of the IUGG, Perugia, Italy,* *July 2007.*

Molodensky, MS, Eremeev, VF & Yurkina, MI 1962, 'Methods for study of the external gravity field and figure of the Earth', *Translation from Russian (1960), Israel program for scientific translation, Jerusalem.*

NRCan 2011, *Height Reference System Modernization,* Geodetic Survey Division, Earth Sciences Sector, Natural Resources Canada, viewed March 2014, *http://www.geod.nrcan.gc.ca/hm/index_e.php.*

Ntambila, D 2012, Validation of the recent geoid models for Tanzania, M.Sc. dissertation of the SGST, Ardhi University (ARU) Tanzania.

Olliver, JG 2007, 'The gravimetric geoid model of Tanzania', *Survey review,* vol. 39, no. 305, pp. 212-225

Pavlis, NK, Holmes, SA, Kenyon, SC & Factor, JK 2008, 'An Earth Gravitational Model to degree 2160: EGM2008', *presented at the 2008 general assembly of the European Geosciences Union, Vienna, Austria, April 13-18, 2008.*

Roman, D & Weston, N 2012, 'Beyond GEOID12-Implementing a New Vertical Datum for North America', *FIG Working Week 2012, TS04B - Heights, Geoid and Gravity, 5691. Rome, Italy, 6-10 May 2012.*

Sánchez, L 2013, 'Towards a vertical datum standardisation under the umbrella of Global Geodetic Observing System', *JGS,* vol. 2, no. 4, pp. 325–342. DOI: 10.2478/v10156-012-0002-x.

Sjöberg, LE 2003a, 'A general model for modifying Stokes' formula and its least-squares solution', *J Geod* vol. 77, pp. 459-464.

Sjöberg, LE 2003b, 'A Computational scheme to model the geoid model by the modified Stokes' formula without gravity reductions', *J Geod,* vol. 77, pp. 423-432.

Sjöberg, LE 2010, 'A strict formula for geoid-to-quasigeoid separation', *J Geod,* vol. 84, pp. 699-702.

Sjöberg, LE. 2012, 'The geoid-to-quasigeoid difference using an arbitrary gravity reduction model', *Stud Geophys Geod,* vol. 56, pp. 929-933.

Sjöberg, LE 2013, 'The geoid or quasigeoid- which reference surface should be referred for a national height system?', *JGS,* vol. 3, pp. 103-109.

Ulotu, PE 2009, 'Geoid Model of Tanzania from Sparse and Varying Gravity Data Density by the KTH Method', PhD Thesis, the Royal Institute of Technology (KTH), Stockholm, Sweden.

Ulotu, PE 2013, 'Validation of Gravimetric Geoid Model TZG08 Using GPS Levelling Method in Mainland Tanzania', *Journal of Building & Land Development,* Vol. 21, no. 1.

Willison, DK 2013, 'Geoid model validation using geoid slopes, study cases: AGP07, TZG07, TZG08 and EGM08 on 28 TPLN Benchmarks', BSc. Dissertation, Department of Geomatics, SGST, Ardhi University, Tanzania, 2012/13.

Wonnacott, R & Merry, C 2012, 'A New Vertical Datum for South Africa?', *Scientific report of the Department of Rural Development and Land Reform, Cape Town, South Africa.*