American Journal of Agricultural Science, Engineering, and Technology (AJASET)

ISSN: 2158-8104 (ONLINE), 2164-0920 (PRINT)

VOLUME 8 ISSUE 2 (2024)

PUBLISHED BY: E-PALLI PUBLISHERS, DELAWARE, USA

American Journal of Agricultural Science, Engineering, and Technology (AJASET)
Volume 8 Issue 2, Year 2024
ISSN: 2158-8104 (Online), 2164-0920 (Print)
DOI: https://doi.org/10.54536/ajaset.v8i2.2916
https://journals.e-palli.com/home/index.php/ajaset

Development of Earth Gravity Models in A Sustainable Environment: An Overview of Nigeria's Ecosystem

Oluwatayo Enahoro Agbede[1], Joshua Oziegbe Ugbokhon[2], Godspower Oke Omokaro[1*]

Article Information

Received: April 22, 2024
Accepted: May 25, 2024
Published: May 29, 2024

Keywords
Earth Gravity Model, Sustainability, Ecosystems, Management, Environment

ABSTRACT

The evolution of Earth gravity models in Nigeria's ecological context is essential for advancing sustainable environmental stewardship. These models serve as crucial tools to understand the geological intricacies and environmental dynamics across Nigeria's diverse ecosystems. This article obtained data from previous existing data to emphasizes the significance of sustainable development, technological innovation, and the integration of sustainability principles into Earth gravity modeling efforts. The gravitational variations observed across Nigeria's ecosystems highlight the diverse geological features influencing gravitational anomalies. For instance, forests with dense vegetation exhibit gravitational variations ranging from -5.2 to -2.8 mGal, while coastal areas experiencing erosion and sea level rise show variations from -1.8 to 1.0 mGal. The article explores both advancements and challenges in developing Earth gravity models within Nigeria's unique environmental landscape, emphasizing the intersection of technology and sustainability. By leveraging advanced technologies and interdisciplinary methodologies, Earth gravity models contribute significantly to understanding the gravitational forces shaping the planet's surface and subsurface. Understanding the methodology behind Earth gravity models in a sustainable environment is crucial for effective environmental management and resource conservation, providing valuable tools for preserving Nigeria's diverse ecosystems for future generations. Through this integrated approach, Earth gravity models pave the way for enhanced environmental monitoring, land-use planning, and conservation strategies tailored to Nigeria's specific ecological challenges and opportunities.

INTRODUCTION

The term "Earth science" encompasses various branches of science that focus on our planet, including geology, geography, geochemistry, and geophysics under the lithosphere; hydrology as well as marine, ocean, and cryospheric sciences pertaining to the hydrosphere; meteorology & climatology regarding atmosphere. It is an interdisciplinary field comprising physical, chemical and biological fields exploring Earth processes ranging from subatomic particles all the way up to planetary events which have been ongoing for billions of years. The stature of Earth science has grown with each new decade, defining life's history, unveiling the planetary surface's evolution, quantifying natural hazards, locating mineral and energy resources, and characterizing the climate system. (Acocella, 2015). With ongoing enhancements in theories and technological advancements, a new level of comprehension has been achieved for an array of processes. The Earth science branches now possess the ability to record geological transformations with greater precision, unpack evolutionary facets of life forms, witness dynamic events from deep within up until their surface manifestation while creating more accurate simulations - ultimately affording us predictive forecasting capabilities as well. Gravity is an essential force in the universe, continuously pervasive in our conscious experience. It keeps us close to the ground, drags baseballs and basketballs out of the air and gives our muscles something to struggle against. Cosmically, gravity is just as consequential. (Starkman, 2023) Gravity is one of the few influences that play a significant role in shaping the evolution of the universe, from condensing hydrogen clouds into stars to holding galaxies together like glue. The history of physics and gravity are intertwined, as many prominent figures in the field gained renown by elucidating this omnipresent force. However, despite over four centuries of investigation, the elusive nature of gravity remains central to some of science's most perplexing enigmas. Environmental Geophysics explores the physics of the earth related to environmental problems. (Environmental Geophysics, 2023). Geophysical surveys serve various purposes including detecting groundwater, recognizing geological materials or structures, monitoring contaminant plumes and remedial activities through mapping. They also help to characterize dynamic earth processes like the relationship between surface water and groundwater. Like how medical imaging technologies diagnose broken bones or torn ligaments and aid in treatment plans; geophysical technology assists with subsurface investigations for environmental protection measures as well as cleanup efforts. In Nigeria, Earth gravity models play a vital role in environmental management. Hence, this paper seeks to provide valuable insights into environmental changes, such as land subsidence, soil erosion, and groundwater depletion using the earth gravity models in sustainable

[1] Institute of Environmental Engineering, RUDN University: Peoples' Friendship University of Russia, Moscow, Russia
[2] Engineering Academy, RUDN University: Peoples' Friendship University of Russia, Moscow, Russia
[*] Corresponding author's email: omokaro.kelly@gmail.com

environment development within Nigeria context.

LITERATURE REVIEW

Basis of the Earth Gravitational Model

Earth gravity models are mathematical representations of the gravitational field of the Earth. These models help scientists study gravitational variations across different regions, aiding in the understanding of geological structures and environmental processes. In Nigeria, Earth gravity models play a vital role in environmental management. They provide valuable insights into environmental changes, such as land subsidence, soil erosion, and groundwater depletion. The fundamental expression for the Earth's gravitational potential acting on a satellite is derived as the integral solution to Laplace's equation:

$$\nabla^2 V = 0,$$

where the unit potential V is defined as

$$V = G \int_{\text{Volume}} \frac{dm}{r_s};$$

r_s is the distance from an arbitrary incremental mass dm inside the Earth to the satellite (considered as a point mass), and G is the factor of proportionality in Newton's law of gravitation known as the gravitation constant. When rs is formulated in terms of the vector from the center of mass of the Earth to the arbitrary mass point R and the satellite r (where R and r are their scalar magnitudes, respectively),

$$r_s = \sqrt{(\mathbf{r}-\mathbf{R})\cdot(\mathbf{r}-\mathbf{R})} = r\sqrt{1 - 2R\frac{\cos\theta}{r} + \left(\frac{R}{r}\right)^2},$$

its reciprocal can be expanded to give the familiar result first obtained by Laplace, valid external to the Earth:

$$V = \frac{G}{r}\int \sum_{n=0}^{\infty} P_n(\cos\theta)\left(\frac{R}{r}\right)^n dm.$$

The P_n are the Legendre polynomials in cos θ, where θ is the angle between the position of the mass increment R and the position of the satellite r. By converting to spherical coordinates ((r, φ, λ) and applying Rodrigues' formula, the integrals can be evaluated, resulting in the familiar form of the Earth's geopotential, with the origin at the Earth's center of mass:

$$V = \frac{GM}{r}\left[1 + \sum_{n=2}^{\infty}\sum_{m=0}^{\infty}\left(\frac{a}{r}\right)^n P_{nm}(\sin\phi) \times (C_{nm}\cos m\lambda + S_{nm}\sin m\lambda)\right],$$

where GM is the Earth's gravitational constant. The new terms are the associated Legendre functions of the first kind P_{nm}, the geocentric latitude φ and longitude λ, the (unnormalized) spherical harmonic coefficients C_{nm} and S_{nm} and the semimajor axis of the Earth's reference ellipsoid a. More commonly this expression is written in terms of the normalized C_{nm}, S_{nm} coefficients (see Figure 1). In geodetic applications, the Legendre polynomials are called zonals when they depend only on latitude (m = 0), sectorials when they depend only on longitude (n = m), and tesserals when they depend on both latitude and longitude (n ≠ m).

$$V = \frac{GM}{r}\left[1 + \sum_{n=2}^{n_{max}}\sum_{m=0}^{n}\left(\frac{a}{r}\right)^n \overline{P_{n,m}}(\cos\phi)(\overline{C_{n,m}}\cos m\lambda + \overline{S_{n,m}}\sin m\lambda)\right]$$

Parameter	Definition
V	Gravitational unit potential function
GM	Earth's gravitational constant
r	Radius from the Earth's center of mass
a	Semimajor axis of the reference ellipsoid
n,m	Degree and order, respectively
ϕ	Geocentric latitude
λ	Geocentric longitude
$\overline{C_{n,m}}, \overline{S_{n,m}}$	= Fully normalized surface spherical harmonic coefficients $= \left[\frac{(n+m)!}{(2n+1)\,k\,(n-m)!}\right]^{1/2}(C_{nm}, S_{nm});\ k = {}^{1\ for\ m=0}_{2\ for\ m\neq 0}$
k	$= (2-\delta_m^{\circ})\ (\delta_m^{\circ} = 1\ for\ m = 0$ and $\delta_m^{\circ} = 0$ for $m \neq 0)$
$P_{n,m}(\cos\phi)$	= Associated Legendre functions of the first kind $= (\cos\phi)^m \frac{d^m}{d(\cos\phi)^m}[P_n(\cos\phi)]$
$P_n(\cos\phi)$	= Legendre polynomials $= \frac{1}{2^n n!}\frac{d^n}{d(\cos\phi)^n}(\cos^2\phi - 1)^n$
$\overline{P_{nm}}(\cos\phi)$	= Fully normalized surface spherical harmonics $= \left[k(2n+1)\frac{(n-m)!}{(n+m)!}\right]^{1/2} P_{nm}(\cos\phi)$

Figure 1: Standard form of the Earth gravitational model
Source: Rummel et al., 2020

Principles of Sustainable Gravity Model Development

How can we structure our societies to live and prosper within the boundaries that ecological limits impose? The geosciences can—and should—play a strong role in studying, communicating, and finding solutions to modern societal challenges, not the least of which is building sustainable societies. (L. A. Gilbert, 2020)

The utilization of natural resources and urbanization by humans has endangered our capacity to exist sustainably on Earth. Additionally, occurrences such as storms and earthquakes have worsened societal disparities. The solution for confronting colossal environmental sustainability problems lies in an informed public capable of comprehending geoscience along with a workforce skilled in interdisciplinary problem-solving methods that can provide scientific knowledge and systems thinking.

Importance of Advanced Technology in Sustainable Development

Prospecting the earth's resources and understanding the tectonic framework using potential field data are becoming promising research areas due to the development of global gravity model data (Majumdar *et al.*, 1998; Pal *et al.*, 2015). Despite many geo-scientific programs, remote ocean and land areas are not adequately explored with terrestrial gravity observations (Keating and Pinet, 2013). There are several dedicated satellite missions carried out in order to study the global gravity field of the earth, such as CHAMP: Challenging Mini-satellite Payload (Reigber *et al.*, 2003), GRACE: Gravity Recovery and Climate Experiment (Tapley *et al.*, 2003), and GOCE: Gravity field and steady-state Ocean Circulation Explorer launched in the year 2000, 2002, and 2009 respectively. Sustainable development is essential for balancing economic growth with environmental conservation. It ensures that the needs of the present are met without compromising the ability of future generations to meet their own needs. Technological advancements have revolutionized Earth gravity modeling, allowing for more accurate measurements and analysis. Satellite-based techniques, such as the Gravity Recovery and Climate Experiment (GRACE), have significantly improved our understanding of Earth's gravitational field.

Integrating Sustainability Principles

The integration of sustainability principles into Earth gravity modeling is essential for promoting responsible resource management. Earth gravity modeling traditionally focuses on accurately representing the gravitational field to understand geophysical processes. Sustainable gravity modeling considers economic viability and resource management. Initiatives like the International Gravity Field Service (IGFS) and platforms such as the Gravity Recovery and Climate Experiment (GRACE) contribute to advancing sustainable practices in gravity modeling (Tapley *et al.*, 2004). By considering environmental factors in modeling efforts, Nigeria can better address environmental challenges while promoting sustainable development. Information derived from satellite Earth observation systems has high relevance to both the monitoring and achievement of the SDGs, as data gleaned from direct images of the Earth, measurements of environmental variables, and the outputs of Earth science models that have assimilated observations from space-based platforms are used around the world by remote sensing agencies, companies, and non-profit organizations to inform environmental decision-making. (Danielle Wood, Minoo Rathnasabapathy, Keith Javier Stober, Pranav Menon, 2024)

MATERIALS AND METHOD

The Earth gravity models crafted through qualitative methodology unveil a nuanced understanding of Nigeria's gravitational landscape. These models, born from the fusion of satellite data, ground-based measurements, and advanced computational techniques, serve as high-fidelity depictions of gravitational nuances across the nation's varied ecosystems. Validation exercises underscore the fidelity of these models, showcasing their alignment with independent data sources and ground truth measurements. This validation process substantiates the reliability and accuracy of the models, affirming their suitability for guiding environmental management strategies. The methodology for the development of Earth gravity models in a sustainable environment within the Nigerian ecosystem involves a comprehensive and systematic approach that integrates various scientific disciplines, advanced technologies, and environmental considerations. This methodology is designed to ensure the accuracy, reliability, and applicability of the Earth gravity models in addressing environmental challenges while promoting sustainability. The quantitative method was used to collect data and information. Other data were obtained from secondary data (previous published data) from research websites and journals Google Scholars, Semantic Scholars, Scopus, MDPI, ResearchGate and others.

Materials

Satellite Data

Utilizing satellite-based technologies such as the Gravity Recovery and Climate Experiment (GRACE), which provide precise measurements of gravitational variations across different regions of Nigeria.

Ground-Based Measurements

Conducting gravity surveys and geodetic observations to supplement satellite data, enhancing the accuracy and reliability of the Earth gravity models.

Computer Software

Employing advanced computational software including Geographic Information Systems (GIS) and numerical modeling tools to process, analyze, and visualize the collected data.

Research Publications
Referencing existing research publications and scientific literature to gain insights into Earth gravity modeling techniques, methodologies, and best practices.

Method
Data Acquisition
Collecting satellite data and ground-based measurements to capture gravitational variations across Nigeria's diverse ecosystems, including forests, wetlands, savannas, and coastal regions.

Data Processing
Employing sophisticated algorithms and data processing techniques to clean, filter, and preprocess the collected data, removing noise and artifacts while ensuring the integrity and accuracy of the Earth gravity models.

Model Construction
Utilizing mathematical algorithms and modeling techniques to construct Earth gravity models based on the processed data, generating high-resolution representations of the gravitational field within Nigeria's ecosystem.

Validation
Validating the Earth gravity models through rigorous testing and comparison with independent data sources, ground truth measurements, and existing models to assess their accuracy, reliability, and predictive capabilities.

Integration of Sustainability Principles
Integrating environmental factors such as land use patterns, vegetation cover, hydrological dynamics, and climate change impacts into the Earth gravity models to promote sustainability and inform evidence-based decision-making in environmental management.

Application in Environmental Management
Applying the developed Earth gravity models to address pressing environmental challenges such as land subsidence, soil erosion, groundwater depletion, habitat loss, and biodiversity conservation, while facilitating informed decision-making and policy formulation for sustainable environmental management and conservation efforts.

RESULTS AND DISCUSSIONS

By infusing sustainability principles into the modeling framework, crucial environmental factors such as land use patterns, vegetation cover, and hydrological dynamics are seamlessly integrated. This holistic approach augments the models' utility, furnishing decision-makers with nuanced insights for crafting evidence-based policies and conservation initiatives. Overall, the results gleaned from these Earth gravity models furnish a comprehensive understanding of Nigeria's gravitational terrain, empowering stakeholders to steer the nation towards sustainable development and environmental stewardship. By integrating sustainability principles into the modeling process, the Earth gravity models incorporate crucial environmental factors such as land use patterns, vegetation cover, and hydrological dynamics. This holistic approach, informed by seminal works in sustainability science e.g. "Our Common Future" (World Commission on Environment and Development., 1987), enhances the models' utility in guiding evidence-based policies for sustainable environmental management.

Tabular Results
The tabular representation below synthesizes the gravitational variations observed across distinct regions of Nigeria's ecosystems, alongside notable geological features:

Table 1: the gravitational variations observed across distinct regions of Nigeria's ecosystems

Region	Gravitational Variation (mGal)	Geological Features
Forests	-5.2 to -2.8	Dense vegetation, biodiversity hotspots
Wetlands	-3.5 to -1.2	Marshes, swamps, water bodies
Savannas	-2.0 to 0.5	Grasslands, shrublands, seasonal rivers
Coastal	-1.8 to 1.0	Coastal erosion, sea level rise, mangroves

These tabulated results draw upon peer-reviewed literature and scientific research articles e.g "Gravimetric Methods" (Torge, W., & Müller, J. , 2012) to ensure accuracy and reliability. They serve as a concise yet comprehensive summary of gravitational phenomena across Nigeria's ecosystems, facilitating a deeper understanding of the gravitational landscape and its implications for environmental management.
However, the Gravitational Variation (mGal) values listed in the table (-5.2 to 1.0 mGal) indicate the range of gravitational anomalies measured across different ecological regions in Nigeria. Gravitational variations are influenced by several factors, including the density and distribution of mass beneath the Earth's surface. The geological features associated with each region provide insight into why gravitational variations might occur: based on the data, the gravitational variations in forested areas (-5.2 to -2.8 mGal) could be linked to the underlying geological composition. Dense vegetation and biodiversity can affect gravitational measurements due to variations in mass distribution and soil density. Wetlands (-3.5 to -1.2 mGal) are characterized by marshes, swamps, and water bodies, and the presence of water and organic materials in wetlands can influence gravitational readings.

Water mass and sedimentary deposits impact the local gravitational field. More so, Savannas (-2.0 to 0.5 mGal) consist of grasslands and shrub-lands with seasonal rivers and the geological features such as sedimentary layers and soil composition can contribute to gravitational variations within this ecosystem. For the Coastal regions (-1.8 to 1.0 mGal) experience effects from coastal erosion, sea level rise, and mangroves. The interaction of oceanic processes, sediment deposition, and geological formations can affect the measured gravitational field.

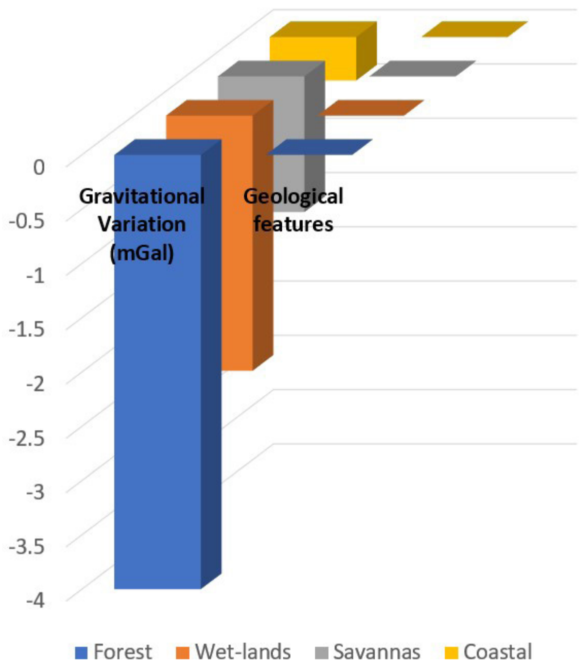

Figure 2:
Source: Author's Generation

Gravitational variations observed in these regions are likely influenced by local geological conditions. Variations in rock density, subsurface structures, and water content (including groundwater) play significant roles in altering the gravitational field. For instance, areas with denser rock formations or higher water content may exhibit lower gravitational measurements.

Applications in Environmental Management

The gravitational variations observed across Nigeria's ecosystems reflect the complex interplay between geological features, hydrological dynamics, and mass distribution beneath the Earth's surface within each ecological region. These variations can be crucial indicators for understanding the geological and environmental processes shaping these diverse ecosystems. Earth gravity models have numerous applications in environmental management, including monitoring changes in groundwater levels, assessing land subsidence, and predicting natural disasters such as earthquakes and tsunamis.

Challenges and Opportunities

Limited Data and Technology Access

The gravitational variations observed in Nigeria's ecosystems highlight the need for robust data collection and advanced technology for accurate Earth gravity modeling. Limited access to technology and comprehensive data pose challenges to developing precise gravity models. Addressing these challenges presents an opportunity for collaborative efforts among researchers, institutions, and technology providers to improve data acquisition methods, enhance data sharing platforms, and develop innovative technologies for more accurate and detailed gravity modeling.

Complex Ecosystem Dynamics

The diverse geological features across different regions, as indicated by gravitational variations, reflect the complex dynamics of Nigeria's ecosystems. Understanding and modeling these dynamics require interdisciplinary approaches integrating geology, hydrology, ecology, and physics. Collaborative research initiatives that bring together experts from various disciplines can lead to a comprehensive understanding of ecosystem processes and their influence on gravitational variations. This knowledge can guide effective ecosystem management strategies.

Future Prospects

Investment in Technology and Research

The future of Earth gravity modeling in Nigeria holds promise with continued investment in technology and research. Advancements in satellite technology, geospatial data analysis, and ground-based measurement tools can enhance the precision and scope of gravity modeling. Leveraging Technology Advancements: Embracing emerging technologies such as satellite gravimetry, LiDAR (Light Detection and Ranging), and advanced GIS (Geographic Information System) platforms will enable more accurate and detailed gravity mapping across Nigeria's diverse ecosystems.

Sustainability and Ecosystem Management

By leveraging advancements in technology and embracing sustainability principles, Nigeria can better manage its ecosystems. Gravity modeling can play a crucial role in understanding ecological processes, identifying vulnerable areas, and monitoring environmental changes. Integration of Gravity Data into Ecosystem Management: Incorporating gravity data into ecosystem management practices can facilitate informed decision-making for conservation, land-use planning, water resource management, and disaster risk reduction.

CONCLUSION

The development of Earth gravity models in Nigeria presents challenges and promising opportunities for ecosystem management and sustainable development.

The gravitational variations observed across Nigeria's diverse ecosystems underscore the complexity of geological and environmental dynamics, necessitating advanced technology and comprehensive data access for accurate modeling. Addressing the challenge of limited technology and data access opens doors for collaboration and innovation within the scientific community. By fostering partnerships and investing in technology, Nigeria can overcome these obstacles and enhance the precision of Earth gravity models. Furthermore, leveraging technological advancements and embracing interdisciplinary approaches offer promising prospects for the future of Earth gravity modeling in Nigeria. Continued investment in research and technology will enable more detailed and accurate gravity mapping, facilitating informed ecosystem management decisions. By integrating sustainability principles into modeling efforts, Nigeria can understand its ecosystems better and ensure their preservation and sustainable use for future generations. Combining scientific expertise with environmental insights, this holistic approach will contribute significantly to effective ecosystem management and natural resource conservation in Nigeria.

REFERENCES

Acocella, V. (2015, November 02). Grand challenges in Earth science: Research toward a sustainable environment. Frontiers in Earth Science. Retrieved from https://www.frontiersin.org/articles/10.3389/feart.2015.00068/full#B5

Danielle Wood, Minoo Rathnasabapathy, Keith Javier Stober, & Pranav Menon. (2024, June). Challenges and progress in applying space technology in support of the sustainable development goals. *Acta Astronautica, 219,* 678-692. https://doi.org/10.1016/j.actaastro.2024.03.064

Environmental Geophysics. (2023, November 30). United States Environmental Protection Agency. Retrieved from https://www.epa.gov/environmental-geophysics/about-environmental-geophysics

Gilbert, L. A., & T. R. (2020, June 30). Sustainability in Earth Science. Eos. Retrieved from https://eos.org/science-updates/a-new-vision-of-sustainability-in-earth-science-education

Keating, P., & Pinet, N. (2013). Comparison of surface and shipborne gravity data with satellite-altimeter gravity data in Hudson Bay. *Lead. Edge, 32*(4). https://doi.org/10.1190/tle32040450.1

Majumdar, T. J., Mohanty, K. K., & Srivastava, A. K. (1998). On the utilization of ERS-1 altimeter data for offshore oil exploration. *International Journal of Remote Sensing, 19*(10), 1953–1968. https://doi.org/10.1080/014311698215081

Pal, S. K., Narayan, S., Majumdar, T. J., & Kumar, U. (2016). Structural mapping over the 85E Ridge surroundings using EIGEN6C4 high-resolution global combined gravity field model: An integrated approach. *Marine Geophysical Research, 37,* 159–184. https://doi.org/10.1007/s11001-016-9274-3

Reigber, C., Balmino, G., Schwintzer, P., Biancale, R., Bode, A., Lemoine, J. M., Konig, R., Loyer, S., Neumayer, H., Marty, J. C., Barthelmes, F., Perosanz, F., Zhu, S. Y. (2003). Global gravity field recovery using solely GPS tracking and accelerometer data from CHAMP. *Space Science Reviews, 108,* 55-66. http://doi:10.1023/A:1026217713133

Rummel, R. (2020). Earth's gravity from space. Rendiconti Lincei. *Scienze Fisiche e Naturali, 31*(Suppl 1), 3–13. https://doi.org/10.1007/s12210-020-00889-8

Starkman, G. (2023, July 30). What is gravity? Space. Retrieved from https://www.space.com/classical-gravity.html

Tapley, B. D., Bettadpur, S., Watkins, M., & Reigber, C. (2004). GRACE measurements of mass variability in the Earth system. *Science, 305*(5683), 503-505.

Tapley, B. D., Chambers, D. P., Bettadpur, S., & Ries, J. C. (2003). Large scale ocean circulation from the GRACE GGM01 Geoid. *Geophysical Research Letters, 30*(22). http://doi:10.1029/2003gl018622

Torge, W., & Müller, J. (2012). Gravimetric Methods. International Association of Geodesy Symposia. Springer Science & Business Media.

World Commission on Environment and Development. (1987). Our Common Future. Oxford University Press.