**ARDHI UNIVERSITY**

# ANALYSIS OF 1′ X 1′ RESIDUAL TERRAIN EFFECTS (RTE) FROM TOPOGRAPHIC POTENTIAL MODEL AND DEMs BY SRTM2GRAVITY.

**SIRIWA PROTAS R**

**BSc Geomatics**

**Dissertation**

**Ardhi University, Dar es Salaam**

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# ANALYSIS OF 1′ X 1′ RESIDUAL TERRAIN EFFECTS (RTE) FROM TOPOGRAPHIC POTENTIAL MODEL AND DEMs BY SRTM2GRAVITY.

**SIRIWA PROTAS R**

A Dissertation Submitted to the Department of Geospatial Sciences and Technology in Partially Fulfilment of the Requirements for the Award of Science in Geomatics (BSc. GM) of Ardhi University

## CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance by Ardhi University, a dissertation titled **"Analysis of 1′ x 1′ Residual Terrain Effects (RTE) from Topographic Potential Model and DEMs by SRTM2gravity"** for fulfillment of the requirements for the award of degree of Bachelor of Science in Geomatics (BSc.GM) of Ardhi University.

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| Signature ……………………… | Signature ………............ |
| Mrs. Regina V Peter | Mr. Humphrey Busega |
| (Main Supervisor) | (Second Supervisor) |
| Date …………………………… | Date ………………………… |

## DECLARATION AND COPYRIGHT

I, SIRIWA, PROTAS R. hereby declare that this thesis is my own original work and that to the best of my knowledge, it has not been presented to any other University or Institution of higher learning for a degree or similar award except where due acknowledgements have been made in the text.

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SIRIWA, PROTAS R

22815/T.2019

(Candidate)

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## DEDICATION

*I dedicate this dissertation to my beloved family; my father, Revocatus A. Siriwa and my mother Lucy Felix Komu for their love, prayers, caring and sacrifices for educating and preparing me for my future, my sisters, Beatrice, Hedwiga, Patricia my only brother Pastory. Your presence always gives me strength.*

## ABSTRACT

Topographic potential models represent the gravitational potential generated by the attraction of the Earth's topographic masses. Topographic masses typically mean all solid matter of Earth's topography (rock, sand, basalts, etc.) but also includes ocean water, lake water and ice sheets. Since gravity in the models is not based on actual gravity measurements, the gravity is only predicted by the models. The accuracy of the prediction mainly is affected by the resolution of the topographic potential model. This study aims at performing analysis of 1′ x 1′ RTE from topographical potential model and DEMs by SRTM2gravity. The analysis was conducted by taking the difference of the RTE between SRTM2gravity and topographic potential model and see if their differences are significant by performing the statistical analysis at 95% confidence level.

The data used during the computation of 1′ x 1′ RTE are: MERIT-3″ DEM to provide computation points i.e. latitude, longitude and height information of the topography, during the computation of RTE from GrafLab were used so as to facilitate the RTE to be computed over the AOI.

During the analysis of the three kind of topographical model i.e. isostasy, isostasy-topography and topography the topography kind seems to provide better RTE with small value of STD and RMS of 5.112mGal and 5.112mGal respectively, compared to the isostasy and isostasy-topography kind of topographic potential model due to their bigger spatial resolution. In comparison of RTE difference between SRTM2gravity and the topographical potential model, the pair of SRTM2gravity and dV_ELL_Earth2014_5480 were validated at 95% confidence level and their differences seems to be significant with small value of STD and RMS of 5.793mGal and 5.821mGal respectively.



**KEYWORDS:** Topographic Potential Model, SRTM2gravity, dV_ELL_Earth2014_5480, 95% confidence level, RMS, STD.

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| | |
|---|---|
| AOI | Area of Interest |
| DEM | Digital Elevation Model |
| DTM | Digital Terrain Model |
| d/o | Degree and Order |
| GGM | Global Geopotential Model |
| GNU | Gnu's Not Unix |
| GRAFLAB | Gravity Field Laboratory |
| GRAVSOFT | Gravity Software |
| MA | Mean Average |
| MATLAB | Matrix Laboratory |
| MERIT | Multi-Error-Removed Improved-Terrain |
| MSL | Mean Sea Level |
| RET | Rock-Equivalent Topography |
| RMS | Root Mean Square |
| RTE | Residual Terrain Effect |
| RTM | Residual Terrain Model |
| SH | Spherical Harmonic |
| SRTM | Shurter Radar Topographic Mapping |
| STD | Standard Deviation |
| TC | Terrain Correction |
| TGF | Terrain Gravity Field |
| GRS80 | Geodetic Reference System 1980 |

| | |
|---|---|
| WGS84 | World Geodetic System 1984 |
| EGM96 | Earth Gravitational Model 1996 |

# CHAPTER ONE

# INTRODUCTION

## 1.1 Background of the study

The earth's gravity field can be divided into three components in the spectral domain, i.e., short, medium and long wavelength components. The topography of the earth is the rich source of the high frequencies of the earth's gravity field on land and as a result a high-resolution DEM/DTM can be used to compute these high frequencies through different topographic mass models and methods. The low frequency component of gravity is due to the large masses beneath the terrain mainly below the Mean Sea Level (MSL) (Heiskanen & Moritz, 1967).

The low frequencies (long-wave component of gravity) approximate the actual gravity on the surface of the earth because they lack the details represented by the terrain. The earth's gravity field determined by the dedicated satellite missions (CHAMP, GRACE, GRACE-FO) contains the low frequency component of gravity but GOCE goes further to medium frequencies which are derived from Airbone. The short-wave component of gravity is one of the spectral components of the earth's gravity field. Sometimes short-wave component of gravity referred as Residual terrain effects (RTE), is the high-frequency gravity effects reflecting the gravitational attraction of Earth's global topography residual using a reference surface of d/o 1800, 2190, 3660 and 5480 spherical harmonics. The high frequency of the earth's gravity field is due to erratic uppermost layer of the earth. Moving away from the earth's surface, the high frequencies of the earth's gravity field grow weaker and for this reason the details of the figure of the earth also are not sensed. Total terrain effects at a point are due to all the topographic masses above the geoid while residual terrain effects are due to topographic masses relative to a level surface through the point or relative to some other approximation to the terrain (Forsberg, 1981).

Topographic gravity field models also known as topographic potential models, topography related models, synthetic gravity models or forward models, represent the gravitational potential generated by the attraction of the earth's topographic masses. Topographic potential model is a mathematical representation of the gravitational effects of topography on a given region of the earth's surface. It is a type of gravitational model that is used to correct for RTEs in gravity measurements. RTEs refer to the deviations in the measured gravity field caused by the presence of topography and other physical features of the Earth's surface, such as mountains, valleys and rivers. These deviations can have a significant impact on the accuracy of gravity measurements, particularly when trying to determine the gravity field of large regions or the entire earth (Claessens & Hirt, 2013). The topographic potential model uses a digital elevation model (DEM) of a region of interest to calculate the gravitational effects of the topography. The DEM is a digital representation of the terrain, with each point on the terrain represented by a set of coordinates and an elevation value. The topographic potential model uses this information to calculate the gravitational potential caused by the topography at each point on the terrain. The gravity in these models is computed based on (a) a model of topographic masses e.g., DEM and (b) assumption of the mass densities inside the topography. The gravitational potential generated from the topographic gravity field models is due to all masses of the earth's topography, i.e., Rock, sand, water bodies such as rivers, lakes and oceans. Some of the models account for isostatic masses while some do not. Those models that do not account for isostasy are often referred to as uncompensated topographic potential models (Forsberg, 1981). Once the topographic potential has been calculated, it can then be subtracted from the measured gravity field to correct for RTEs. This allows for a more accurate determination of the earth's gravity field, which can be used for variety of applications, such as geodesy, satellite orbit determination and mineral explorations (Flechtner, 2003).

In Tanzania especially at Ardhi University, the Residual Terrain Effects (RTE) have been computed by several authors for different purposes in their research. Among of them include;

(Ulotu, 2020), determined the Surface Gravity using Pure GGMs and DEMs without Observed Ground Gravity Data and Observed Absolute and Relative Gravity Data in Tanzania Mainland was used for validation. Tanzania Mainland was the selected study area with 56-relative and 1-absolute ground gravity stations used for validation. 5-GOCE GGMs, 1-topographic-isostatic gravity field model and SRTM2gravity data-set were used to provide the long & medium, short and very-short wavelength components of gravity respectively. Among the five selected models, the combination of $SPW\_R4^{280}$ + $TOIS^{1800}$ +RTE showed the best performance within the study area when compared to the actual surface gravity anomaly data. The topographical model used in this research was RWI_ TOIS_2012_plusGRS80 which was released in 2014 which was isostasy-topography kind with degree and order of 1800 and their value of STD and RMS are 15.785mGal and 15.785mGal respectively. (Kabala, 2022), conducted the numerical analysis of short-wave component of gravity using different computation sources/packages and its performance in different terrains in Tanzania. The topographical model used by this previous researcher was dv_ELL_EARTH2014_5480_plusGRS80 with degree and order of 5480 which by that time was the topographical model with the highest degree and order compared to other. The researcher used different computation sources/packages i.e. TGF, SRTM2gravity and GRAFLAB. Among the three packages, SRTM2gravity showed the best performance within the study area and on the five selected terrains when compared to other packages for the same DEM, Crustal density model and coverage with the best mean and STD of -0.368 and 3.270mGals. (Layda, 2020), determined and performed an assessment of 1′ x 1′ RTE, Constant and LITHO1.0 crustal density models in Tanzania was used. 1′ x 1′ RTE was computed by using LITHO1.0 crustal density model and a constant density model. Whereby, in both cases MA and SH reference surfaces were used. Thereafter, the computed RTE was combined with surface gravity anomalies from GO_CONS_GCF_2_SPW_R5 and EGM08 as demonstrated in Spectral Enhancement Method (SEM) to yield the predicted surface gravity anomaly. The predicted surface gravity anomaly was then compared with the actual surface gravity anomaly from terrestrial gravity point data. The results showed that LITHO1.0 crustal density model had a better prediction of the actual surface gravity anomalies with RMS of 23.812mGal compared to a constant density assumption with RMS of 23.974mGal at 95% confidence level when SH reference surface was used. Also, when MA reference surface was used, LITHO1.0 crustal density model had a better prediction of the actual surface gravity anomalies with RMS of 34.951mGal compared to a constant to a constant density assumption of 35.299mGal at 95% confidence level. The researcher concluded that LITHO1.0 crustal density have better representation of the Earth’s crust density.

Therefore in Tanzania the different topographic potential model have not been used in computation of RTE. It is known that there are three different kinds of topographical potential model i.e. isostasy only, isostasy-topography and topography only, and between the three kinds only the two kind has been used by previously researchers here in Tanzania, thus left us with one kind of the topographical model which is isostasy kind. But we do not know between the three kinds of the topographical models which one will provides RTE that are more reliable than the other. The advantage of using the topographical model over DEMs is that, computation of RTE from the topographic potential model is straight forward compared to Digital Elevations Model (DEM) since in DEM the smooth mean elevation surface should be created. According to (Forsberg, 1984)

Mean Elevation Surface (MES) should be generated from DEM model of no more than 10-20km spacing so as to have a reasonably smooth representation of the reference grid.

In geodesy and geophysics, research on Residual Terrain Effects (RTE) is ongoing with the goal of enhancing the precision of many applications that depends on readings and measurements of the Earth's gravitational field and the topographical potential model plays a critical role in geodesy by accounting for the gravitational effects of the Earth's topography on measurements. Therefore, this study aims at performing analysis of the computed RTE from different topographic potential model and see how reliable their differences are compared to those RTE that are computed from SRTM2gravity which perform better in Tanzania mainland computed from Merit-DEM with 3-arcsec resolution. As we know the RTE from SRTM2gravity are already computed so it's the matter of accessing them through MatLab and perform an interpolation to get a single value (Hirt, et al., 2019).

### 1.2 Statement of the problem

We do not know how significance the differences is between RTE computed from topographic potential model and RTE computed from DEMs especially SRTM2gravity which provides RTE from Merit-DEM with 3-arcsec resolution. Computation of RTE from topographic potential model is straight forward compared to DEMs. Therefore, this research aims at performing analysis of the 1′ x 1′ RTE from topographic potential model and DEMs by SRTM2gravity, also to check the performance between the topographic potential models since there are three kind of topographic potential model i.e. isostasy, isostasy-topography and topography.

### 1.3 Objectives

#### 1.3.1 Main Objectives

The main objective of this research is analysis of 1′ x 1′ Residual Terrain Effects (RTE) from topographic potential model and DEMs by SRTM2gravity.

#### 1.3.2 Specific Objectives

i. To compute 1′ x 1′ RTE from different topographic potential model and its assessment.
ii. Validation of 1′ x 1′ RTE obtained from topographic potential model and the computed RTE from SRTM2gravity.

## 1.4 Scope and limitation of the research

The study is limited to Tanzania Mainland found between 0ºN to 12ºS latitude and 29ºE to 41ºE longitude (as shown in Figure: 1.1). The RTE was computed at a resolution of 1′ x 1′ over the AOI.

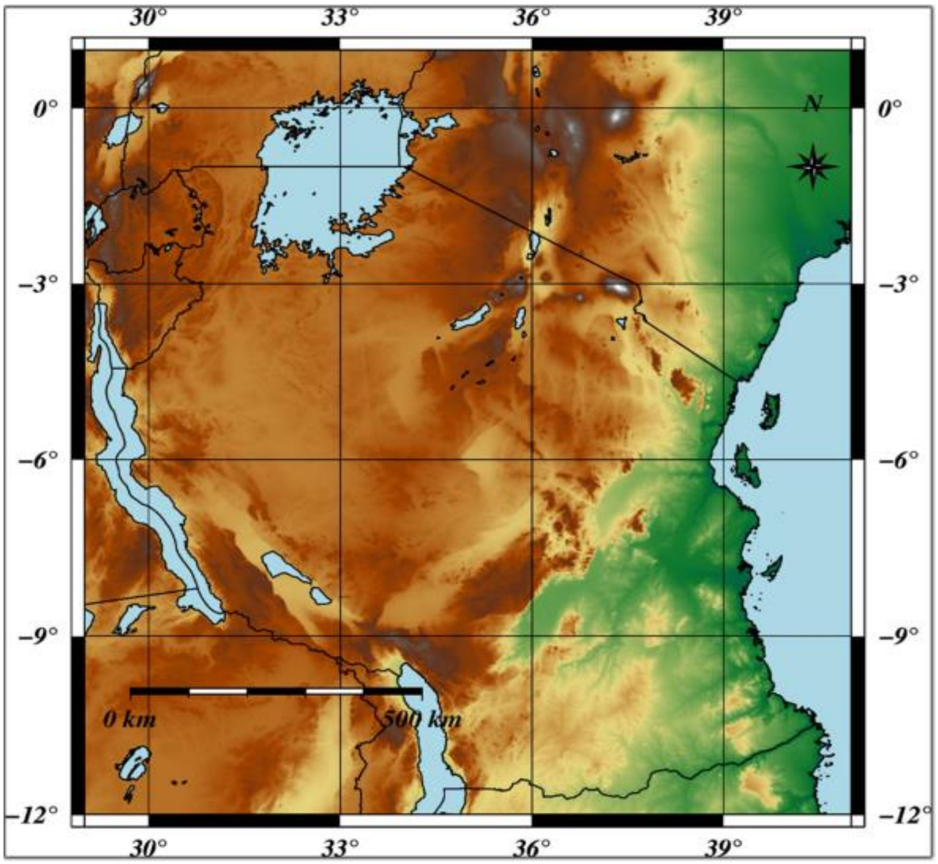


Figure 1.1: The study area

## 1.5 Benefits of the study

This research will benefit geoscientists especially geodesists and geomatician in

i. Densifying the sparse gravity to a suitable density and distribution.
ii. This study will also be used for the gravity prediction in areas where there is no gravity data at all.
iii. To replace erroneous or less precise gravity data.
iv. To avail gravity where it is missing.

### 1.6 Significance of the study

Once the RTE computed from topographic potential model are found to be more significance compared to those computed from DEMs by SRTM2gravity, then the RTE computed from the topographical models will be used for various gravity and geophysics applications in Tanzania.

### 1.7 Research questions

i. How significance are the RTE computed from topographic potential model and RTE from SRTM2gravity?

ii. Between isostasy, topography and isostasy-topography, which topographic potential model perform better than the other?

### 1.8 Structure of Dissertation.

This dissertation consists of five chapters as follows;

(a) Chapter One

This chapter introduces the study by explaining the background of the study, statement of the problem, main objective, research hypothesis, scope of the research, study area, significance and beneficiaries of the research.

(b) Chapter Two

Chapter two of this study is all about literature review concerning topographical potential model, method of analysis of the result and the method selected to be used in this research.

(c) Chapter Three

This chapter details the methods used, data acquisitions, data descriptions, data preparations, mathematical models used in computations and software used in this research.

(d) Chapter Four

This chapter gives the results and discussions of the results.

(e) Chapter Five

This chapter consists of Conclusion drawn from this study and recommendations for the future related researches.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 Overview of the topographic potential model

Topographic gravity field models also known as topographic potential models, topography related models, synthetic gravity models or forward models, represents the gravitational potential generated by the attraction of the earth's topographic masses. The gravity in these models is computed based on (a) a model of topographic masses e.g., DEM and (b) assumption of the mass densities inside the topography. The gravitational potential generated from the topographic gravity field models is due to all masses of the earth's topography, i.e., rock, sand, water bodies such as rivers, lakes and oceans. Some of the models account for isostatic masses while some do not. Isostasy means the equality between the mantle and the crust, where the crust floats at an elevation that depend on its thickness and density. Those models that do not account for isostasy are often referred to as uncompensated topographic potential models ( Ince, et al., 2019). Topographic potential models are mathematical representations of the gravitational potential energy of a landscape, which can be used to estimate the elevation of a terrain surface and to predict the spatial distribution of different landforms. Topographic potential models take into account the elevation and topography of the Earth's surface, as well as the distribution of mass within the Earth. They can be used to estimate the gravitational attraction between different parts of the Earth, which is important in various fields such as geodesy, geography, and hydrology. Topographic potential models have various applications in geosciences, such as geoid modeling, satellite altimetry, and global gravity field modeling. They are also used to identify terrain features such as ridges, valleys, and drainage basins. The study of topographic potential models is an active area of research, with the aim of improving their accuracy and applicability in various fields. ( Ince, et al., 2019)

The models are given in terms of spherical harmonic coefficients and can be evaluated with spherical harmonic synthesis software at any point on the earth's surface. The main difference between the spherical harmonic coefficients in a Global Geopotential Model (GGM) and in a topographic gravity field model is that the latter does not include the zonal harmonic coefficients implied by the reference ellipsoid. Therefore, to evaluate the spherical harmonic coefficients in the topographic gravity field models using synthesis software for evaluating the spherical harmonic coefficients in the GGM additional version of topographic gravity field models which accounts for the zonal harmonic coefficients implied by the reference ellipsoid such as the Geodetic Reference Surface 1980 (GRS80) should be employed ( Ince, et al., 2019).Some of the recent topographic gravity field model are dV_ELL_RET2014_5480**,** ROLI_EllApprox_SphN_3660, RWI_TOIS_2012, RWI_TOIS_2012_plusGRS80, RWI_ISOS_2012 and RWI_ISOS_2012_plusGRS80 (Hirt & Rexer , 2015).

The gravitational potential has been forward modelled by spectral integration of volumetric mass layers as represented by the Earth2014 topographic database. Potential models for each layer (crust, ocean, ice, lakes) and for their combined effect are available explicitly as a series of spherical harmonic coefficients of the spherical topographic potential (STP) and the ellipsoidal topographic potential (ETP), relying on spherical and ellipsoidal approximation, respectively. For details on the computational procedure and for more information on the differences between STP and ETP refer (Hirt & Rexer , 2015)

### A. dV_ELL_RET2014_5480.

DV_ELL_RET2014 is a spherical harmonic model of the gravitational potential implied by Earth's Rock-Equivalent Topography with respect to the GRS80 reference ellipsoid expanded up to d/o 5480. The water masses of the oceans and major lakes, as well as the ice sheets are compressed to layers equivalent to topographic rock of mass-density 2670 kg m−3. Earth's topography is modelled without isostatic compensation. The dV_ELL_RET2014 model is based on latest topographic and ice-sheet data over Greenland and Antartica (Hirt & Rexer , 2015). dV_ELL_RET2014_5480 takes into account:

(a) Earth's land topography (based on SRTM and SRTM30plus) with a mass-density of 2670 kg m−3,

(b) The ocean water bodies (based on SRTM30plus bathymetry) with a mass-density of 1030 kg m−3,

(c) The ice shields of Antarctica and Greenland (based on Bedmap2 and GBT v3) with a mass-density of 917kg m−3, and

(d) The water bodies of Earth's major lakes (Superior, Michigan, Huron, Erie, Ontario and Baikal) and the Caspian Sea (based on SRTM30plus inland bathymetry) with a mass-density of 1000kg $m^{-3}$.

**B. RWI_TOIS_2012_plusGRS80**

Rock-Water-Ice Topographic-Isostatic gravity field model is a topographic gravity field model representing the Earth's isostatic gravitational potential based on a 29 three-layer decomposition of the topography with variable density values and a modified Airy-Heiskanen concept incorporating seismic Moho depths up to d/o 1800 (Grombein, Seitz, & Heck, 2016)). RWI_TOIS_2012_plusGRS80 takes into account

(a) Three-layer decomposition of the topography using information of the 5′ x 5′ global topographic database DTM2006.0,

(b) Rigorous separate modeling of rock, water, and ice masses with layer-specific density values (2670, 1000, 920 kg $m^{-3}$) respectively,

(c) Avoidance of geometry changes compared to classical condensation methods (e.g., rock-equivalent heights).

(d) Ellipsoidal arrangement of the topography using the GRS80 ellipsoid as reference surface.

(e) Adapted and modified Airy-Heiskanen isostatic concept.

(f) Incorporation of seismic Moho depths derived from CRUST2.0

(g) Location-dependent estimation of the crust-mantle density contrast.

**C. RWI_ISO_2012_plusGRS80**

Rock-Water-Ice isostasy gravity field model is a topographic gravity field model representing the Earth's topographic gravitational potential based on a three-layer decomposition of the topography with variable density values up to d/o 2190 (Grombein, Seitz, & Heck, 2016). RWI_ISO_2012_plusGRS80 takes into account

(a) Three-layer decomposition of the topography using information of the new 1′ x 1′ Earth2014 topography model,

(b) Rigorous separate modeling of rock, water, and ice masses with layer-specific density values (2670, 1000, 920 kg m−3) respectively,

(c) Ellipsoidal arrangement of the topography using the GRS80 ellipsoid and geoid undulations as height reference surface.

**D. ROLI_EllApprox_SphN_3660**

Rock-Ocean-Lake-Ice topographic gravity field model expanded up to d/o 3660 is a representation of the Earth's topographic potential that is implied by masses of four layers, namely, rock, ocean, lake, and ice sheets computed using ellipsoidal approximation approach in spectral domain. The four layer-specific density values of the topography as given by the new 1′ x 1′ Earth2014 topography model (2670, 1030, 1000, 917 kg m−3) (Hirt & Rexer , 2015).

### 2.2 Short wave components of gravity

The short-wave component of gravity is one of the spectral components of the earth's gravity field. Sometimes short-wave component of gravity referred as Residual terrain effects (RTE), is the high-frequency gravity effects reflecting the gravitational attraction of Earth's global topography residual using a reference surface of d/o 2160 SH, i.e. at scales less than 10 km (Hirt, et al., 2019) .The topography of the earth is the rich source of the high frequencies of the earth's gravity field on land and as a result a high resolution DEM/DTM can be used to compute these high frequencies through different topographic mass models and methods e.g. Simple and Complete Bouguer plates (planar 11 or spherical), Isostatic reduction schemes, Residual Terrain Effect (RTE) etc. The high frequency of the earth's gravity field is due to erratic uppermost layer of the earth. Moving away from the earth's surface, the high frequencies of the earth's gravity field grow weaker and for this reason the details of the figure of the earth also are not sensed. Total terrain effects at a point are due to all the topographic masses above the geoid while residual terrain effects are due to topographic masses relative to a level surface through the point or relative to some other approximation to the terrain. (Heiskanen & Moritz, 1967)

### 2.3 Residual Terrain Effects (RTE).

Residual terrain effects (RTE) refer to the gravity signal caused by the Earth's topography that is not accounted for in a global gravimetry model. This signal can be significant, particularly in regions with complex terrain, and can affect various applications such as satellite altimetry, oceanography, and geodesy. RTE arise because the Earth's topography influences the gravity field by changing the distance between the Earth's mass and a point on its surface. This can result in deviations from the expected gravity field, which are not accounted for in a global gravimetry model. RTE can be calculated using topographic potential models, which represent the gravitational potential energy of a landscape. RTE can be significant in regions with large topographic variations, such as mountainous regions or oceanic trenches. In these regions, RTE can cause errors in measurements of the Earth's gravity field, which can affect the accuracy of various applications (Yahaya & El azzab, 2018). To mitigate the effect of RTE, various methods have been proposed, such as the use of local gravimetry models, the removal of the topographic signal from satellite measurements, or the use of specific corrections in geoid modeling. The study of RTE is an active area of research in geodesy and geophysics, with the aim of improving the accuracy of various applications that rely on measurements of the Earth's gravity field (Yahaya & El azzab, 2018).

### 2.4 Applications of the short-wave components of gravity.

i. Used in the context of Remove Compute Restore geoid computations to smooth gravity anomalies prior to interpolation.
ii. Spectral enhancement of the geopotential models.
iii. Construction of ultra-high-resolution map of gravity field functionals including geoid height, gravity disturbance, height anomaly, gravity anomalies.

### 2.5 Factor affecting Residual Terrain Effects (RTE)

i. Density: In the research conducted by Yang, et al., (2018), found that the use of mass-density model in computations of RTE performed better compared to the constant density on flat terrains while on rough terrains constant density performed better due to greater variations of topographic density. Therefore, effect of density model on RTM should be carefully taken into consideration.
ii. Elevations: In the place or area with small value of elevations especially in the area with valleys expected to have large values of residual terrain effect (RTE) due to effect of topographical masses, which is very small while in the mountainous area tends to have large effects and hence result to effect on short wave components of gravity.

iii. Topography and mean surface: Since the high frequency gravity field component are mainly caused by the topography which can be used to complement high -resolution combined static gravity field models for the very high frequency components of gravity (RTE) as well as to fill information into regions lacking terrestrial gravity measurements. Topography enhances high frequency components of gravity for different terrains over the AOI and also creation of mean surface can cause variation of RTE simply because the more smoothed surface seemed to have large value of RTE compared to rough surface of the topography.

### 2.6 Residual Terrain Model (RTM)

Residual Terrain Model is a technique to compute the Earth's short scale gravitational potential from topographic mass models. In the RTM approach, a smooth mean elevation surface also called reference surface is chosen and the topographic masses above this surface removed and fill up the valleys below (Abulaitijiang, 2019). RTM provides information on the short wavelength spectral content of gravity due to topography. The information of mass distribution of the topography can be presented mainly in the Digital Elevation Model (DEM). With the help of these DEM, we are able to account for the topographic masses at finer resolutions of up to 1 arcsecond (Abulaitijiang, 2019). Residual Terrain Model method used in determining residual terrain effects are all affected by one or two specific approximation errors due to

i. Harmonic correction needed for points located inside the reference topography

The harmonic correction for RTM gravity calculations, applied for points located inside the reference topography and this method condenses the mass layer between the computation point and the reference surface into an infinitesimal thick mass layer immediately below the computation point and its employed during the computation of RTE in various computation sources such as TGF, TC from GRAVSOFT and SRTM2gravity and hence it is sufficient to choose the smoothness of the RTM surface such that the high frequency signal in the gravity that cannot be resolved for the given data distribution and accuracy are reduced as much as possible , to some extent in other area may allow the choice of rougher RTM surfaces.

ii. Mass simplification:

The size of the masses of the object is proportional to the gravity effect and weakens as the distance between them increases. So, mass simplification can affect the RTE computed in the sense the more the mass simplified to a small value the more the smaller the value of the RTM gravity obtained.

iii. Vertical computation point inconsistency:

Preparation of vertical computation point may affect the RTM during the computation of RTE since the poor preparation of computation points the poor the performance of the computation sources especially TGF.

iv. Neglect of terrain correction of the reference topography:

When computing RTE in terms of gravity anomaly under RTM method the terrain correction of reference topography is neglected, this is because RTE are due to topographic masses with respect to the mean elevation surface but not to the geoid. Hence this affects the RTM method during computation of RTE.

**2.7 Very-short wavelength gravity components (RTE) from SRTM2gravity data-set**

SRTM2gravity is a global gravity map with 3-arc second spatial resolution. It represents the gravity field implied by the Multi-Error-Removed Improved-Terrain (MERIT) DEM and a constant mass-density of 2670kg/m$^3$. The SRTM2gravity model represents the total gravitational signal of the Earth's topography in spherical approximation. The SRTM2gravity model has transformed the SRTM heights to implied gravity effects via evaluation of Newton's integral by combining spectral and spatial domain techniques for efficient and accurate computation of gravity effects (Hirt, et al., 2019).

The SRTM2gravity offers two data sets namely, FullScaleGravity and Residual Gravity. The FullScaleGravity is a gravimetric terrain correction reflecting the gravitational attraction of Earth's global topography measured with respect to the geoid. It represents the linear effect of the topography on gravity, the Bouguer shell of thickness H (from DEM) together with the gravity effect of all irregularities of the topography relative to the Bouguer shell. It accounts for the total topographic effects above the geoid. In the FullScaleGravity product, these long-wavelength signals are included.

Residual Gravity: High-frequency gravity effects reflecting the gravitational attraction of Earth's global topography residual to a degree-2160 spherical-harmonic reference surface. The SRTM2gravity data set can be freely downloaded (only residual gravity) from the website http://ddfe.curtin.edu.au/models/SRTM2gravity2018.

As aiming at conduct, analysis of 1′ x 1′ RTE from topographical models by SRTM2gravity the RTE from SRTM2gravity will be obtained from the residual gravity downloaded data set through modifying only the TestAccess_s2g.m script with the geographical coordinates of area of interest (AOI).Then open the TestAccess_s2g.m, run the script in MATLAB in which the result are three matrices, X containing the longitudes, Y the latitudes and Z containing the extracted residual gravity effects.

### 2.8 Spectral Enhancement Method (SEM) with Topographic Gravity Field Models

Gravity field quantities observed on the earth's surface contain the full spectrum of gravity signals while gravity field quantities observed from satellite are limited to the long wavelength signals only. To complement the spectral gap of the gravity field quantities 27 observed by satellites such as the gravity anomalies, the SEM is employed. SEM uses high resolution geopotential models such as combined GGM like Earth Gravitational Model 2008 (EGM08) or topographic gravity field models such as Rock-Equivalent Topography (RET) to account for the missing short wavelength and the omission error estimates sourced from Residual Terrain Model (RTM. If a GGM is evaluated to its maximum d/o 300, then the topographic model is used to recover the spectral bands from d/o 301 to its maximum d/o. Beyond the maximum d/o of the topographic model the RTM is used to complete the spectrum (El-Ashquer, Al-Ajami, Zaki, & Rabah, 2020).

### 2.9 SRTM2gravity

SRTM2gravity is a freely available global model of gravimetric terrain corrections at 3 arc second spatial resolution. It contains implicitly the effect of the Bouguer shell and all gravity terrain effects residual to the Bouguer shell. The gravimetric terrain corrections reflect the gravity effect of Earth's global topographic masses, as represented through the MERIT digital elevation model together with the constant mass density $\rho$ = 2670 kg/ $m3$. They include both the gravity effect of a spherical Bouguer shell and that of the terrain irregularities (e.g., valleys, summits) around the globe in a single, readily usable data set. SRTM2gravity values facilitate a simple procedure for the compilation of Bouguer gravity maps: The pre-computed data set can be interpolated and directly subtracted from measured gravity disturbances (differences between g-values and normal gravity) to remove the topographic signal from a gravity survey. This yield Bouguer gravity anomalies, without the need to further evaluate terrain correction integrals through tedious numerical integrations. SRTM2gravity has some tasks such as to reflect the total gravitational attraction of the topography and to capture high frequency topographic gravity signal only. The typical applications of residual gravity (RTE) as output of SRTM2gravity use in the context of Remove Compute Restore geoid computations to smooth gravity anomalies prior to interpolation and spectral enhancement of the geopotential models like EGM 20008 beyond the nominal ~10km model resolution (Hirt, et al., 2019)

The key input for SRTM2gravity is the 3arc second resolution global MERIT DEM data set since MERIT elevations represent good approximation on the bare ground and improve the representation of topographic masses (where the lower bound of the MERIT topographical model is the geoid /mean sea level) (Yamazaki et al.,2017) and also 90m SRTM2gravity resolution may be crucial to improve the spectral consistency with measured gravity (Balmino, Bonvalot , Briais, & Vales, 2012).

### 2.9.1 GrafLab

GRAvity Field LABoratory is a MATLAB-based graphical user interface program for computing functionals of the geopotential (geoid height, gravity anomaly, height anomaly, gravity disturbance and deflection of the vertical) up to ultra-high degrees and orders, which allows Evaluation of 38 functionals of the geopotential up to ultra-high degree and order and evaluation of commission error of 26 functionals using full variance-covariance matrix of spherical harmonic coefficients. GrafLab (GRAvity Field LABoratory) for Spherical Harmonic Synthesis (SHS) created in MATLAB (R).Most difficult part of the Spherical Harmonics Synthesis, namely the evaluation of the fully normalized associated Legendre functions (fnALFs), it uses three different approaches according to required maximum degree: (i) the standard forward column method (up to maximum degree 1800, in some cases up to degree 2190); (ii) the modified forward column method combined with Homer's scheme (up to maximum degree 2700); (iii) the extended-range arithmetic (up to an arbitrary maximum degree). For the maximum degree 2190, the SHS with fnALFs evaluated using the extended-range arithmetic approach takes only approximately 2-3 times longer than its standard arithmetic counterpart, i.e the standard forward column method as per this study of only short-wave component of gravity.

In the GrafLab, the functionals of the geopotential can be evaluated on a regular grid or point-wise, while the input coordinates either can be read from a data file or entered manually. For the computation on a regular grid, it is possible to apply the lumped coefficients approach due to significant time-efficiency of this method. Furthermore, if a full variance-covariance matrix of spherical harmonic coefficients is available, it is possible to compute the commission errors of the functionals. When computing on a regular grid, the output functionals or their commission errors may be depicted on a map using automatically selected cartographic projection ( Buchaa & Janak, 2013).

# CHAPTER THREE

# METHODOLOGY

This chapter describes the methods, practical applications of the mathematical models, all data and the software used in this study. It explains the methodology implied in the computation of Residual Terrain Effects (RTE) from Topographic Potential Models for gravity prediction on terrestrial gravity stations by Residual terrain model in Tanzania.

## 3.1 Computation of 1′ x 1′ Residual Terrain Effect (RTE).

The residual terrain modeling (RTM) is applied for the determination of RTE, which yield the short-wavelength gravity field constituents only over AOI with the knowledge of geometry and density-distribution for the topography of Tanzania. In this study, the computation of RTE was done using GrafLab software.

### 3.1.1 Computation of 1′ x 1′ RTE from GrafLab.

Graf lab software version 2.1.4 written in MATLAB programming language was used in Graphical User Interface (GUI) mode as shown in Figure 3.1 in computing short -wave components of gravity as follows;

First, the Geopotential and reference system selection tab, **dv_ELL_EARTH2014_5480** topographical model was inserted by using the browse button, nmin box was filled with the 301 which is the lowest degree and nmax was filled with 5480 which is the maximum degree for computing the spherical harmonic model. Failure in computing to the maximum degree will result to severe error patterns, especially at high latitudes. This is because, the last 30 coefficients account for the ellipsoidal shape of the earth (Claessens & Hirt, 2013) .

Second, in the Point type selection tab, a computation file was inserted by clicking the Browse button and load data button was selected. The computation file should be in text file format with longitude, latitude and height above the reference ellipsoid. The computation point was extracted from merit-DEM with 1′ x 1′ coverage, as we know the aim was to extract 1′ x 1′ RTE from Graflab.

The calculated parameters and output selection tab, gravity anomaly parameter was selected to be printed in the results report. The output folder and file selection were used to specify the output folder and file name.

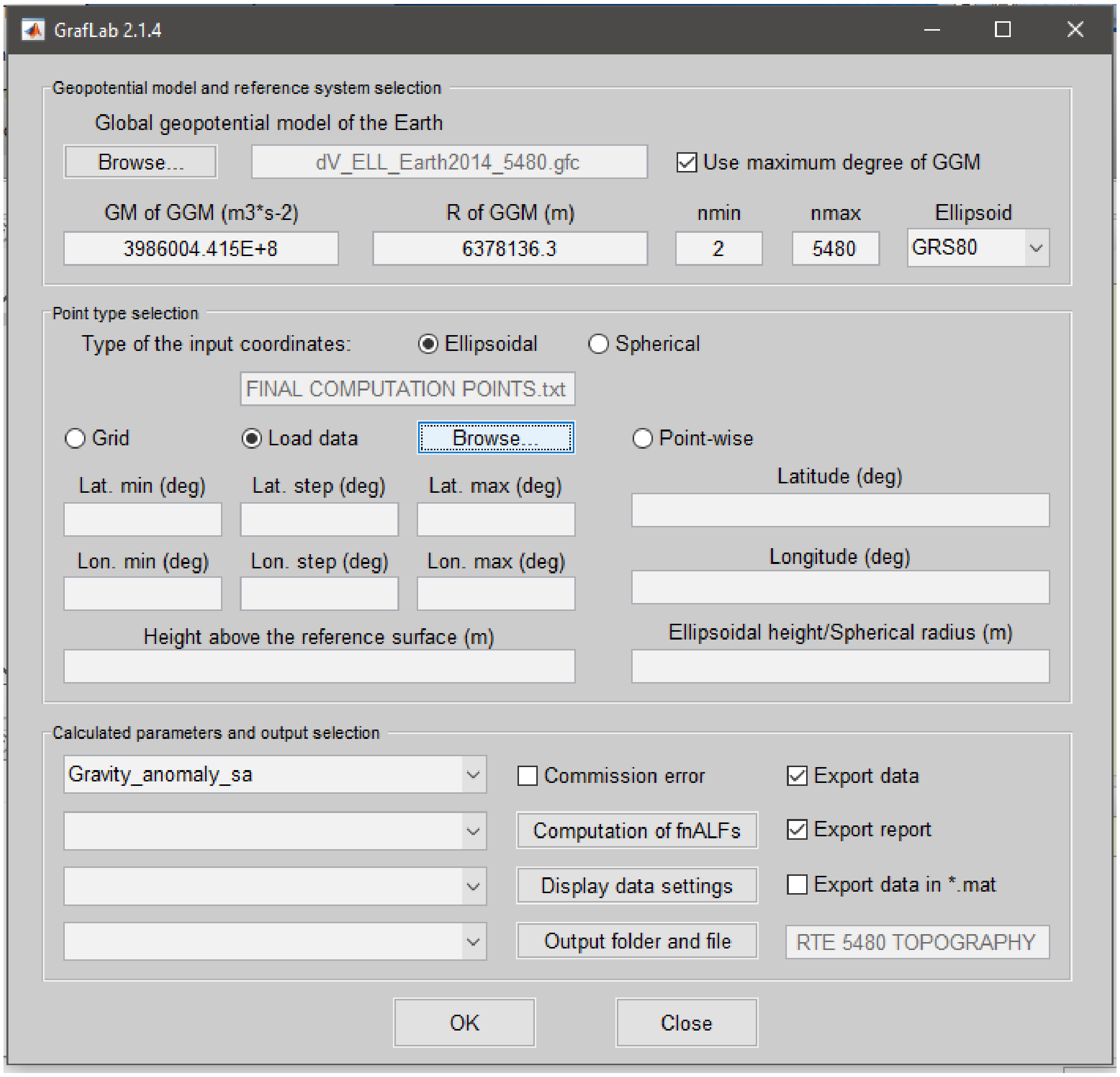


Figure 3. 1: A GUI of Graf lab software that was used in computation of RTE

### 3.1.2 Accessing and Downloading 1′ x 1′ RTE from SRTM2gravity data-set.

The Residual Gravity data set of SRTM2gravity for the study area is downloaded from the website: http://ddfe.curtin.edu.au/models/SRTM2gravity2018. It can be tricky to access the SRTM2gravity data set. The code has been prepared to ease the download of the SRTM2gravity data set specifically for the study area (N00E000, N00E030, S30E000 and S30E030) of this research. It is required to download and install the latest version of GNU Wget: GNU Wget is defined as a free software package for retrieving files using HTTP, HTTPS, FTP and FTPS, the most widely used internet protocols. It's a non -interactive command line tool, so it may easily be called from scripts, cron jobs, terminals without X-windows support.

Once GNU Wget is already installed, navigate to the folder where the downloaded data is to be stored, copy the code below in the appendices and save it as data_access.bat and run the data_access.bat file by double clicking.

Each downloaded tile has a $1^{\circ} \times 1^{\circ}$ coverage with a spatial resolution of $3'' \times 3''$. Once the data is downloaded and merged, the MATLAB inbuilt function inter2p is used to extract its values at $1' \times 1'$ resolution on the study area. (Hirt, et al., 2019)

### 3.2 Required Data

In this study, short wave components of gravity (RTE) were computed from different topographic potential model by GRAFLAB. A brief description is presented below. The international center of global earth's model (ICGEM) is where the data of the models can be found.

#### 3.2.1 Topographic potential model

Six topographic gravity field model were used in this research. The model that preferably account for isostasy are RWI_ISOS_2012 and RWI_ISOS_2012_plusGRS80 which has degree and order of 1800, The models that do not account for isostasy are dV_ELL_Earth2014_5480, ROLI_EllApprox_SphN_3660, RWI_TOIS_2012_plusGRS80 and RWI_TOIS_2012. Table 3.1 show the selected topographic potential model downloaded from ICGEM website, also the year were the model was released and the maximum degree of the model.

Table 3. 1: Selected topographic gravity field model from ICGEM website

| Topographic Potential Model | Year | MaxDegree | Data |
|---|---:|---:|---|
| RWI_ISOS_2012 | 2014 | 1800 | Isostasy |
| RWI_TOIS_2012 | 2014 | 1800 | Topo-Isostasy |
| RWI_TOIS_2012_plusGRS80 | 2014 | 1800 | Topo-Isostasy |
| RWI_ISOS_2012_plusGRS80 | 2014 | 1800 | Isostasy |
| ROLI_EllApprox_SphN_3660 | 2019 | 3660 | Topography |
| dV_ELL_Earth2014_5480 | 2017 | 5480 | Topography |

### 3.2.2 Digital Elevation Model (DEM)

Digital Elevation Models were used in this research to provide height information of the topography. The MERIT DEM with a resolution of 3-arc second were used in this research. Due to fact that the SRTM2gravity have the pre-computed RTE over the global that computed using MERIT DEM. MERIT DEM file has a name that refers to interval of latitudes and longitudes of the specific area in which it covers where by only four tiles with a resolution of 5°x5° were enough to cover my AOI. The horizontal and vertical datum of MERIT-3″ are WGS84 and EGM96 respectively. The MERIT DEM with a 3″ was used to provide computation points of 1′ x 1′ resolution which was used to enhance the computation of 1′ x 1′ RTE from topographic potential model by GrafLab software. The computation points comprises of latitudes, longitude and height above reference ellipsoid over the AOI.

## 3.3 Software

In this research several software related to earth sciences were used. These are; GrafLab, Global Mapper, Golden Surfer and Generic Mapping Tools (GMT). Table 3.2 shows the purpose of each software in this research.

Table 3. 2: Software used in this research for data processing.

| S/N | Software | Version | Purpose in this research |
|---|---|---|---|
| 1 | GrafLab | 2.1.4 | Computing RTE from topographic gravity field models up to high d/o. |
| 2 | Golden surfer software | 15.4.354 | Gridding, contouring and statistics computation. |
| 3 | MatLab | 1.0.0.1 | Computations and extraction of RTE. |
| 4 | Generic Mapping Tool (GMT). | | Displaying image and contour maps from respective grid files. |

# CHAPTER FOUR

# RESULT, ANALYSIS AND DISCUSSION

## 4.1. Results

This chapter describes the results obtained and the discussion of results. The computations and results under consideration are those related to the methodology and data described in Chapter 3.

### 4.1.1 1′ x 1′ Residual Terrain Effects (RTE) from SRTM2gravity

The Residual Terrain Effects (RTE) from SRTM2gravity were accessed from MATLAB within the study area at a resolution of 1′ × 1′. The RTE from SRTM2gravity was used to validated the RTE obtained from topographic potential model to see how reliable are the RTE from the topographical potential model. Table 4.1 show some of the RTE computed from the SRTM2gravity data-set and Table 4.2 show the statistics of the computed RTE from SRTM2gravity as presented in below

Table 4. 1: Sample of the computed 1′ × 1′ RTE over the AOI from the SRTM2gravity in mGal.

| Longitude (d.ddd) | Latitude (d.ddd) | RTE (mGal) |
|---:|---:|---:|
| 38.92 | -10.28 | -0.11 |
| 38.93 | -10.28 | -0.32 |
| 38.95 | -10.28 | -0.44 |
| 38.97 | -10.28 | -0.43 |
| 38.98 | -10.28 | -0.28 |
| 39.00 | -10.28 | -0.06 |
| 39.02 | -10.28 | 0.19 |
| 39.03 | -10.28 | 0.31 |
| 39.05 | -10.28 | 0.34 |
| 39.07 | -10.28 | 0.26 |
| 39.08 | -10.28 | 0.06 |
| 39.10 | -10.28 | -0.14 |
| 39.12 | -10.28 | -0.27 |
| 39.13 | -10.28 | -0.34 |

Table 4. 2: Statistics of the computed Residual Terrain Effects (RTE) from SRTM2gravity (mGal).

| Number of values | Min | Max | Mean | STD (mGal) | RMS (mGal) |
|---|---|---|---|---|---|
| 519831 | -107.10 | 93.23 | -0.34 | 5.95 | 5.98 |

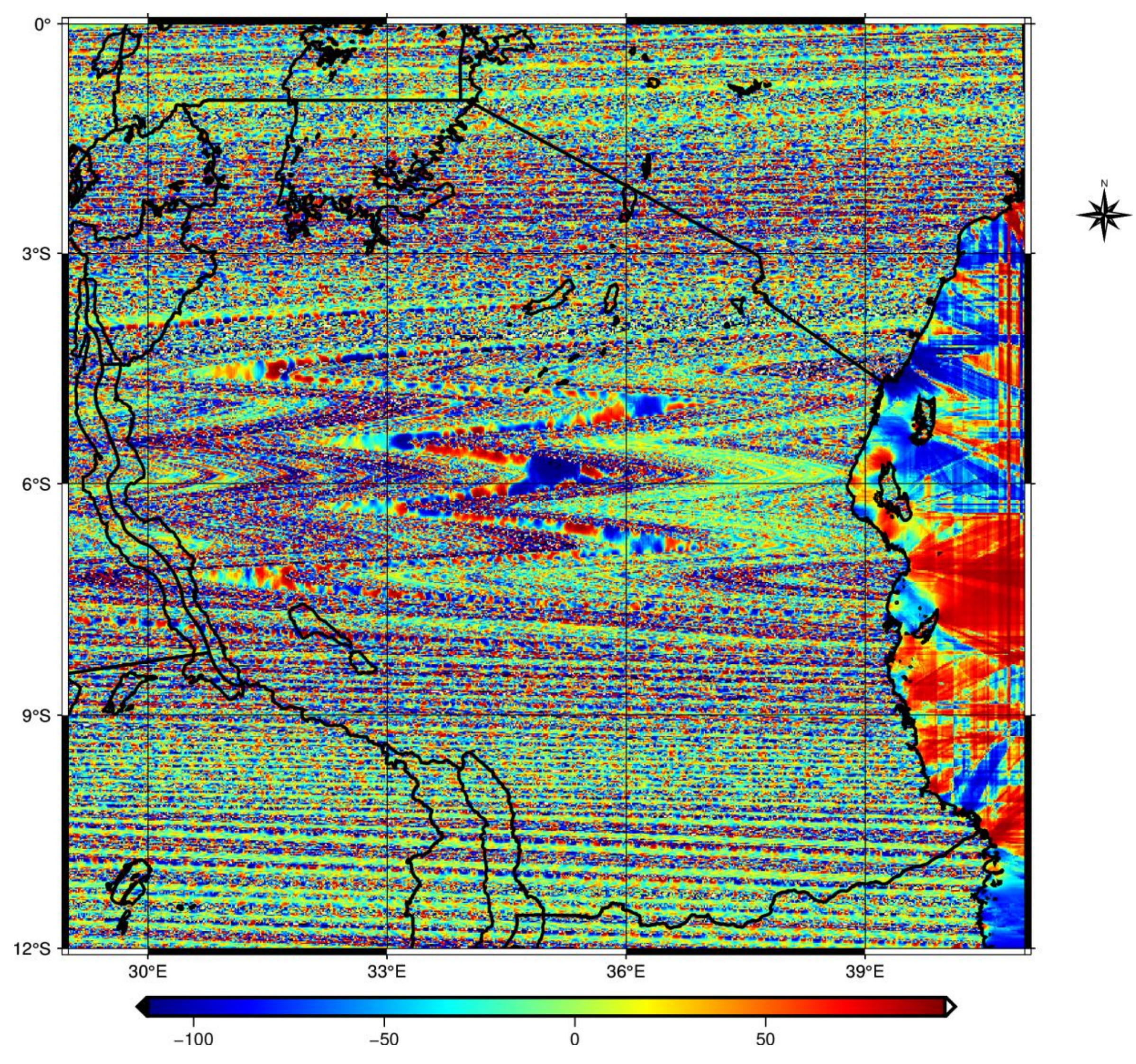


Figure 4. 1: Surface map of the RTE from SRTM2gravity in mGal.

### 4.1.2 1′ x 1′ RTE from Topographic Potential Models computed from GrafLab

The Residual Terrain Effects (RTE) from the selected topographical potential model as shown in Table 3.1 were computed within the study area at a resolution of 1′ x 1′ from GRAFLAB software. Table 4.3 shows statistics of the computed RTE from topographic potential model in mGal.

Table 4. 3: Statistics of the computed RTE from Topographic potential models in mGal.

| S/N | Model | Min | Max | Mean | STD | RMS |
|---|---|---|---|---|---|---|
| 1 | RWI_TOIS_2012 | -67.957 | 99.521 | -0.0013 | 7.973 | 7.973 |
| 2 | RWI_TOIS_2012_plusGRS80 | -67.957 | 99.522 | -0.0013 | 7.973 | 7.973 |
| 3 | RWI_ISOS_2012 | -82.228 | 95.815 | -0.0015 | 7.774 | 7.764 |
| 4 | RWI_ISOS_2012_plusGRS80 | -82.228 | 95.815 | -0.0015 | 7.774 | 7.764 |
| 5 | ROLI_EllApprox_SphN_3660 | -85.092 | 88.934 | 0.0012 | 7.099 | 7.099 |
| 6 | dV_ELL_Earth2014_5480 | -201.516 | 174.498 | 0.0014 | 5.112 | 5.112 |

Figure 4.2 below show the surface grid map of the 1′ x 1′ RTE from the topographic potential model RWI_ISOS_2012 computed from GrafLab software.

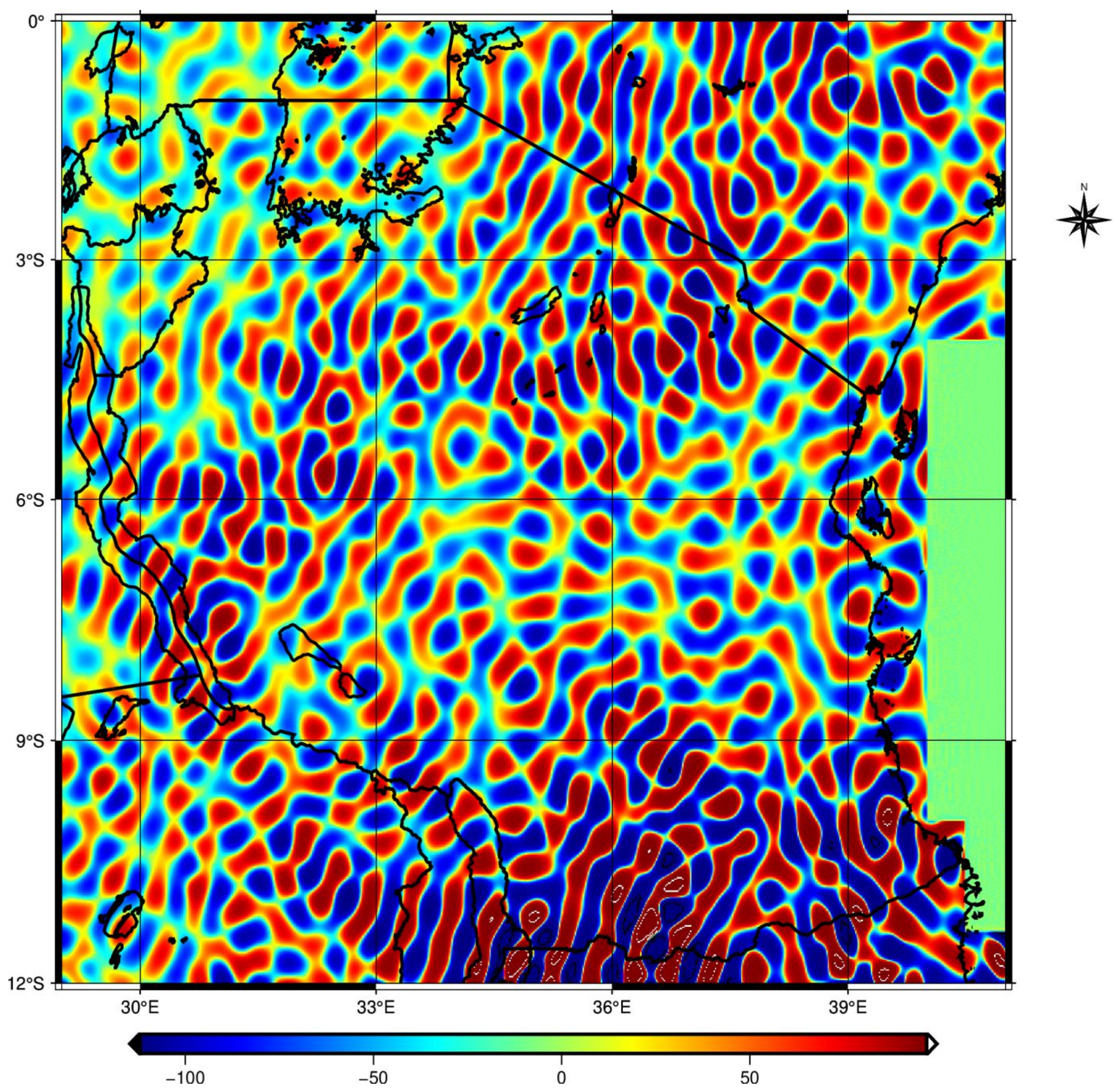


Figure 4. 2: Surface map of the RTE from RWI_ISOS_2012 in mGal.

Figure 4.3 below show the surface grid map of the 1′ x 1′ RTE from the topographic potential model RWI_ISOS_2012_plusGRS80 computed from GrafLab software.

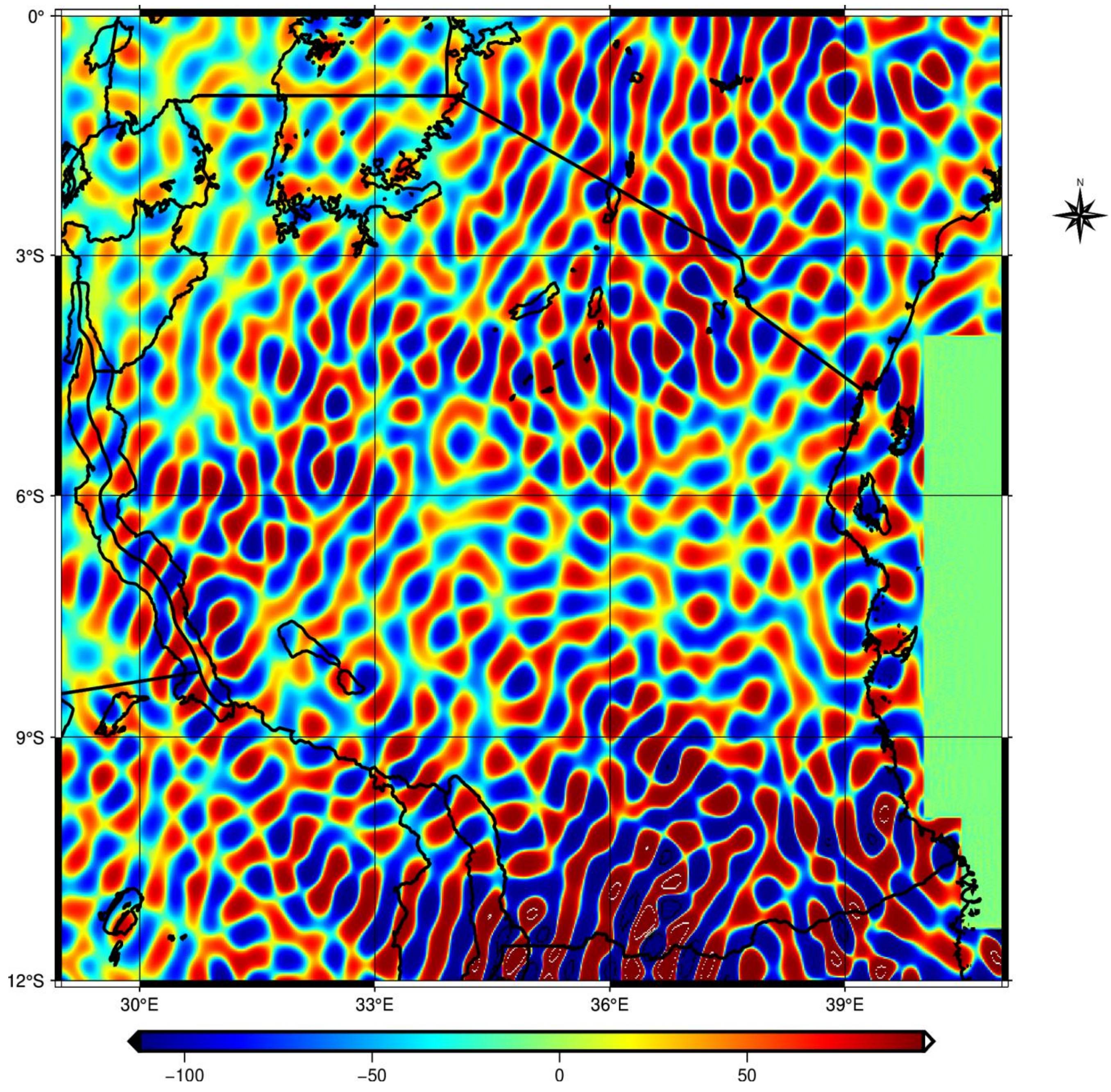


Figure 4. 3: Surface map of the RTE from RWI_ISOS_2012_plusGRS80 in mGal

Figure 4.4 below show the surface grid map of the 1′ x 1′ RTE from the topographic potential model RWI_TOIS_2012 computed from GrafLab software.

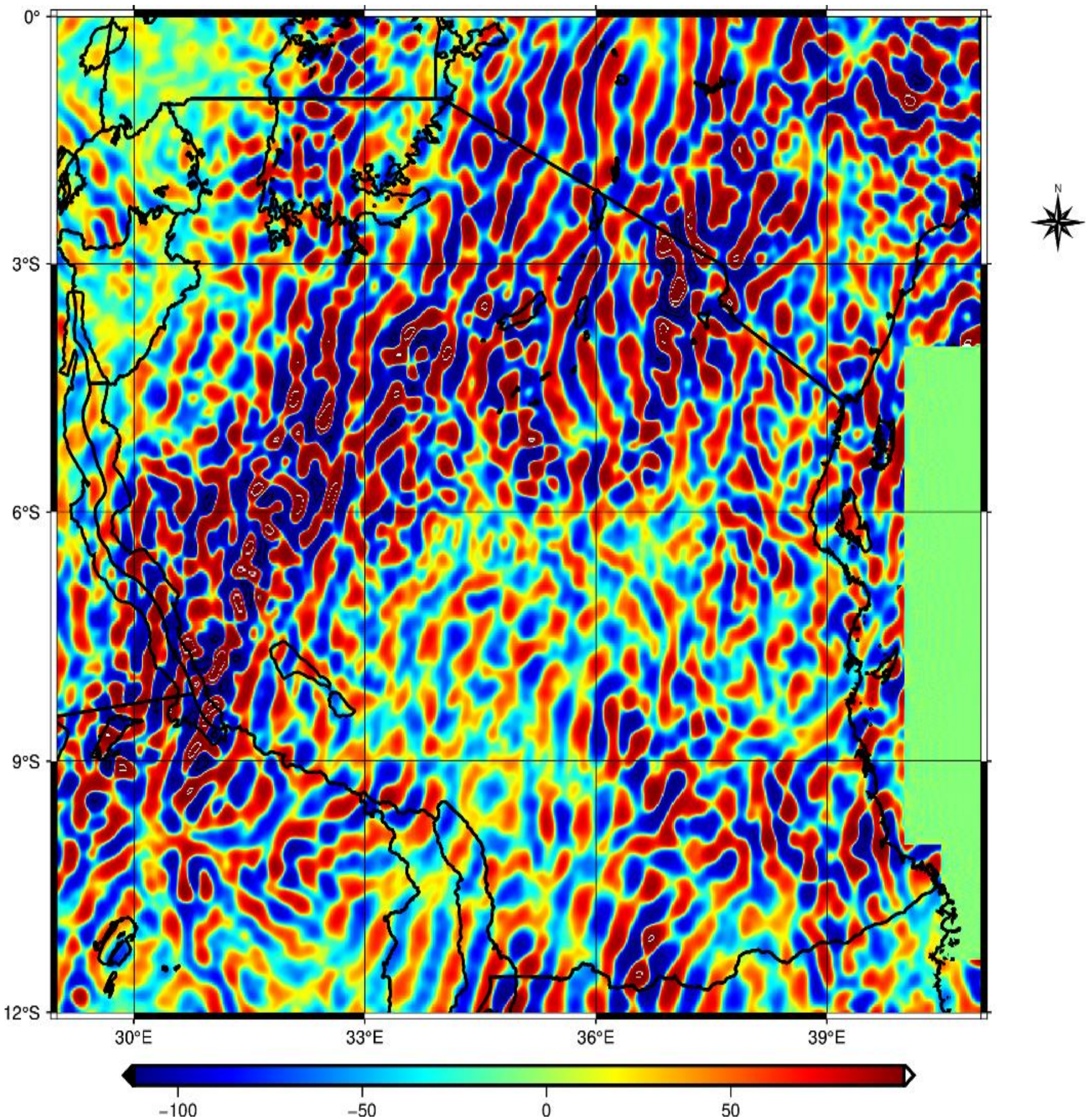


Figure 4. 4: Surface map of the RTE from RWI_TOIS_2012 in mGal

Figure 4.5 below show the surface grid map of the 1′ x 1′ RTE from the topographic potential model RWI_TOIS_2012_plusGRS80 computed from GrafLab software.

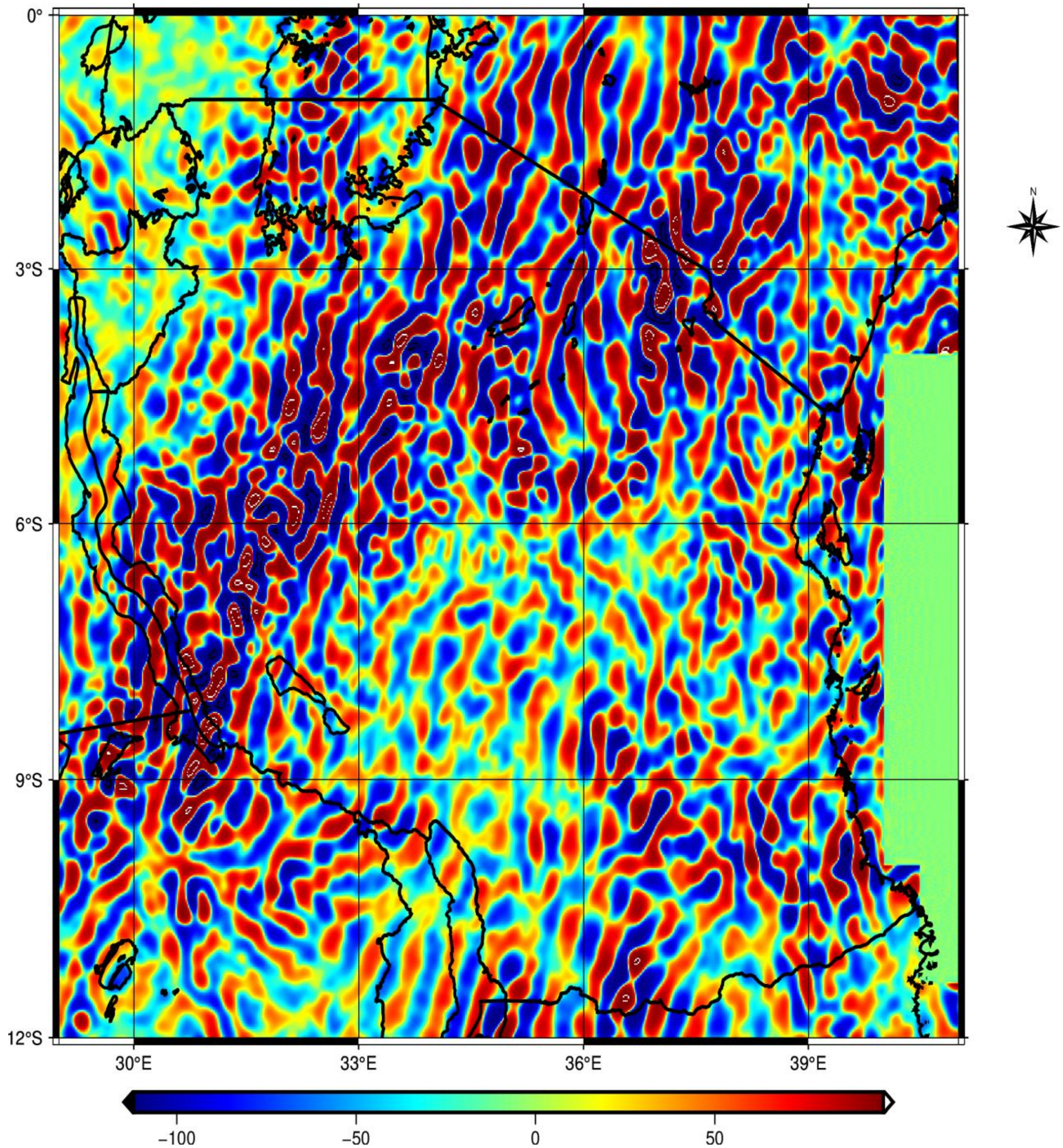


Figure 4. 5: Surface map of the RTE from RWI_TOIS_2012_plusGRS80 in mGal

Figure 4.6 below show the surface grid map of the 1′ x 1′ RTE from the topographic potential model ROLI_EllApprox_SphN_3660 computed from GrafLab software.

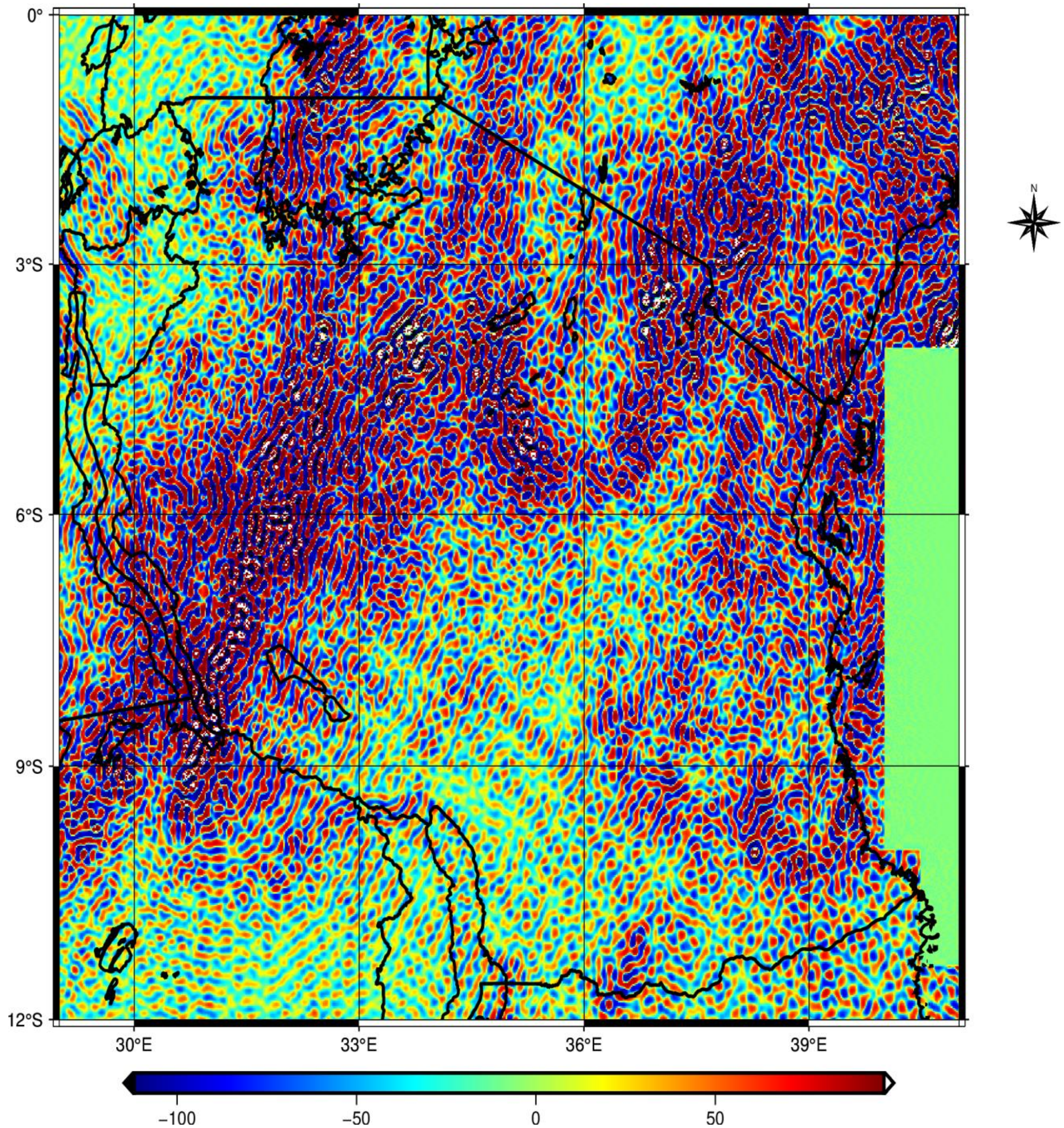


Figure 4. 6: Surface map of the RTE from ROLI_EllApprox_SphN_3660 in mGal

Figure 4.6 below show the surface grid map of the 1′ x 1′ RTE from the topographic potential model dV_ELL_Earth2014_5480 computed from GrafLab software.

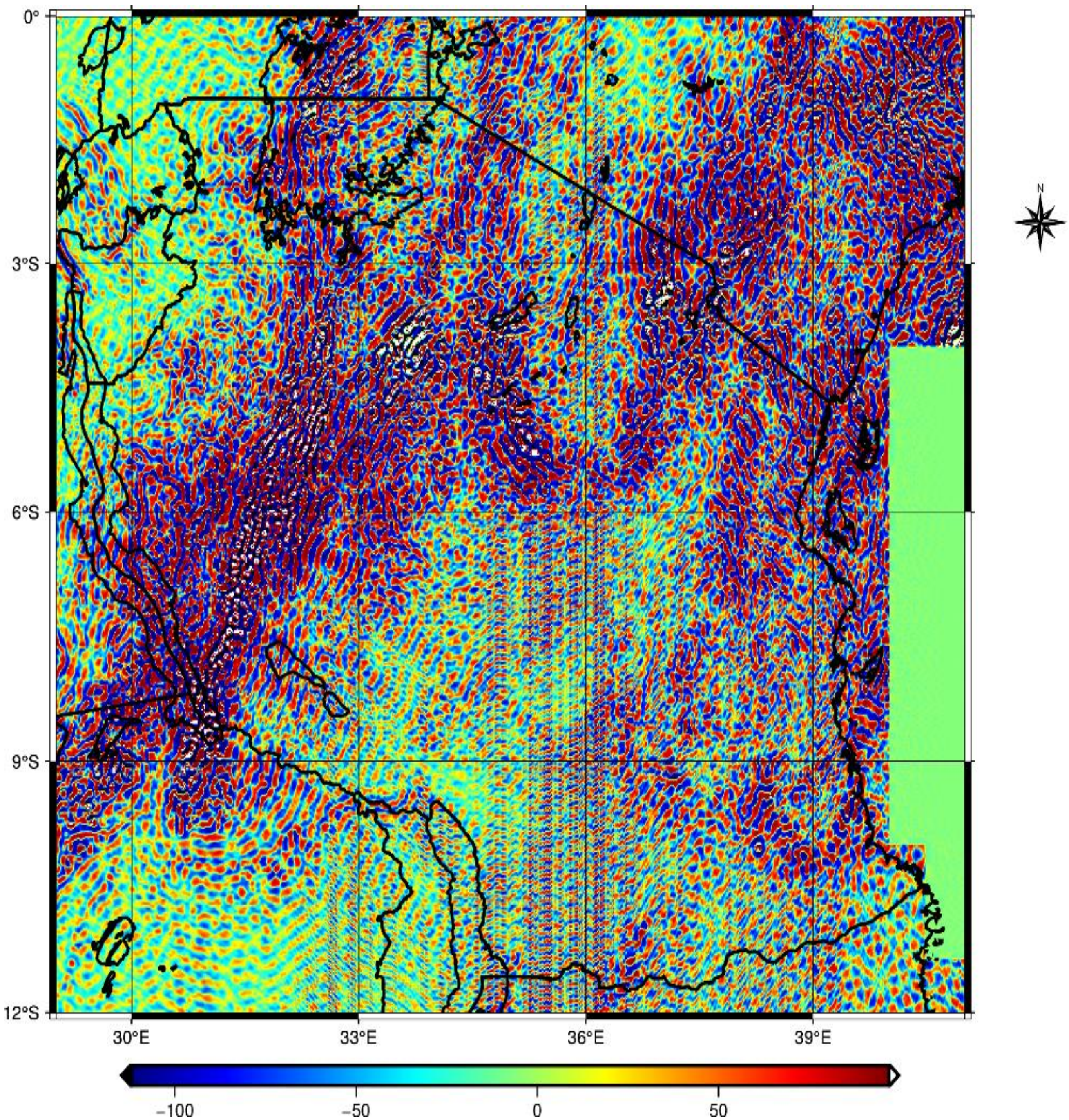


Figure 4. 7: Surface map of the RTE from dV_ELL_Earth2014_5480 in mGal

### 4.2 Analysis of computed RTE differences between SRTM2gravity and Topographic potential model in mGal

The results including statistics of the computed RTE in the selected topographic potential model and the RTE accessed from SRTM2gravity, the analysis of their differences is as shown in the Table 4.4. The RTE from SRTM2gravity were used to validate the RTE from the topographic potential model

Table 4. 4: Statistical information of the differences between computed RTE from SRTM2gravity and Topographic potential model at 95% confidence level after removing outliers in mGal.

| S/N | Difference in RTE | Min | Max | Mean | STD | RMS |
|---|---|---|---|---|---|---|
| 1 | SRTM2gravity-ISO$^{1800}$ | -15.724 | 15.037 | -0.283 | 8.134 | 8.144 |
| 2 | SRTM2gravity-ISO1800GRS80 | -15.724 | 15.037 | -0.283 | 8.134 | 8.144 |
| 3 | SRTM2gravity- TOISO$^{1800}$ | -25.918 | 25.237 | -0.207 | 7.818 | 7.821 |
| 4 | SRTM2gravity-TOISO1800GRS80 | -25.918 | 25.237 | -0.207 | 7.818 | 7.821 |
| 5 | SRTM2gravity-TOPO$^{5480}$ | -24.194 | 23.505 | -0.297 | 5.793 | 5.821 |
| 6 | SRTM2gravity-TOPO$^{3660}$ | -20.539 | 19.540 | -0.261 | 6.423 | 5.973 |

### 4.3 Discussion of Results

Referring to Table 4.2, the RTE from SRTM2gravity seems to have the small value of STD and RMS of 5.95mGal and 5.98mGal respectively which seems to perform better in Tanzania mainland. The SRTM2gravity was used to validate the results from the topographic potential model due to its small value of STD and RMS.

Referring to Table 4.3, the results were validated at 95% confidence level and the outliers were removed. At 95% confidence level, RTE from topographic potential model with degree and order 5480 (dV_ELL_Earth2014_5480) seems to be significance since it has small RMS of 5.112mGal and STD of 5.112mGal compare to other topographic potential model. The topography-isostasy kind of topographic potential model seems to have large value of RMS and STD of 7.973mGal and 7.983mGal respectively.

Referring to Table 4.4, the results were validated at 95% confidence level after the outliers have been removed. At 95% confidence level the statistical difference between SRTM2gravity and dV_ELL_Earth2014_5480 seems to be significance because of the small RMS and STD of 5.821 mGal and 5.793 mGal respectively. Also, by the statistical difference of SRTM2gravity and ROLI_EllApprox_SphN_3660 seems to be the second with small value of STD and RMS of 6.423 mGal and 5.973 mGal respectively.

Therefore, as stated above the RTE from topography kind of topographical model seems to provide better results as the facts that their spatial resolution is bigger i.e. dV_ELL_Earth2014_5480 ≈ 3.6 km and ROLI_EllApprox_SphN_3660 ≈ 5.5 km compared to other topographical potential model with lower degree of 1800, in which their spatial resolutions is approximately to 11.1 km. Also the difference between RTE from topographical potential model dV_ELL_Earth2014_5480 and SRTM2gravity seems to be significance due to the small value of STD and RMS.

# CHAPTER FIVE

# CONCLUSION AND RECOMMENDATION

## 5.1 Conclusion

The main purpose of this research was to perform analysis of 1′ x 1′ RTE from topographical potential model and DEMs by SRTM2gravity. It has been analyzed that the difference of RTE between SRTM2gravity and topographical model dV_ELL_Earth2014_5480 seems to be significant with the small value of RMS and STD of 5.821mGal and 5.793mGal respectively. It was followed by the difference of RTE between SRTM2gravity and topographical potential model ROLI_EllApprox_SphN_3660 with RMS and STD of 5.973mGal and 6.422mGal respectively.

From the discussion of the results of this research the following conclusion has been made;

i. During the analysis of the three kind of topographical model i.e isostasy, isostasy-topography and topography the topography kind seems to provide better RTE with small value of STD and RMS of 5.112mGal and 5.112mGal respectively, compared to the isostasy and isostasy-topography kind of topographic potential model due to its bigger spatial resolution.
ii. In comparison of RTE difference between SRTM2gravity and the topographical potential model, the pair of SRTM2gravity and dV_ELL_Earth2014_5480 their differences seem to be significant with small value of STD and RMS of 5.793mGal and 5.821mGal respectively.

## 5.2 Recommendation

Since newer topographic potential model are continually being released, and the topographical model with higher degree and order of 5480 provides good RTE because of its spatial resolution is bigger, therefore it is recommended that further research should be carried out so as to see if they can give us good RTE than this.

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# APPENDICES

# Appendix 1

## GMT codes

The GMT codes used to generate the figures in this research are printed below. For interested readers please see P. Wessel et al., (2019) for more information on how to use GMT.

```
gmt begin SRTM21_rte png
 set FONT Times-BoldItalic
REM Set variables for all grids
 set cpt1=rte1.cpt
 set cpt2=rte2.cpt
 set grd1=SRTM2.grd
 set grd2=rte1.nc

REM Make CPT for visualizing the RTE grid
gmt makecpt -Cjet -T0/255/1 -H -Z > %cpt1%
gmt makecpt -Cjet -T-112/97 -H -Z > %cpt2%

REM Histogram Equalize the input grid
gmt grdhisteq %grd1% -G%grd2% -C256

REM Convert the Histogram Equalized grid above to image
gmt grdimage %grd2% -C%cpt1% -JM6i -R29/41/-12/0 -Ba3g3

REM Map border & Frame
gmt basemap -JM6i -Ba3g3 -R29/41/-12/0

REM Map Coastlines
gmt coast -Dh -N1/1.35p -W1.25p -R29/41/-12/0 -Tdg42.0/-2.5+w0.8c+f2+l,,,N

REM Add Color Legend
gmt colorbar -DJBC + w5i/0 .13 i + h + e -C%cpt2% -Ba

REM Delete un-neccesary files
 Del *.nc *.cpt
gmt end
```

**Appendix 2**

## SRTM2gravity Data-Set Access Code.

The following code has been prepared to ease the download of the SRTM2gravity data-set specifically for the study area of this research.

It is required to download and install the latest version of GNU Wget: A free utility for non-interactive download of files from the Web. It supports http, https, ftp protocols and retrieval through http proxies. Once GNU Wget is already installed, navigate to the folder where the downloaded data is to be stored, copy the code below and save it as data_access.bat and run the data_access.bat file by double clicking.

```
REM =======================================================
REM
REM
REM
REM Batch script to download SRTM2gravity2018 for the AOI
REM
REM
REM
REM
REM 1. ResidualGravity
REM =======================================================
REM Download directory N00E000
 wget -r -np -nH --cut-dirs =3 -R index . html http://ddfe . curtin . edu
.au/models/SRTM2gravity2018/data/ResidualGravity/N00E000/

REM Download directory N00E030
 wget -r -np -nH --cut-dirs =3 -R index . html http://ddfe . curtin . edu
.au/models/SRTM2gravity2018/data/ResidualGravity/N00E030/

REM Download directory S30E000
 wget -r -np -nH --cut-dirs =3 -R index . html http://ddfe . curtin . edu
. au/models/SRTM2gravity2018/data/ResidualGravity/S30E000/

REM Download directory S30E030
 wget -r -np -nH --cut-dirs =3 -R index . html http://ddfe . curtin . edu
.au/models/SRTM2gravity2018/data/ResidualGravity/S30E030/

REM NB:
REM Append '-c ' after 'wget ' to contiue a download that was stopped
before completion
```