ESTABLISHMENT OF ABSOLUTE GRAVITY STATIONS REFERENCED TO INTERNATIONAL GRAVITY STATIONS NETWORK OF 1971 DATUM IN 21 COUNTIES IN KENYA

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AGRICULTURE AND TECHNOLOGY

2018

Establishment of Absolute Gravity Stations Referenced to International Gravity Station Network of 1971 Datum in 21 Counties in Kenya

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A thesis Submitted in Partial Fulfillment for the degree of Master of Science in Applied Geophysics in the Jomo Kenyatta University of Agriculture and Technology

2018

DECLARATION

This thesis is my original work and has not been presented for a degree in any other university.

Signature………………………… Date………………………..

Hillary Kipkoech Korir

This thesis has been submitted for examination with our approval as university supervisors.

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DEDICATION

This work is dedicated to my family; my parents and my siblings, who have always encouraged me to pursue my dreams and who also worked tirelessly to see to it that I was well nourished to successfully do my studies.

ACKNOWLEDGEMENTS

This thesis is based on research conducted in the 21 counties in Kenya between the years 2015 and 2016. I am grateful for my supervisors, Dr. Githiri and Dr. K'orowe, for encouraging me to start the work, persevere with it, and finally to publish it. I am indebted to my colleagues; Mr. Odero and Mr. Bogi, who supported me during field work.

Many thanks to the university laboratory technicians, Mr. Olume and Mr.Adenya, who were always available to assist me and encouraged me to move on. I would also like to acknowledge with gratitude, the support and love of my family; my parents and my siblings. They all kept me going, and this thesis would not have been possible without them.

Finally, I would like to thank the Jomo Kenyatta University of Agriculture and Technology, through the Research, Planning and Extension (RPE) department for providing funding for the project.

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LIST OF ABBREVIATIONS

JKUAT	Jomo Kenyatta University of Agriculture and Technology
GPS	Global Positioning System
IGSN-71	International Gravity Standardization Network of 1971
USA	United States of America
IUGG	International Union of Geodesy and Geophysics
UEGN	Unified European Gravity Network
IAG	International Association of Geodesy

LIST OF SYMBOLS

m	mili
µ	micro
mGal	mili Gals

ABSTRACT

Gravimeters measure relative readings and to obtain absolute gravity values, they have to be referenced to a station whose gravity is accurately known. International Gravity Stations Network of 1971 (IGSN-71) consists of stations distributed all over the world whose absolute gravity has been measured accurately. In Kenya there are three IGSN-71 stations located in Nairobi, Kisumu and Mombasa. To carry out gravity survey at any location in Kenya, at least one of the three reference IGSN station has to be used as a reference station. The stations are sparsely spaced and there is need to establish more stations closer for any researcher conducting local surveys and to support; geodynamic studies, global climate change monitoring, international studies of secular variations of gravity among other applications. The IGSN-71 datum was computed based on the 1967 geodetic reference system and there was need to update new gravity values to the 1980 geodetic reference system, it also contains a Honkasalo Term that has been deemed inappropriate. A Worden Sodin gravimeter model 403 was used to determine relative gravity of the new station with reference to IGSN-71 datum. Profile method survey design was used to collect data hence ensuring efficient monitoring of gravimeters' drift. The obtained gravity values of new stations were subject to; least squares adjustment, tidal correction, and drift correction in order to obtain a fair representation of absolute gravity at those points. The gravity values obtained are accurate to 0.15 mgal hence they are categorized as the 3rd order gravity control network. The residues of adjustment obeyed the approximately 50% positive and 50% negative rule, while normalized residues obtained were below 3 and the standard errors of unit weight of all adjusted values were below 1, showing that the weighting and adjustment process was excellent.

CHAPTER ONE

INTRODUCTION

This chapter outlines the introductory aspects of the study such as the background of the study and study area. Statement of research objectives, problem and justification has been covered in this chapter.

1.1. Background of the Study

A datum is a reference from which measurements are made and are typically used for relative quantities. The need for gravity datum is connected to the instruments used to measure gravitational acceleration and the establishment of reference stations.

'Historically, the instruments used to make absolute gravity measurements had poor accuracies. Thus, most instruments used to measure gravity were relative instruments. Relative instruments determine the gravity difference between station with known gravity value and new station. Relative instruments may be used to measure gravity difference of a site relative to a national base station. Therefore, it is possible to establish other reference base stations. Both simple pendulum and spring-based gravimeters could make relative measurements reliably, quickly, and accurately. Before the 1960s, the only accurate way to make an absolute measurement was with a reversible pendulum done in laboratory conditions (Moose, 1986).'

Since the 1960s, 'numerous ballistic, absolute gravimeters have been made. Today, these gravimeters make routine measurements with accuracies of under ±10 μGals (Woollard

& Rose, 1963). Modern absolute gravimeter measurements loosely confirm the IGSN-71 values, within its error limits. The absolute gravimeter measurements are technically their own datum, since they measure gravity directly without relative ties to any other stations. Internal design elements and the ways they are combined to make a gravimeter cannot guarantee that the published number is a 'true' gravity value any more than old pendulum gravimeter could. The best researchers can do is to compare gravimeters to each other to be sure they are all measuring similarly and thus have a semblance of being a datum.'

Gravity control networks are required to support several applications on national and international scales, basically in two major domains of geosciences; geodesy and geophysics. Local gravity field representations are essential in establishing geodetic control and carrying out engineering surveys.

1.1.1. Study area

'The Republic of Kenya is a country in Africa and a founding member of the East African Community (EAC). Its capital and largest city is Nairobi. Kenya's territory lies on the equator and overlies the East African Rift covering a diverse and expansive terrain that extends roughly from Lake Victoria to Lake Turkana (formerly called Lake Rudolf) and further south-east to the Indian Ocean. It is bordered by Tanzania to the south, Uganda to the west, South Sudan to the north-west, Ethiopia to the north and Somalia to the north-east. Kenya covers 581,309 km^2 (224,445 sq mi) and had a population of approximately 45 million people in July 2014. At 580,367 km^2 (224,081 sq mi) (C.I.A, 2013), Kenya is the world's forty-seventh largest country (after Madagascar). It lies between latitudes 5°N and 5°S, and longitudes 34° and 42°E. From the coast on the Indian Ocean, the low plains rise to central highlands. The highlands are bisected by the Great Rift Valley, with a fertile plateau lying to the east. The geology of Kenya may generally be grouped into the following five major geological successions: Archean (Nyanzian and Kavirondian), Proterozoic (Mozambique Belt and Bukoban), Palaeozoic/Mesozoic sediments, Tertiary/Quaternary volcanics and Tertiary/Quaternary sediments (Wikimedia, 2015).'

The research aimed at setting up absolute gravity stations in counties within; Riftvalley, Nyanza, and Western provinces of Kenya, as the first phase of gravity survey, as illustrated in Figure 1-1, and ultimately setting up absolute gravity stations in all the 47 counties of Kenya. These counties are; Kericho, Kakamega, Homa Bay, Tras-Nzoia, Vihiga, Uasingishu, Siaya, Elgeiyo Marakwet, Migori, Nandi, Kisii, Bungoma, Kisumu, Bomet , Busia , Nyamira, Kajiado, Narok , Nakuru, and Baringo.

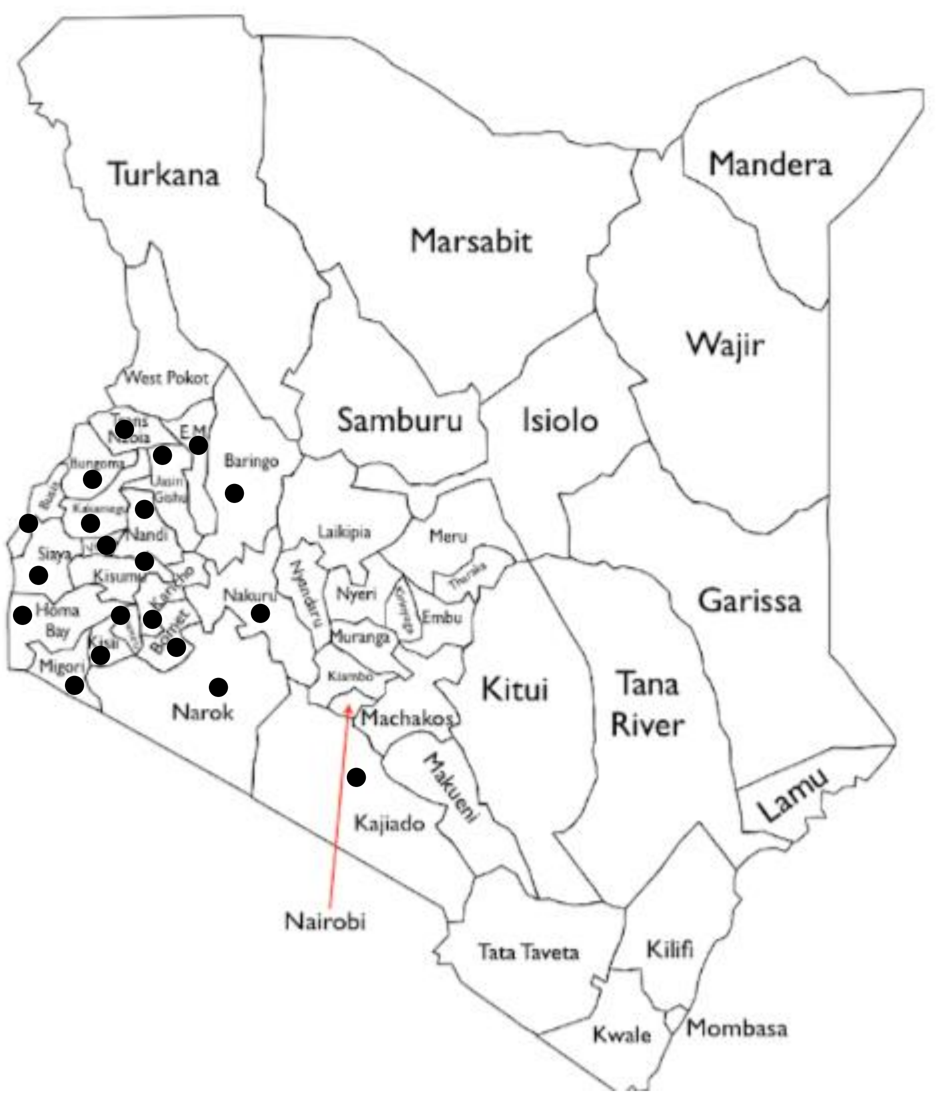

Figure 1-1: Map of Kenya showing the 47 Counties and the counties where new absolute gravity stations have been set up represented by the dotted marks (Wikimedia, 2015)

1.2 Statement of Problem

In conducting a gravity survey, one needs to know absolute gravity of a nearby control station so as to add up or subtract the relative value obtained using a relative gravity meter.

In Kenya, absolute gravity values were acquired in 1971 only for Kisumu railway station, Mombasa airport and Nairobi survey office as these were easily accessible locations then. This is limiting when a survey has to be conducted in areas remote from the major towns as much time will be used in travelling and also challenges in accessing the station due long bureaucracies in obtaining permission to access the locations since they are highly secured. Hence there is need to establish more control stations each county in Kenya in an easily accessible location.

1.3 Justification

The major problem in determining absolute gravity value is the precision of such measurements. The national distribution of such stations is sparse which makes it difficult to access such stations when conducting a gravity survey. The intent of this work is to create more absolute gravity stations referenced to the International Gravity Standardization Network of 1971, that are well distributed all over the country. The map in Figure 1-2, illustrates that countries like Ethiopia and Sudan have relatively good station distribution compared to Kenya.

Gravity measurements will enhance prospecting of minerals, oil, and gas that will take our country closer to attaining millennium goals.

Figure 1-2: Gravity base stations established in North Eastern Africa (Uotilia, 1980)

1.4 Objectives

1.4.2 Main objective

To establish additional national network of absolute gravity stations

1.4.3 Specific Objectives

1. To establish accessible locations for the absolute gravity stations at county survey headquarters.
2. To determine relative gravity of the reference stations and new stations using Worden Sodin gravimeter.
3. To determine precise absolute gravity values of the new station at county survey headquarters.

CHAPTER TWO

LITERATURE REVIEW

‘In the late 19^{th} century, the Vienna Gravity System was established by F.R.Helmert based on pendulum measurements in Vienna, Austria (Moose, 1986).’ This system had an estimated relative accuracy of ±10 mGals. By 1909, this system was replaced by the Potsdam Gravity System, which had a relative accuracy of ±3 mGals and corrected the Vienna System by 16 mGals. However, in the 1960s, it was realized that the Potsdam datum was off by about -14 mGals. ‘However, until a better system could be devised, world experts agreed that it was better to leave all measurements on a single datum. In the late 1950s and 1960s, concerted efforts were made to make new worldwide pendulum and spring based gravimeter ties and to include the new ballistic absolute gravimeter measurements in the adjustment (Duerksen, 1949).’ These data were combined and solved simultaneously and published as the International Gravity Standardizartion Net 1971 (IGSN-71). ‘About 1,900 worldwide sites, including about 450 U.S. sites, were in this network. Each site had an estimated standard error of less than ±50 µGals, with a correction of ±14.0 mGals at the Potsdam site (Morelli, 1976).’ The IGSN-71 remains the official gravity datum worldwide today.

‘The International Union of Geodesy and Geophysics (IUGG) has long been planning to set up a unified scale and datum gravimetric network which could be applicable in the whole world. The needs for increasing accuracy of global geodetic reference systems and solving of several geodynamic and geotectonic problems have brought about the realization of this objective as a daily routine (Csapo *et al.*, 2003).'

Several countries, especially the developed nations are advocating for adding and updating gravity networks. 'A recent and accurate gravity framework for Egypt has been established through the Egyptian National Gravity Standardization Network 1997 (ENGSN97). With a national homogenous distribution and the utilization of precise instrumentation, the ENGSN97 serves as the accurate national gravity datum for Egypt (Dawod, 1998).'

In Sweden, a supreme network of 25 stations, known as The Fundamental Gravity Network of Sweden, has been established. 'It was measured in 1981-1982 by Lenart Petterson and Lars Ake Haller, both using two La Coste and Romberg gravimeters. Furthermore, the measurements of the fundamental network were sent for inclusion in the Unified European Gravity Network (UEGN) (Haller & Ekman, 1988).'

The first Version of the Unified European Gravity Net (UEGN) was set up in 1993, based on the participation of 11 countries. The aim was basically the generation of the unified European geodetic basement for global geologic and geodynamic application. 'The unified scale of the network is ensured by numerous absolute gravimetric stations. Since 1995, further countries (inter alia Hungary) have been joined to the network (Csapo *et al.*, 2003).'

In Kenya, gravity measurements started way back in 1955. A catalogue of gravity measurements Swain & Khan (1978) contains compilation of these data all the way from

1955 to 1975. This compilation is one of the end products of a research programme which began at Leicester University in 1965. It supersedes previous catalogues by Searle and Darracot, Searle & Darracot (1971) and Khan (Khan, Mansfield & Swain, 1973). ‘The datum used in reducing the gravity observations is defined by the IGSN-71 (Morelli *et al.*, 1972) together with the 1967 gravity formula (IAG, 1967) as recommended by the IUGG (Morelli, 1976). Station elevation was measured using the leap frog method, where two “Baromec” aneroid barometers were used. It was later supplemented by two “paulin” altimeters (Searle, 1969).’ A few errors in measurements were possible, ranging between ±2.8 m and ±2.0 m. According to swain and Khan, station positions have all been established on scale maps thus in the Southern and Western parts of Kenya these maps tend to be detailed and accurate while in the northern and eastern parts, they are less detailed thus less accurate.

‘In December 1979, The New Geodetic Reference System 1980 was adopted at the XVII General Assembly of IUGG in Canberra. The International Union of Geodesy and Geophysics (IUGG) recognizing that the Geodetic Reference System 1967, adopted at the XIV General Assembly of IUGG in Lucerne 1967, no longer represent the size, shape and gravity field of the Earth to an accuracy adequate for many geodetic, geophysical, astronomical and hydrographic applications and considering that more appropriate values are now available, recommends that the Geodetic Reference System 1967 be replaced by a new Geodetic Reference System 1980 (Moritz, 1980).’

It is evident that the gravity data contained in the Catalogue of gravity measurements Swan & Khan (1978) are not updated to meet the current accuracy standards required for application in the field of geosciences, yet it is the major document known to contain homogenous gravity data of Kenya which have been referenced to IGSN-71 station. This calls for the need to update the data to meet standards recommended by IUGG and set up accessible absolute gravity stations distributed evenly in the country. With availability of Global Positioning Devices (GPS) with accuracy of ±3 m thus, challenges encountered by early researchers in height and position measurement will be solved. Also, by application of the new Geodetic Reference formulae of 1980 to the data, more accurate theoretical values of gravity at sea level will be achieved.

2.1 Theoretical Concept

2.1.1 Absolute Gravity Measurements

'The first absolute measurements were done with pendulums, partly in vacuum. One of the stations is in Potsdam, Germany and was used as a reference station in Central Europe (Moose, 1986).

The compound pendulum consisted quartz rod attached to the moveable mass. Near each end of the rod is a fixed pivot, consisting of quartz knife edge resting on a flat quartz plane. The period of the pendulum is measured for oscillations about one of the pivots. The pendulum is then inverted and its period about the other pivot determined. The position of the movable mass is adjusted until the periods of the two pivots are equal.' The distance

L between the pivots is then measured accurately and the period of instrument is related to the period (T) and absolute gravity (g) is obtained by the equation (2-1).

$$T = 2\pi\sqrt{\frac{L}{g}} \tag{2-1}$$

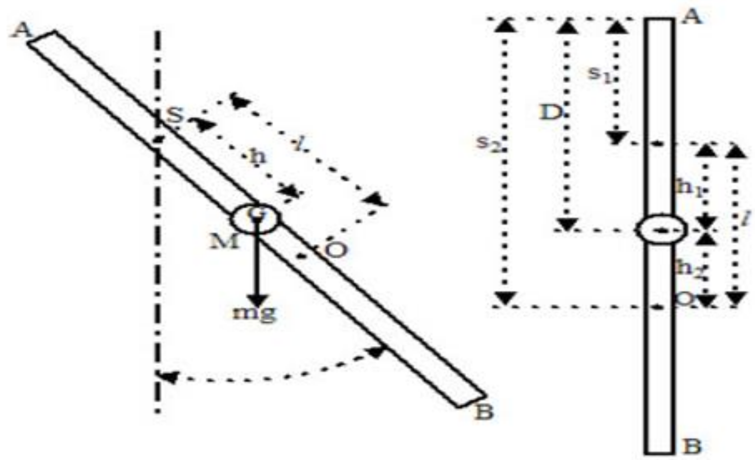

Figure 2-1: Diagram showing principle of operation of a compound pendulum (Pearson, 2009)

The sensitivity of the compound pendulum is found by differentiating equation 1 which yields (2-2).

$$\frac{\Delta g}{g} = -2\frac{\Delta T}{T} \tag{2-2}$$

To obtain a sensitivity of 1mgal, it is necessary to determine the period with accuracy of about 0.5µs. The precise timing of the swings was not possible in the 1930’s due to available clocks at that time. The apparatus were bulky but were used until the 1950's as the main method of absolute measurements.

'Modern absolute measurements of gravity are based on the free fall of an object, whose fall path and corresponding time of fall is measured precisely as shown in Figure 2-2.

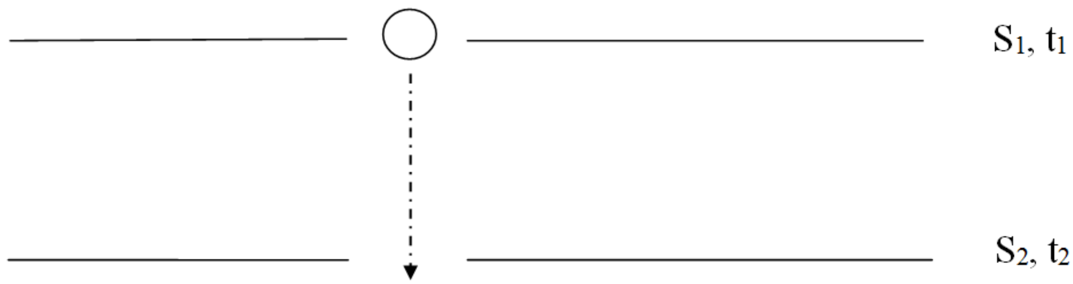

Figure 2-2: Principle of the free fall measurement of gravity

From equation of linear motion adapted for free-fall, the path length (S_i) is expressed as (2-3) where t_i is the time of fall and g the absolute acceleration due to gravity.

$$S = \frac{1}{2} g t_i * t_i \tag{2-3}$$

Considering an object falling through two levels, acceleration due to gravity can be determined using (2-4).

$$g = 2(\frac{s2 - s1}{t2 - t1}) \tag{2-4}$$

The fall distance (s_1-s_2) is measured using Michelson interferometer and the travel times counted electronically (Moose, 1986).'

2.1.2 Relative gravity measurements

2.1.2.1 Gravimeter

A gravimeter is an instrument used in measuring relative values of gravity. A gravimeter consists of a spring balance carrying a constant mass and variations in the weight of the mass caused by gravity change causes the length of the spring to vary. It uses the principle of Hooke's Law whereby a mass m suspended from a spring of length x_o causes it to stretch to a new length x. The extension or change in length of the spring is proportional to the restoring force of the value of gravity as shown in (2-5).

$$F = mg = -K(X - X_o) \quad (2\text{-}5)$$

Where **k** is the elastic constant of the spring.

The gravimeter is usually calibrated at a location whose absolute gravity is known. When the gravimeter is moved to another location of different gravity, the extension of the spring changes and the change in gravity can be determined.

2.1.2.2 Worden Sodin Gravimeter.

'The essentials of a Worden Sodin gravimeter are a very light weight mass 5 mg and main zero spring coupled to its upper end to two subsidiary springs. The springs are of different strengths and each is attached to a micrometer. The system is held in unstable equilibrium about axis H-H as shown in the Figure 2-3. Any increase in gravitational pull causes a slight anticlockwise rotation angle between the main spring and the inclined arm attached to its base. The decreased angle lessens the opposing clockwise moments of spring and provides necessary instability. The upper end of the main spring is attached to micrometers through two springs. The micrometers measure the displacement needed to restore the beam to its null position on its scale. One of this micrometer dials has a scale, which is adjusted to the order of 100 mgal in range and can be read to 0.01 mgal. The other is a geodetic dial having a range of several thousand mGal but can read to an accuracy of 0.2 mgal. The geodetic dial is used for measurement of large gravity difference and is a coarse adjustment used brings the small dial on scale when gravimeter is moved to different latitude (Telford *et al*., 1990).'

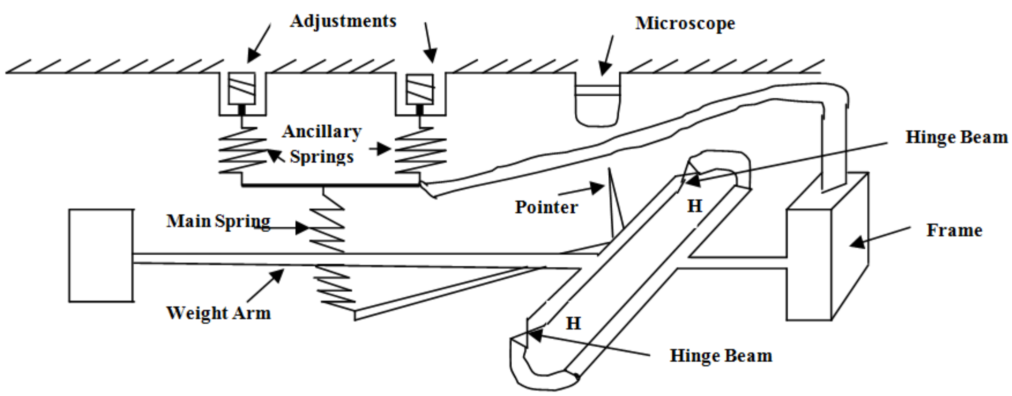

Figure 2-3: Diagram showing principle of operation of a Worden Gravimeter (Telford et al., 1990)

Large deflections of the gravimeter would be produced by effect of temperature on the spring. In the Worden gravimeter, temperature effects are minimized by using quartz spring and a bimetallic beam, which compensates for temperature changes automatically. The instrument is housed in an evacuated flask. The instrument can be read to an accuracy of 0.01 mgal.

2.1.2.3 Gravity Observation Techniques

'The basic survey procedure in gravity surveying is the loop. This procedure is required to computationally remove the systematic drift error of the instrument and to provide redundant observations at stations for quality assurance purposes. A loop consists of a set of gravity stations, for which gravity differences are observed by the same observer and the same gravimeter. The gravimeter must be in its operating temperature for at least six hours prior to the loop observations and remains at this condition during the observation time for the entire loop. The loop must start from a station with known gravity value (Dawod, 1998).'

Relative gravimeters exhibit a temporal variation in the display of the zero position, which is known as the instrument drift. The drift is a function of several factors, such as the structure of the gravimeter, the age and usage of the instrument, external temperature variation during transportation and measurements, and uncompensated change of voltage of the power supply. 'The drift can be determined by repeated measurements, which should be distributed as uniformly as possible over the measured period. Therefore, various measurement schemes were developed particularly for drift control.

The following are some example of the useful observation methods (Torge, 1989).'

a. The Difference Method

In this method, gravity measurements start from a station where absolute gravity value is already known and then to station where its' absolute gravity is to be determined. For four stations where, absolute gravity value is already known for example stations; 1, 3, 4, 5 and a station whose gravity value is to be determined for example station 2, the procedure for gravity measurement for one complete loop is as follows; 1-2-1-2-4-2-4-5-4-5-4-5-2-5-2-3-2-3-1-3-1.

The procedure is well shown in the Figure 2-4. This method has immediate drift control in the endpoint of each gravity difference. Although this method is more efficient, it is also time consuming and expensive.

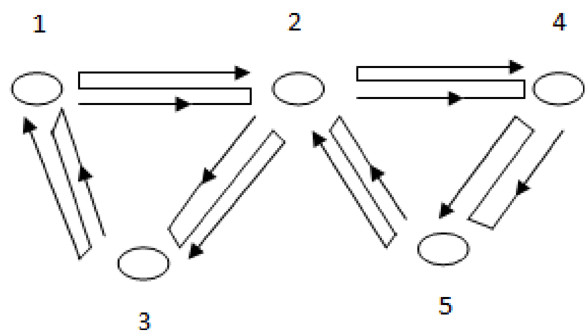

Figure 2-4: The Difference Method

b. Star Method

In this method, gravity measurements start from a station where absolute gravity value is already known and then to station where its' absolute gravity is to be determined. For three stations whose absolute gravity value is already known for example stations; 1, 3, 4, and a station whose gravity value is to be determined for example station 2, the procedure for gravity measurement for one complete loop is as follows; 1-2-4-2-3-1. The procedure is well shown in the Figure 2-5. This method has ties to a central point and immediate drift control.

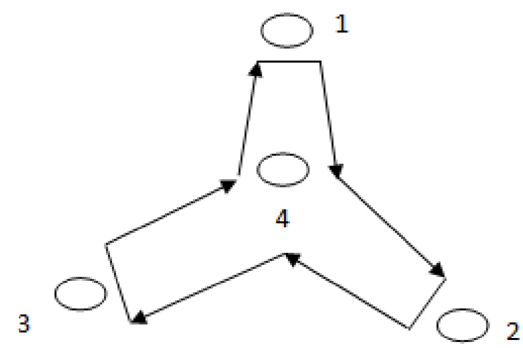

Figure 2-5: The Star method

c. **Step Method**

For four stations whose absolute gravity value is already known for example stations; 1, 3, 4, 5 and a station whose gravity value is to be determined for example station 2, then the procedure for data collection will be as follows; 1-2-1-2-3-2-3-4-3-4-5. This process is well illustrated in the Figure 2-6. This method has at least triple station occupation in quick successions. It is efficient method but time consuming and expensive.

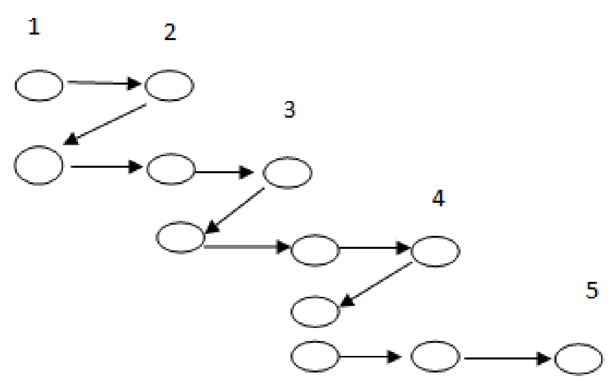

Figure 2-6: The Step method

d. Profile method

With four stations whose absolute gravity values are known for example stations; 1, 3, 4, 5 and a station whose gravity value is to be determined for example station 2, the procedure for data collection will be as follows; 1-2-3-4-5-5-4-3-2-1. The procedure is well shown in the Figure 2-7. This method is efficient and cheap. It is also a method with single, double or multiple station occupation at continuous station occupation in the profile.

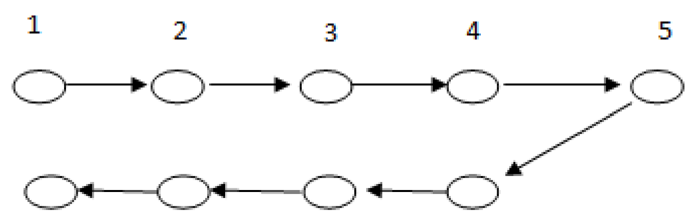

Figure 2-7: The Profile Method.

2.1.3 Error Theory and Propagation

The measurement of a physical quantity can never be made with perfect accuracy, there will always be some error or uncertainty present. 'For any measurement there are an infinite number of factors that can cause a value obtained to deviate from the true (theoretical) value. Most of these factors have a negligible effect on the outcome of a survey and can usually be ignored. However, some effects can cause a significant alteration, or error, in the survey result. If a measurement is to be useful, it is necessary to have some quantitative idea of the magnitude of the errors. Therefore, when survey results are reported, they are accompanied by an estimate of the measurement error, called the uncertainty. This uncertainty indicates how reliable the researcher believes the results to be (Taylor, 1997).'

If for example; D_1, D_2, and D_3 are three consecutive dials readings of a gravimeter at a station measured within 5 min period. Then $D = (D_1 + D_2 + D_3)/3$, where D is the average gravimeter dial reading representing the station, thus residues associated with the measurement will be given as;

$$V1 = D - D1 \tag{2-6}$$

$$V2 = D - D2 \tag{2-7}$$

$$V3 = D - D3 \tag{2-8}$$

Thus the standard deviation, S, will be given as;

$$S = \sqrt{S^2} = \sqrt{\frac{\sum v^2}{n-1}} = \frac{\sqrt{v1^2 + v2^2 + v3^2}}{2} \tag{2-9}$$

Hence, the absolute dial reading representing a station will be;

$$D \pm S \tag{2-10}$$

'When these measurements are used in mathematical calculations, the errors associated with the measurements tend to propagate to the final result. In order to take into consideration these errors, the general formula in (2-11), (Taylor, 1997), was the main guiding principle in every mathematical calculation. Where A(x,y) is a function with a variables x and y. $\partial A(x,y)$, ∂x, and ∂y are the uncertainties in A(x,y), x, and y respectively.'

$$\partial A(x,y) = \sqrt{\left(\frac{dA}{dx}\partial x\right)^2 + \left(\frac{dA}{dy}\partial y\right)^2} \quad (2\text{-}11)$$

If for example; A = B + C, and S_B, S_C are errors associated with B and C, the error associated with value A, (S_A), will be given as;

$$S_A = \sqrt{\left(\frac{dA}{dB}\partial B\right)^2 + \left(\frac{dA}{dC}\partial c\right)^2} \quad (2\text{-}12)$$

Where;

$$\frac{dA}{dB} = 1, \frac{dA}{dc} = 1, \partial B = S_B\ \partial c, = S_C$$

$$S_A = \sqrt{(S_B)^2 + (S_c)^2} \quad (2\text{-}13)$$

So;

$$A \pm S_A \quad (2\text{-}14)$$

‘In order to analyze repeated measurements and draw conclusions about the quality of the said measurements in surveying, statistics are used and are based on the laws of probability. The various statistical terms and equations that were used here are described as follows as explained in (Navidi *et al.*, 1998).

Residue (v). The difference between adjusted value and the measured value or the amount the measurement has adjusted. It will be denoted by v**.** Having approximately 50% of the residue as negative and approximately 50% as positive is an indication of normally distributed data set.

Residue = adjusted value (e.g. Mean height) – measured value (e.g. height)

Variance (S^2) and Standard deviation (S). Variance is a measure of precision of data set and will be denoted by S^2 while standard deviation is used to draw conclusion about probability. Approximately 68% of data will fall within the range defined by the standard deviation. Standard deviation is the square root of variance and will be denoted by S.

$$S = \sqrt{S^2} = \sqrt{\frac{\sum v^2}{n-1}} \quad (2\text{-}15)$$

Where n is the number of data sets.

Weights (w). This are estimates of the relative reliabilities of observations. A high precision as indicated by a small standard deviation implies a good observation and hence high weight. Conversely, a low precision as indicated by a large standard deviation implies poor observation and hence a small weight. Weights are generally based on the reciprocal of standard deviation as shown by (2-16) . Weights will be denoted here by *w*.

$$w = \frac{1}{S^2} \quad (2\text{-}16)$$

Weighted Mean (Xw). This is a mean where some values contribute more to the final value as compared to others due to the weight assigned to them. It will be denoted as *Xw*.

$$X_w = \frac{\sum X_i W_i}{\sum W_i} \quad (2\text{-}17)$$

Where; *Xw* = weighted mean, *Wi* = Weight assigned to measurement *Xi.*

Standard Deviation of the Weighted Mean (S_{Xw})

$$S_{XW} = \sqrt{\frac{\sum wv^2}{(\sum w)(n-1)}} \quad (2\text{-}18)$$

Where; w =Weight assigned to the measurement X, v = residual, n = number of measurements.

Normalized Residuals (N_R). This is the ratio of residuals to the standard deviation or error estimate. It will be denoted as N_R. For a normally distributed data set, 68% of normalized residuals should be equal to or less than one. Normalized residuals equal to or greater than three should be closely examined as potential outliers. Normalized residuals are used to indicate the weighting of individual measurement.

$$N_R = \frac{/v/}{S} \quad (2\text{-}19)$$

Where; $/v/$ = magnitude of residual

Degrees of freedom (DF). This is the number of measurements in excess of those needed to solve for the unknowns. It will be denoted as DF.

DF = (Total number of measurements + Total number of fixed values – Total number of Measurements to be determined)

Standard Error of Unit Weight (SEUW). This is used to assess the weighting that has been applied to the entire network. If the weighting was perfect the standard error of unit weight would be equal to one.'

$$SEUW = \sqrt{\frac{\sum wv^2}{DF}} \tag{2-20}$$

2.1.4 Least Squares Adjustment by Weighted Average

'Least-squares adjustment is a mathematical procedure based on the theory of probability that derives the statistically most likely gravity value of stations defined by multiple measurements in a network. In mathematical terms, a least-squares adjustment defines a best-fit solution for weighted measurements by finding a minimum for the sum of the squares of the measurement residuals. A measurement residual is the amount needed to correct a measurement for it to fit into the best-fit solution found by the least-squares adjustment (ArcGis Resource Centre, 2011).'

The method of least squares is a standard approach to the approximate solution of over determined systems, i.e., sets of equations in which there are more equations than unknowns. "Least squares" means that the overall solution minimizes the sum of the squares of the errors made in the results of every single equation.

A single observation from an existing gravity station can be used to compute the absolute gravity for a new station. However, relying on a single observation is risky, since there is no way to tell whether the measurement is correct. A second measurement from the same or another existing gravity station will confirm, or check, the value defined by the first measurement. Generally, the more measurements fixing the absolute gravity value of a station, the more reliable the value. These additional measurements are called redundant measurements.

All measurements contain some degree of error. Therefore, each measurement will compute slightly different absolute gravity value for the same gravity station. For practical reasons, there should be one absolute gravity value for a gravity station. A single, best estimate value can be derived by computing a weighted average of the additional or redundant measurements, with each weight defined by the measurement accuracy.

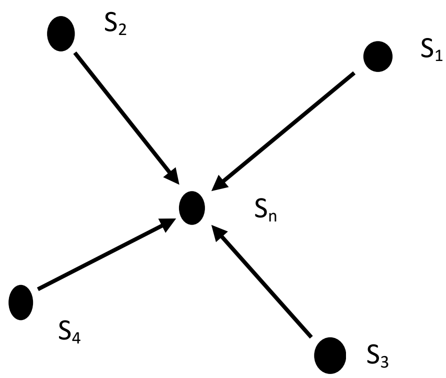

Figure 2-8: Stations referenced to a single point by application of weighted average. S_1, S_2, S_3 and S_4 are the existing absolute gravity stations that are used to compute the absolute gravity value of the new station, S_n.

Although the weighted average approach works for a single point, as illustrated in Figure 2-8 , it is not sufficient to compute the gravity values for multiple stations in a network such as the parcel fabric illustrated in Figure 2-9. A more advanced method is needed to account for the numerous possible measurement paths between the stations. The techniques and algorithms in a least-squares adjustment provide the most rigorous and widely accepted solution for processing a network of measurements and stations.

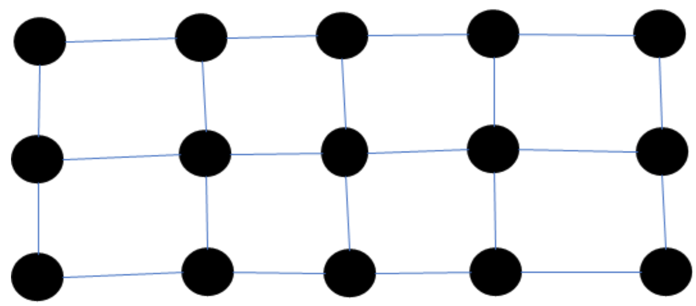

Figure 2-9: Least squares adjustment of several stations.

CHAPTER THREE

METHODOLOGY

In Section 3.1 instruments which were used in data collection are described. In Section 3.2 and Section 3.3, conditions which were followed in identifying a suitable location for setting up the new station are outlined and also procedures followed in calibrating gravimeter to ensure it measures full force of gravity are described. Procedure of data collection and recording is also explained in Section 3.4

3.1 Instruments

The instrument used for the relative gravity measurement was the Worden Sodin gravimeter model 403. It measured the difference in gravity between two stations to a resolution of 0.01 mgal with accuracy of 0.005 mgal. It is used in various field applications such as faults and geological mapping, mining and location of deeply buried materials. Worden sodin gravimeter as illustrated in Figure 3-1, uses 2C cell industrial grade batteries mainly to provide lighting to an internal lighting bulb.

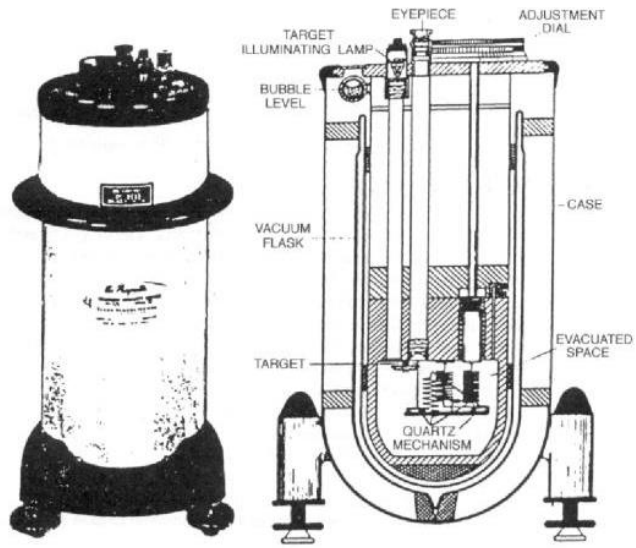

Figure 3-1: A Sketch of a Worden Sodin Gravimeter

3.2 Monumentation

‘To select a location that is suitable for establishing a gravity station, the following conditions were to be fulfilled (Boedecker, 1985);

1) Stable in terms of structural, hydrological and geological conditions. This is to ensure stability of gravity values over time since gravity is affected by density variations of the subsurface.
2) Away from highways, railroads, Electrical power supplies. Electromagnetic waves and vibrations affect functionality of gravimeters hence this condition has to be fulfilled.
3) Accessible 24 hours a day, 7 days a week.

4) Suitable for setting up gravimeters, GPS receivers, and precise leveling rods. The location has to be spacious and well leveled so as to facilitate setting up of instruments.'

Each station was established by a brass disc cemented to the ground. A code is engraved at the center of the disc to identify the station.

3.3 Calibration

Some regular checks were performed to the gravimeter to ensure that the levels and sensitivity setting are proper adjusted. These checks were performed daily before commencing data collection. The first check was to ensure that the cross level of the gravimeter was exactly in the horizontal position when its bubble was in its mid-range. This test was quite important since if the gravimeter was tipped to one side or the other, it wouldn't measure the full force of gravity. The second test was to check the sensitivity of the reading line. The reading line could be high sensitive or low sensitive which could cause uncertainties in adjusting the cross hair during the data collection. These tests were a must to ensure that the gravimeter was adjusted and will measure the gravity acceleration precisely. They can be thought of as an indicator if the gravimeter needs permanent inspections and calibration.

3.3.1 Calibration Constant

Calibration constant given for the gravimeter by the manufacturer is 0.1004 mGal/div, but this value is subject to change due to aging, usage, and vibrations due to transportation of the equipment. A new calibration constant of 0.19608 mGal/div was obtained after recording gravimeter dial readings in two IGSN-71 gravity control station within a span of 30 minutes.

The gravimeter was taken to a station of known absolute gravity value that had been referenced to an IGSN-71 station. It was leveled by rotating knobs at its base simultaneously and overlapping the bubbles. The corresponding scale value in divisions was then read. It was then taken to another station and procedure repeated. Ng'oiwa station (N 9880413 E 281852) with absolute gravity value 977581.9 mgal and Ndarugo station (N 9884816 E 284053) with absolute gravity value 977580.9 mgal, were used as the first and second reference stations respectively. Meter readings in the two stations are 436.5 dial units and 431.5 dial units respectively. The difference between known absolute values was determined and divided by difference in dial units in the two stations which was the calibration constant in mgal/scale unit, as shown in the equation below;

$$K = \frac{(G^{2nd} - G^{1st})}{(D^{2nd} - D^{1st})} \qquad (3\text{-}1)$$

Where G^{1st}, G^{2nd} and D^{1st}, D^{2nd} are the absolute gravity values and gravimeter dial units of the 1^{st} and 2^{nd} reference stations respectively. K is the calibration constant of the equipment.

3.4 Measurement

The Worden Sodin gravimeter model 403 was used to measure gravity difference between established new reference stations to the existing nearest IGSN station.

The main observation scheme that was applied in the survey was the profile method. This method was useful in controlling the gravimeter's drift and was a suitable loop since most stations were extended in one direction.

At each site three consecutive readings of the meter were recorded in less than 5 minutes. In the data processing stage, the average of these readings was taken as the unique observation of that station.

The observer's name, the date of observations, the gravity meter readings along with their recording time were all recorded precisely in a field work sheet. Any break in the observation scenario was also recorded in the field sheet, as this was important in accounting for the gravimeter drift.

The difference in gravity between the IGSN station and the new station is given by (3-2) where K is the calibration constant and δs is the difference in scale value in the two stations.

$$\delta g = K \times \delta s \tag{3-2}$$

At least three 2nd order stations which had been referenced to IGSN were used to reference the new station. These stations exist only in a catalogue thus a GPS was used to identify the stations on the ground.

CHAPTER FOUR

RESULTS AND DISCUSSION

In this chapter, various steps of data processing and analysis are outlined. In section 4.1 and 4.2, procedures for removing contributions of external factors to the measured parameters are outlined. Section 4.3 outlines the least squares adjustment by weighted average analysis process of the data, in order to come up with the absolute gravity value of the new station. Also, an overview of application of statistical indicators is analyzed in this section.

4.1 Reduction of the Observed values

4.1.1 Drift Correction

The main reason for collecting data based on the profile method was to investigate gravimeters drift. This was achieved by observing graphically the dial readings for the first leg of the loop and the return leg. This was possible by plotting the "*dial readings*" for both first and second leg as shown in Figure 4-1. It was observed that the gravimeter gave consistent dial readings in each station as the magnitude of both first and second legs were approximately equal.

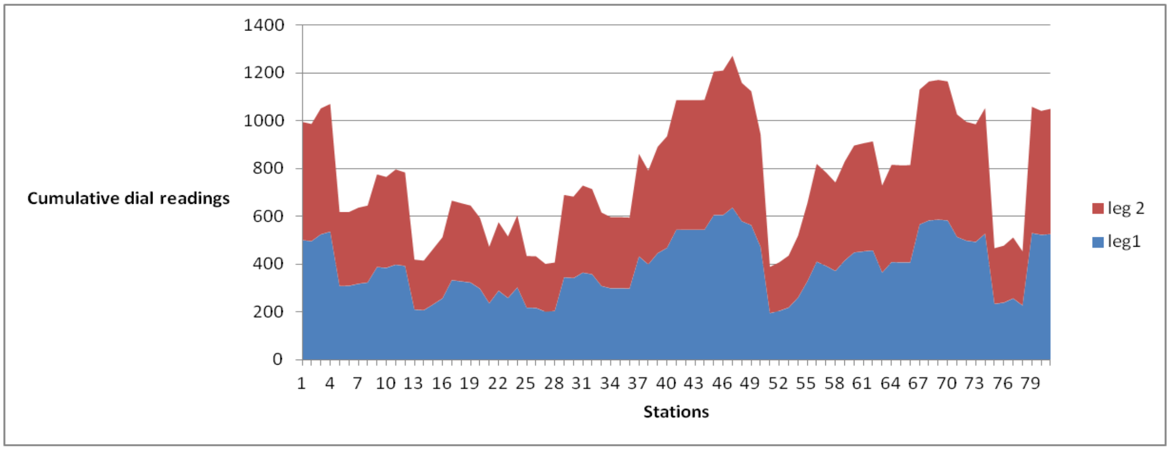

Figure 4-1: A Stacked area showing the trend of magnitude of dial readings for the first leg and second leg of gravimetric data observation**.**

Maximum dial units difference that was experienced due to drift was 0.1 units which is equivalent to 0.02 mGal. By performing weighted average on the values, this effect is further minimized hence contributing negligible error to final absolute gravity value.

4.1.2 Tidal Correction

'Variations in the configuration of the Earth, Moon, and Sun cause the lunar-solar attraction at a particular point on the Earth to vary as much as 280 microgals. This attraction has significant effect on gravity observation on the earth's surface.

According to Heikinen, (Heikkinen, 1978), that if φ denotes the geodetic latitude, then the time average of the vertical component of the tidal force on the surface of the ellipsoid is;

$$(F_{ver})_{aver} = -15.14 + 45.62\cos 2\varphi + 0.072\,\varphi\ \mu Gal \qquad (4\text{-}1)$$

This average is symmetric with respect to the equator, so in general we have;'

$$(F_{ver})_{aver} = -15.14 + 45.62\cos 2\varphi + 0.07/\sin 2\varphi/\ \mu Gal \qquad (4\text{-}2)$$

Comparing the $(F_{ver})_{aver}$ of two reference points as in the case of Kajiado county; reference station 1 (Latitude = -1.8289) and reference station 2 (Latitude = -1.875), the $(F_{ver})_{aver}$ of reference station 1 and reference station 2 was found to be 60.7091μGal and 60.7065μGal respectively. The difference in tidal effect between the two stations is about 0.0026 μGal, this value is small to be detected by the Worden Sodin gravimeter. Part of this effect is also eliminated by performing drift correction. Thus, from these results it was assumed that the tidal effect was uniform on gravimeter readings on each day, since data for a particular day were taken within a span of 2 hours and locations of reference points were approximately within a radius of 3 km and this effect is eliminated during calculations.

4.1.3 Earth's Magnetization

'A magnetic field represents the physical field, which influences gravimetric instruments (Pálinkáš et al., 2005). Earth's magnetic field reaches values 48 μT (vertical component 44 μT and horizontal component 20 μT).

An artificially excited magnetic field (sources inside building, transmitters and so on) should be also meaningful sources of errors. There is possibility to expect big changes of the magnetic field nearby artificial sources. The elimination of the magnetic field influences is usually secured by an orientation of the gravimeter to the same azimuth at the gravity station. For instant, sensitivity to the magnetic field of the gravimeter La-coste and Romberg (LCR G No. 137) reaches values about 0.5 μGal/μT in the vertical as well as in the horizontal direction.'

A fixed orientation with respect to the local magnetic north was observed throughout the measuring campaign in order to minimize possible beam magnetization.

4.2 Updating Gravity values of the Reference Stations

4.2.1 Conversion from 1967 Geodetic reference system to 1980 geodetic reference system.

The gravity values in the catalogue of gravity measurements, Swain & Khan (1978), were computed based on the 1967 Geodetic Gravity formula yet in 1979 a new gravity formula was adopted by the International Union of Geodesy and Geophysics as discussed below;

'The International Union of Geodesy and Geophysics, recommended changes on the Geodetic Reference System 1967 adopted at the XIV General Assembly of IUGG, Lucerne, 1967. This is because it no longer represents the size, shape, and gravity field of the Earth to an accuracy adequate for many geodetic, geophysical, astronomical and hydrographic applications and considering that more appropriate values are now available, the union recommends;

a) That the Geodetic Reference System 1967 be replaced by a new Geodetic Reference System 1980, also based on the theory of the geocentric equipotential ellipsoid, defined by the following conventional constants:

i. Equatorial radius of the Earth: a = 6,378,137 m,

ii. Geocentric gravitational constant of the Earth (including the atmosphere):

$$GM = 3986\ 005 \times 108\ m^3\ s^{-2},$$

iii. Dynamical form factor of the Earth, excluding the permanent tidal deformation:

$$J_2 = 108\ 263 \times 10^{-8},$$

iv. Angular velocity of the Earth: $\omega = 7292\ 115 \times 10^{-11}$ rad s^{-1},

b) That the same computational formulas, adopted at the XV General Assembly of IUGG in Moscow 1971 and published by IAG, be used as for Geodetic Reference System 1967, and

c) That the minor axis of the reference ellipsoid, defined above, be parallel to the direction defined by the Conventional International Origin, and that the primary meridian be parallel to the zero meridian of the BIH adopted longitudes". (Moritz, 1979, sec.2).'

$$\text{Gravity Formula 1980 } (\Upsilon) = \Upsilon e\ (1 + f\ sin^2\varphi - f4\ sin^2 2\ \varphi)$$

$$= 9.780\ 327\ (1 + 0.005\ 3024\ sin^2\varphi - 0.000\ 0058\ sin^2 2\ \varphi)\ \text{m}\ s^{-2} \quad (4\text{-}3)$$

It has only an accuracy of 1 μms^{-2} = 0.1 mGal.

It can, however, be used for converting gravity anomalies from the International Gravity Formula (1930) to the Gravity Formula 1980:

$$\Upsilon 1980 - \Upsilon 1930 = (-16.3 + 13.7\, sin^2 \varphi)\ \text{mGal} \quad (4\text{-}4)$$

Also, for converting gravity anomalies from the international Gravity Formula (1967) to the Gravity Formula 1980:

$$\Upsilon 1980 - \Upsilon 1967 = (0.8316 + 0.0782\, sin^2 \varphi - 0.0007\, sin^4 \varphi)\ \text{mGal} \quad (4\text{-}5)$$

Where φ is the latitude in radians

4.2.2 Removal of the Honkasalo Term

'IGSN-71 values include a correction of the Honkasalo term (Honkasalo, 1964) which removes the average part of the tidal force. This correction term has been deemed inappropriate (Heikkinen, 1979) because of resulting errors in calculation of the geoid from gravity values corrected with the Honkasalo term. Therefore, following the recommendations of the International Association of Geodesy (Uotila, 1980), the Honkasalo term, Δg_h, will be removed from all the measured gravity values that had been referenced to the IGSN71 station.' This will be done by adding a latitudinal varying correction in milligals, given by (4-6);

$$\Delta gh = 0.0371(1 - 3sin^2 \varphi) \quad (4\text{-}6)$$

Where φ is the latitude south or north of the gravity station and it is in radians.

The two corrections were performed to the gravity values at each reference station and results are as tabulated in Table 4-1.

Table 4-1: Gravity values contributed by the Honkasalo term and difference in geodetic reference system with respect to latitude, where; I, II, III are the 1st, 2nd, and 3rd reference stations respectively.

County	Reference Station	Latitude	Honkasalo term (mgal)	1967 to 1980 Geodetic reference system (mgal)	Updated Absolute Gravity Value (mgal)
Kajiado County	I	-1.8389	0.8316805	0.0369854	977563.2687
	II	-1.8750	0.8316837	0.0369808	977586.1687
	III	-1.90350	0.8316863	0.0369772	977588.3687
Narok County	I	-1.1040	0.8316290	0.0370587	977461.2687
	II	-1.0980	0.8316287	0.0370591	977467.0687
	III	-1.1040	0.8136290	0.0370587	977471.1687
Nakuru County	I	-0.2810	0.8316019	0.0370973	977472.4687
	II	-0.2720	0.8136018	0.0370974	977458.8687
	III	-0.2630	0.8136018	0.0370975	977436.8687
Bomet County	I	-0.7062	0.8316119	0.0370831	977503.7687
	II	-0.7116	0.8316121	0.0370828	977514.0687
	III	-0.7604	0.8316138	0.0370804	977508.6687
Kericho County	I	-0.3481	0.8316029	0.0370959	977409.7687
	II	-0.3780	0.8316034	0.0370952	977421.1687
	III	-0.4159	0.8316041	0.0370941	977435.5687

Baringo County	I	0.4835	0.8316056	0.0370921	977451.3687
	II	0.4971	0.8316059	0.0370916	977423.2687
	III	0.4980	0.8316059	0.0370916	977451.3687
El-Geiyo Marakwet County	I	0.6725	0.8316108	0.0370847	977410.2687
	II	0.6617	0.8316104	0.0370852	977400.4687
	III	0.6584	0.8316103	0.0370853	977404.2687
Trans-Nzoia County	I	1.0119	0.8316243	0.0370653	977479.4687
	II	1.1077	0.8316292	0.0370584	977493.6687
	III	1.1375	0.8316308	0.0370561	977489.3687
Uasin-Gishu County	I	0.4900	0.8316057	0.0370919	977453.9687
	II	0.5027	0.8316060	0.0370914	977453.4687
	III	0.4583	0.8316050	0.0370929	977456.7687
Kisii County	I	-0.7063	0.8316119	0.0370831	977516.4687
	II	-0.6367	0.8316097	0.0370863	977552.9687
	III	-0.6584	0.8316103	0.0370853	977560.8687
Kisumu County	I	-0.0959	0.8316002	0.0370997	977591.3687
	II	-0.0452	0.8316000	0.0370999	977592.2687
	III	-0.1203	0.8316003	0.0370995	977593.3687
Homa Bay County	I	-0.5490	0.8316072	0.0370898	977621.6687
	II	-0.5165	0.8316064	0.0370910	977644.6687
Migori County	I	-1.1145	0.8316296	0.0370579	977604.7687
	II	-1.2292	0.8316360	0.0370488	977549.2687

Nandi County	I	0.2043	0.8316010	0.0370986	977440.3687
	II	0.2034	0.8316010	0.0370986	977445.3687
	III	0.1971	0.8316009	0.0370987	977455.9687
Vihiga County	I	0.1049	0.8316003	0.0370996	977542.9687
	II	0.0751	0.8316001	0.0370998	977532.6687
	III	0.0516	0.8316000	0.0370999	977514.8687
Kakamega County	I	0.2695	0.8316017	0.0370975	977555.4687
	II	0.2360	0.8316013	0.0370981	977550.7687
	III	0.2813	0.8316019	0.0370973	977551.8687
Bungoma County	I	0.5707	0.8316078	0.0370890	977574.0687
	II	0.5436	0.8316070	0.0370900	977574.3687
	III	0.5860	0.8316082	0.0370884	977574.4687
Busia County	I	0.4514	0.8316049	0.0370931	977653.6687
	II	0.4831	0.8316056	0.0370921	977655.8687
	III	0.4659	0.8316052	0.0370926	977640.1687
Siaya County	I	0.0606	0.8316001	0.0370999	977624.0687
	II	0.0525	0.8316001	0.0370999	977618.3687
	III	0.0859	0.8316002	0.0371000	977627.5687
Nyamira County	I	-0.5616	0.8316075	0.0370893	977474.1687
	II	-0.5923	0.8316084	0.0370881	977485.5687
	III	-0.5390	0.8316069	0.037090	977468.1687
Kiambu County	I	-1.0813	0.8316278	0.0370604	977581.7687

II	-1.0415	0.8316258	0.0370632	977582.7687

Finally, after ensuring that dial readings were clean from drift and that gravity values of the reference stations are updated, the difference in gravity (δg) between the new station and the IGSN station was calculated based on the equation (4-7) where K is the calibration constant and (δs) is the difference in scale value in the two stations.

$$\delta g = K \times (\delta s) \tag{4-7}$$

This value (δg) was added to the reference values to obtain the possible value of the new station. Since three reference values were used, three possible values of the new station were obtained and these values were slightly different due to errors associated with them. To obtain the most probable absolute gravity value of the new station, least squares adjustment by weighted average was performed to the three values and statistical analysis was done to assess the quality of adjustment.

4.3 Least Squares adjustment by weighted average

The difference in gravity (δg) between the IGSN station and the new station is given by the equation (4-7). Since at most three stations were used to reference the new station, three probable absolute gravity values were obtained representing the new station and these values differ due to errors associated with them. For example;

$$g_A = \Delta g_{01} + g_1 \pm S_{01}$$

$$g_A = \Delta g_{02} + g_2 \pm S_{02}$$

$$g_A = \Delta g_{03} + g_3 \pm S_{03}$$

Where;

g_A = Probable gravity value of the new station with respect to a reference station.

g_{01} = Difference in gravity between the new station and the 1st reference station.

g_{02} = Difference in gravity between the new station and the 2nd reference station.

g_{03} = Difference in gravity between the new station and the 3rd reference station.

g_1 = Absolute gravity of the 1st reference station.

g_2 = Absolute gravity of the 2nd reference station.

g_3 = Absolute gravity of the 3rd reference station.

S_{01} = Error associated with measuring and referencing 1st station to the new station.

S_{02} = Error associated with measuring and referencing 2nd station to the new station.

S_{03} = Error associated with measuring and referencing 3rd station to the new station.

In order to find the absolute gravity value representing the new station from the three most probable values, least squares adjustment by weighted average was applied.

Thus, the most probable gravity value (g_w) of the new station was obtained by the weighted mean method as follows;

$$g_w = \frac{\sum g_i w_i}{\sum w_i} \qquad (4\text{-}8)$$

Where;

w_i = weight $= \frac{1}{{s_i}^2}$ = weight given to each probable absolute gravity value.

g_i = probable absolute gravity value of the new station with respect to a reference station

s_i= standard deviation of g_i

And the standard deviation associated with the most probable absolute gravity value of the new station was given by;

$$S_{g_w} = \sqrt{\frac{\sum wv^2}{(\sum w)(n-1)}} \tag{4-9}$$

Where;

v = residue; e.g $g_w - g_A$

n = number of terms in the sample; for this case it was 3.

w= weight given to each probable absolute gravity value.

Hence the most probable absolute gravity value of the new station is represented as;

$$g_w \pm s_w \tag{4-10}$$

Before the adjustment results were detailed, the priori indicators, that determine the adjustment quality, were analyzed. These indicators are priori error estimates; the residuals, the normalized residuals (standardized residuals), and the standard error of unit weight (variance of unit weight).

The residuals are the amounts by which the adjusted values have been shifted in the adjustment. They are the difference between the observed values and the adjusted values. Having approximately 50% of the residuals as negative and approximately 50% as positive is an indication of normally distributed data set.

The normalized residuals are the residuals divided by the priori standard error as shown by equation (2-19). The normalized residuals indicate outliers. A normalized residual of

2.0 indicates that the residual is twice as large as it should be based on the priori errors. If the priori errors are realistic and the standard error of unit weight is close to 1; statistical outliers will have value of 3 or more.

The standard error of unit weight indicates the degree with which the data and the priori errors agree. The ideal, standard error of unit weight equal to 1.0, indicates that the quality of the data exactly fits the model (the adjusted value). The standard error of unit weight should approach 1.0 or less. Exceeding 1.0 by more than a very small amount indicates problem with the data, or overly optimistic error estimates, i.e. the a priori standard error are too small. On the other hand, a very small standard error of unit weight indicates pessimistic priori errors or extremely good data. If estimates are pessimistic, i.e. if they can be realistically reduced, they should be. Pessimistic priori errors can hide data with problems. When the priori errors are too large; the normalized residuals will be smaller than they should be, and data that might be an outlier with realistic error estimates can be hidden.

The main software that was used to do calculations was Microsoft excel. Results of adjustment and associated statistical indicators are tabulated in Table 4-2 below.

Table 4-2: Probable absolute gravity values and adjusted absolute gravity values of the new stations together with their associated statistical indicators. I, II, and III are 1st, 2nd, and 3rd reference stations respectively.

County/ Reference Station		Possible absolute gravity value of the new station (mgal)	Adjusted absolute gravity value of the new station (mgal)	residues	Normalized residues	Standard error of unit weight
Kajiado County	I	977574.3536	977574.4461	0.093	0.008	0.009
	II	977574.4611		-0.015	-0.001	
	III	977574.5687		-0.123	-0.009	
Narok County	I	977465.5547	977465.6076	0.053	0.012	0.022
	II	977465.6025		0.005	0.003	
	III	977465.7597		-0.152	-0.028	
Bomet County	I	977508.7919	977508.54	-0.252	-0.051	0.063
	II	977508.9097		-0.370	-0.072	
	III	977508.5395		0.001	0.004	
Kericho County	I	977418.6613	977418.7212	0.060	0.007	0.005
	II	977418.7258		-0.005	-0.002	
	III	977418.6914		0.030	-0.001	
Nakuru County	I	977472.6642	977472.643	-0.001	-0.007	0.054
	II	977472.4856		0.157	0.075	
	III	977472.4848		0.158	0.012	
Baringo County	I	977425.683	977425.4968	-0.186	-0.007	0.0052
	II	977425.4953		0.002	0.001	
	III	977425.5124		-0.02	-0.001	
	I	977407.9108	977407.7915	-0.119	-0.051	0.059

El-Geiyo marakwet County	II	977407.6792		0.112	0.015	
	III	977407.5797		0.212	0.065	
Trans-Nzoia County	I	977484.2684	977484.3359	0.068	0.014	0.016
	II	977484.4955		-0.160	-0.018	
	III	977484.3618		-0.026	-0.005	
Uasin-Gishu County	I	977455.8813	977455.835	-0.046	-0.024	0.0856
	II	977455.5976		0.237	0.113	
	III	977455.8675		-0.032	-0.036	
Kisii County	I	977541.7389	977541.6413	-0.098	-0.004	0.0074
	II	977541.5714		0.069	0.006	
	III	977541.7814		-0.140	-0.007	
Kisumu County	I	977592.4857	977592.3788	-0.107	-0.097	0.0917
	II	977592.3760		0.003	0.022	
	III	977592.4544		-0.076	-0.084	
Homa Bay County	I	977624.9315	977624.9226	-0.009	-0.003	0.012
	II	977624.5852		0.337	0.017	
Migori County	I	977604.1125	977604.1124	0.020	0.019	0.068
	II	977603.1716		-0.483	-0.095	
Nandi County	I	977440.4244	977440.4245	8.548	-0.001	0.047
	II	977440.725		-0.301	0.066	
	III	977440.6367		-0.212	0.014	
Vihiga County	I	977514.9762	977514.5232	-0.453	-0.016	0.012
	II	977514.4277		0.096	0.005	
	III	977514.5232		3.567	-0.001	
Kakamega County	I	977544.9546	977544.7542	-0.200	-0.019	0.022
	II	977544.6222		0.132	0.022	
	III	977544.8373		-0.083	-0.012	

Bungoma County	I	977566.9107	977566.8581	-0.053	-0.007	0.082
	II	977566.8651		-0.007	0.001	
	III	977566.7903		0.068	0.009	
Busia County	I	977644.4817	977644.6084	0.127	0.014	0.024
	II	977644.3133		0.295	0.026	
	III	977644.6841		-0.076	-0.017	
Siaya County	I	977624.4069	977624.4109	0.004	0.012	0.071
	II	977624.4093		0.002	0.001	
	III	977624.6944		-0.283	-0.099	
Nyamira County	I	977472.5477	977472.5751	0.027	0.017	0.035
	II	977472.7256		-0.150	-0.012	
	III	977472.7767		-0.202	-0.044	
Kiambu County	I	977583.7629	977583.6020	-0.161	-0.082	0.062
	II	977583.5756		0.026	0.033	

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

In section 5.1 and section 5.2, conclusion of the findings is outlined and recommendation of what should be done is suggested.

5.1 Conclusion

The research was carried out successfully, relative gravity measurements were made using the Worden Sodin Gravimeter at reference stations in the respective counties. These values were used to compute the gravity values of the new station.

Accessible locations were selected at the respective county headquarters compound. Several criterions were considered when selecting the locations. Firstly, it was supposed to be stable in terms of; structural, hydrological and geological conditions. This was to ensure stability of gravity values over time because gravity is affected by density variation of subsurface materials. Secondly, a location away from; highways, railroads and electrical power supplies was selected. This was to avoid interferences from electromagnetic signals and vibrations which majorly affects the operation of relative gravimeters. Finally, apart from ensuring that the station location was accessible throughout the day, the space and monumentation of the station was designed so as to ensure proper setting up of; gravimeters, GPS receivers and precise leveling rods.

Based on the relative gravity data collected, the absolute gravity values of the new stations were computed. These values were obtained with minimal standard deviations. Residues at all stations obeyed the approximately 50% negative values and approximately 50%

positive values rule, and also normalized residues were below 3.0 at all stations indicating that the adjustment process was excellent. Standard error of unit weight at all stations was below 1.0 thus confirming that the adjustment process was excellent.

The gravity values obtained for the new stations and their respective coordinates are shown in the summarized Table 5-1 below.

Table 5-1: Absolute gravity values and coordinates of the new stations

County	Absolute gravity value (mGal)	Standard Deviation (mGal)	Easting	Northing
Kajiado	977574.4461	0.0423	9795389	252289
Narok	977465.6076	0.0296	9880963	818767
Bomet	977508.54	0.0095	9923850	735309
Kericho	977418.7212	0.0117	9959341	754630
Nakuru	977472.643	0.0098	9967788	173795
Baringo	977425.4968	0.0110	54407	805524
El-Geiyo Marakwet	977407.7915	0.1090	74256	779133
Trans-Nzoia	977484.3359	0.0526	112056	722521
Uasin-Gishu	977455.835	0.0646	57968	753376
Kisii	977541.6413	0.0665	9924949	697283

Kisumu	977592.3788	0.0112	9988504	695442
Homa Bay	977624.9226	0.0388	9940730	663100
Migori	977604.1124	0.0083	9882167	664424
Nandi	977440.4245	0.0036	734412	22499
Vihiga	977514.5232	0.0042	691873	8782
Kakamega	977544.7542	0.0930	695636	30927
Bungoma	977566.8581	0.035	673548	63240
Busia	977644.6084	0.0906	622232	51254
Siaya	977624.4109	0.0710	643039	6878
Nyamira	977472.5751	0.0116	9938107	715225
Kiambu	977583.7629	0.0210	9885249	285615

Monumentation of the new station was done by cementing a brass disc on the ground. Each brass disc has a code on top (e.g. KIGSN 001) to provide extra identification of the new station.

5.2 Recommendation

Further survey is required to set up other new gravity stations in the whole country. Also, this new gravity network has accuracy of 0.15 mGal hence it is categorized as the 3rd order network, more research is encouraged to improve the accuracy. Finally, researches on climate change and tectonic movement monitoring is encouraged so as to utilize data of this new network.

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APPENDICES

Appendix I: Gravity measurements and new base station data

1A: Kajiado County and Narok County

	KAJIADO COUNTY				NAROK COUNTY			
	1ST REF	2ND REF	3RD REF	NEW STATION	1ST REF	2ND REF	3RD REF	NEW STATION
EASTING	254336	252627	252798	252289	821941	81709	813920	818767
NORTHING	9796593	9792598	9789445	9795389	9877818	9878487	9877826	9880963
ABSOLUTE GRAVITY VALUE (mGal)	977562.4	977585.3	977587.5		977460.4	977466.2	977470.3	
1967-1980	0.831680	0.831684	0.831686	0.831680	0.8316290	0.8316287	0.8136290	
HONKASALO TERM	0.036987	0.036981	0.036977	0.036987	0.03705868	0.03705913	0.03705868	
UPDATED GRAVITY VALUE (mGal)	977563.2687	977586.1687	977588.3687		977461.2687	977467.0687	977471.1687	
WEIGHTED DIAL READING (Div)	439.854 ±1.174	556.095 ±0.627	566.767 ±1.89	496.387 ±0.054	288.055 ±0.274	317.391 ±0.284	337.500 ±0.1	309.914 ±1.107
POSSIBLE ABSOLUTE GRAVITY VALUE OF NEW STATION (mGal)	977574.3536 ±10.9519	977574.4611 ±11.5652	977574.5687 ±13.6364		977465.5547 ±4.2398	977465.6025 ±1.4663	977465.7597 ±5.3476	
ABSOLUTE GRAVITY OF NEW STATION (mGal)				**977574.4461**				**977465.6076**
STANDARD DEVIATION				**0.0423**				**0.0296**
RESIDUES	0.093	-0.015	-0.123		0.053	0.005	-0.152	
NORMALIZED RESIDUES	0.008	-0.001	-0.009		0.012	0.003	-0.028	
STANDARD ERROR OF UNIT WEIGHT	0.0088				0.022			

1B: Nakuru County and Baringo County

	NAKURU COUNTY				BARINGO COUNTY			
	1ST REF	2ND REF	3RD REF	NEW STATION	1ST REF	2ND REF	3RD REF	NEW STATION
EASTING NORTHING	174605 9968900	174705 9969298	175206 9969896	173795 9967788	807094 53503	805487 55008	803595 55106	805524 54407
ABSOLUTE GRAVITY VALUE (mGal)	977471.6	977469.5	977458		977450.5	977422.4	977450.5	
1967-1980	0.831601881	0.813601833	0.813601762		0.813605569	0.813605886	0.813605908	
HONKASALO TERM	0.037097323	0.037097391	0.037097492		0.037092074	0.037091622	0.037091592	
UPDATED GRAVITY VALUE (mGal)	977472.4687	977470.3687	977458.8687		977451.3687	977423.2687	977451.3687	
WEIGHTED DIAL READING	331.580 ±0.026	321.679 ±0.219	263.033 ±1.102	332.475 ±0.085	367.230 ±0.168	224.877 ±0.165	368.100 ±0.5	236.233 ±0.122
POSSIBLE GRAVITY VALUE OF NEW STATION (mGal)	977472.6442 ±0.1813	977472.4856 ±2.0921	977472.4848 ±13.4515		977425.683 ±25.3718	977425.4953 ±2.2003	977425.5124 ±25.5404	
ABSOLUTE GRAVITY OF NEW STATION (mGal)				**977472.643**				**977425.4968**
STANDARD DEVIATION				**0.0098**				**0.0114**
RESIDUES	-0.001	0.157	0.158		-0.186	0.002	-0.02	
NORMALIZED RESIDUES	-0.007	0.075	0.012		-0.007	0.001	-0.011	
STANDARD ERROR OF UNIT WEIGHT	0.054				0.0052			

1C: Kisumu County and Homabay County

	KISUMU COUNTY				HOMA BAY COUNTY			
	1ST REF	2ND REF	3RD REF	NEW STATION	1ST REF	2ND REF	3RD REF	NEW STATION
EASTING	705293	700895	704892	695442	661692	664899		663100
NORTHING	9989395	9995002	9986696	9988504	9939299	9942892		9940730
ABSOLUTE GRAVITY VALUE (mGal)	977590.5	977591.4	977592.5		977620.8	977643.8		
1967-1980	0.831600219	0.83160049	0.83160034		0.831607179	0.831606355		
HONKASALO TERM	0.037099688	0.03709931	0.03709959		0.037089782	0.037090956		
UPDATED GRAVITY VALUE (mGal)	977591.3687	977592.2687	977593.3687		977621.6687	977644.6687		
WEIGHTED DIAL READING	538.573 ±0.177	543.723 ±0.015	548.933 ±0	544.270 ±0.205	585.634 ±0.016	704.700 ±0		602.274 ±0.357
POSSIBLE GRAVITY VALUE OF NEW STATION (mGal)	977592.4857 ±1.1058	977592.376 ±0.1239	977592.454 ±0.9054		977624.9315 ±3.2241	977624.5852 ±19.8382		
ABSOLUTE GRAVITY OF NEW STATION				**977592.3788**				**977624.9226**
STANDARD DEVIATION				**0.0112**				**0.0388**
RESIDUES	-0.107	0.003	-0.076		-0.009	0.337		
NORMALIZED RESIDUES	-0.097	0.022	-0.084		-0.003	0.017		
STANDARD ERROR OF UNIT WEIGHT		0.0917				0.012		

1D: El-Geiyo Marakwet County and Trans Nzoia County

	EL GEIYO MARAKWETCOUNTY				TRANS NZOIA COUNTY			
	1ST REF	2ND REF	3RD REF	NEW STATION	1ST REF	2ND REF	3RD REF	NEW STATION
EASTING	779092	778692	778300	779133	723406	723700	724099	722521
NORTHING	74403	73208	72842	74256	111914	122510	125806	112056
ABSOLUTE GRAVITY VALUE (mGal)	977409.4	977399.6	977403.4		977478.6	977492.8	977488.5	
1967-1980	0.813610773	0.81361043	0.831610326		0.831624389	0.831629225	0.83160818	
HONKASALO TERM	0.037084667	0.037085156	0.037085304		0.037065288	0.037058405	0.03705613	
UPDATED GRAVITY VALUE (mGal)	977410.2687	977400.4687	977404.2687		977479.4687	977493.6687	977489.368	
WEIGHTED DIAL READING	228.978 ±0.025	180.180 ±0.033	200.067 ±0.808	216.953 ±0.404	320.520 ±0.235	391.782 ±0.223	370.533 ±0.252	344.998 ±0.327
POSSIBLE GRAVITY VALUE OF NEW STATION (mGal)	977407.9108 ±2.3309	977407.6792 ±7.123	977407.5797 ±3.2757		977484.268 ±4.7419	977484.4955 ±9.0616	977484.3618 ±4.9466	
ABSOLUTE GRAVITY OF NEW STATION (mGal)				**977407.7915**				**977484.3359**
STANDARD DEVIATION				**0.109**				**0.0526**
RESIDUES	-0.119	0.112	0.212		0.068	-0.160	-0.026	
NORMALIZED RESIDUES	-0.051	0.015	0.065		0.014	-0.018	-0.005	
STANDARD ERROR OF UNIT WEIGHT		0.0593				0.0164		

1E: Uasin Gishu Countv and Kisii Countv

	UASIN GISHU COUNTY				KISII COUNTY			
	1ST REF	2ND REF	3RD REF	NEW STATION	1ST REF	2ND REF	3RD REF	NEW STATION
EASTING	755791	782610	751409	753376	697195	695295	694292	697283
NORTHING	54203	55607	50696	57968	9921894	9929592	9927193	9924949
ABSOLUTE GRAVITY VALUE (mGal)	977453.1	977452.6	977455.9		977515.6	977552.1	977560	
1967-1980	0.831605719	0.83160602	0.831605003		0.831611883	0.831609656	0.831610326	
HONKASALO TERM	0.03709186	0.037091432	0.037092879		0.037083088	0.037086256	0.037085304	
UPDATED GRAVITY VALUE (mGal)	977453.9687	977453.4687	977456.7687		977516.4687	977552.9687	977560.8687	
WEIGHTED DIAL READING	298.150 ±0.061	297.047 ±0.076	312.500 ±0.3	307.904 ±0.022	302.744 ±0.564	489.748 ±0.288	428.967 ±0.833	432.622 ±0.617
POSSIBLE GRAVITY VALUE OF NEW STATION (mGal)	977455.8813 ±1.89	977455.5976 ±2.104	977455.8675 ±0.894		977541.7389 ±24.9619	977541.5714 ±11.2589	977541.7814 ±18.8551	
ABSOLUTE GRAVITY OF NEW STATION (mGal)				**977455.835**				**977541.9413**
STANDARD DEVIATION				**0.0646**				**0.0665**
RESIDUES	-0.046	0.237	-0.032		-0.098	0.069	-0.140	
NORMALIZED RESIDUES	-0.024	0.113	-0.036		-0.004	0.006	-0.007	
STANDARD ERROR OF UNIT WEIGHT	0.0856				0.0074			

1F: Bomet County and Kericho County

	BOMET COUNTY				KERICHO COUNTY			
	1ST REF	2ND REF	3RD REF	NEW STATION	1ST REF	2ND REF	3RD REF	NEW STATION
EASTING	727900	732799	731594	735309	749616	753016	747206	754630
NORTHING	9921893	9921294	9915897	9923850	9961495	9958187	9953993	9959341
ABSOLUTE GRAVITY VALUE (mGal)	977502.9	977513.2	977507.8		977408.9	977420.3	977434.7	
1967-1980	0.8316119	0.8316121	0.8316138		0.8316029	0.8316034	0.8316041	
HONKASALO TERM	0.03708309	0.03708283	0.03708040		0.03709589	0.03709516	0.03709414	
UPDATED GRAVITY VALUE (mGal)	977503.7687	977514.0687	977508.6687		977409.7687	977421.1687	977435.5687	
WEIGHTED DIAL READING (Div)	361.812 ±1.232	413.741 ±0.949	388.089 ±0.265	387.430 ±0.187	163.854 ±0.62	221.665 ±0.602	439.100 ±0.7	209.206 ±0.023
POSSIBLE GRAVITY VALUE OF NEW STATION (mGal)	977508.7919 ±4.968	977508.9097 ±5.0997	977508.5395 ±0.1511		977418.6613 ±8.7849	977418.7258 ±2.4165	977418.6914 ±44.5264	
ABSOLUTE GRAVITY OF NEW STATION (mGal)				**977508.54**				**977418.7212**
STANDARD DEVIATION				**0.0095**				**0.0117**
RESIDUES	-0.252	-0.370	0.001		0.060	-0.005	-0.030	
NORMALIZED RESIDUES	-0.051	-0.072	0.004		0.007	-0.002	-0.0001	
STANDARD ERROR OF UNIT WEIGHT	0.0626				0.005			

1G: Migori County and Nyamira County

	MIGORI COUNTY				NYAMIRA COUNTY			
	1ST REF	2ND REF	3RD REF	NEW STATION	1ST REF	2ND REF	3RD REF	NEW STATION
EASTING	661803	664111		664424	715792.7	713298.3	713500.	
NORTHING	9876774	9864091		9882167	9937890.6	9934496.1	9940390.7	
ABSOLUTE GRAVITY VALUE (mGal)	977603.9	977548.4			977473.3	977484.7	977467.3	
1967-1980	0.831629585	0.831635987			0.831607513	0.831608357	0.831606920	
HONKASALO TERM	0.037057893	0.037048781			0.037089307	0.037088106	0.03709015	
UPDATED GRAVITY VALUE (mGal)	977604.7687	977549.2687			977474.1687	977485.5687	977468.1687	
WEIGHTED DIAL READING	563.119 ±0.4014	304.868 ±0.019		579.773 ±0.438	241.367 ±0.1	298.6 ±0.133	209.599 ±0.01	233.100 ±0.067
POSSIBLE GRAVITY VALUE OF NEW STATION (mGal)	977604.1125 ±0.6604	977603.172 ±53.2441			977472.5477 ±1.6021	977472.7256 ±12.6863	977472.7767 ±4.5520	
ABSOLUTE GRAVITY OF NEW STATION (mGal)	**977604.1124**				**977472.5751**			
STANDARD DEVIATION	**0.0083**				**0.0116**			
RESIDUES	-0.001	0.9408			0.027	-0.150	-0.202	
NORMALIZED RESIDUES	-0.0002	0.0177			0.017	-0.0119	-0.0443	
STANDARD ERROR OF UNIT WEIGHT	0.0125				0.0346			

1H: Nandi County and Vihiga County

	NANDI COUNTY				VIHIGA COUNTY			
	1ST REF	2ND REF	3RD REF	NEW STATION	1ST REF	2ND REF	3RD REF	NEW STATION
EASTING	22596.8	22496.7	21799.5		11599.86	8304.56	5705.95	
NORTHING	735699.5	731891.4	728094.5		691399.3	691098.9	691700.1	
ABSOLUTE GRAVITY VALUE (mGal)	977439.5	977444.5	977455.1		977542.1	977531.8	977514	
1967-1980	0.831600994	0.831600986	0.831600925		0.831600262	0.831600134	0.831600063	
HONKASALO TERM	0.037098585	0.037098597	0.037098683		0.037099627	0.037099809	0.03709991	
UPDATED GRAVITY VALUE (mGal)	977440.3687	977445.3687	977455.9687		977542.9687	977552.6687	977514.8687	
WEIGHTED DIAL READING	193.583 ±0.05	217.550 ±0.083	272.060 ±0.0539	193.867 0	470.100 ±0.0577	420.367 ±0.1	329.100 ±0.116	327.338 ±0.0179
POSSIBLE GRAVITY VALUE OF NEW STATION (mGal)	977440.4244 ±0.075	977440.725 ±4.587	977440.6367 ±15.1447		977514.9762 ±27.6503	977514.4277 ±18.018	977514.5232 ±0.3457	
ABSOLUTE GRAVITY OF NEW STATION (mGal)				**977440.4245**		**977514.5232**		
STANDARD DEVIATION				**0.0036**		**0.0042**		
RESIDUES	8.548	-0.301	-0.212		-0.453	0.095	3.567	
NORMALIZED RESIDUES	0.001	0.066	-0.014		-0.016	0.005	0.001	
STANDARD ERROR OF UNIT WEIGHT		0.0473				0.0222		

1I: Bungoma County and Busia County

	BUNGOMA COUNTY				BUSIA COUNTY			
	1ST REF	2ND REF	3RD REF	NEW STATION	1ST REF	2ND REF	3RD REF	NEW STATION
EASTING	673802.3	672801.3	671074.8		626602	626401	630497	
NORTHING	63103.12	60106.37	64794.11		49903.18	53407.64	51506.82	
ABSOLUTE GRAVITY VALUE (mGal)	977573.2	977573.5	977573.6		977652.8	977655	977639.3	
1967-1980	0.831607758	0.831607039	0.83160818		0.831604854	0.831605559	0.831605171	
HONKASALO TERM	0.037088958	0.037089982	0.037088358		0.037093092	0.037092088	0.03709264	
UPDATED GRAVITY VALUE (mGal)	977574.0687	977574.3687	977574.4687		977655.6687	977655.8687	977640.1687	
WEIGHTED DIAL READING	451.647 ±0.0402	453.409 ±0.0702	454.301 ±0.0667	415.141 ±0.0144	612.940 ±0.0609	625.019 ±0.0164	543.057 ±0.0659	566.086
POSSIBLE GRAVITY VALUE OF NEW STATION (mGal)	977566.9107 ±7.0707	977566.8651 ±7.4121	977566.7903 ±7.5847		977644.4817 ±9.0749	977644.3133 ±11.4143	977644.6841 ±4.4606	
ABSOLUTE GRAVITY OF NEW STATION (mGal)				**977566.8581**		**977644.6084**		
STANDARD DEVIATION				**0.0350**		**0.0906**		
RESIDUES	-0.053	-0.007	0.068		0.127	0.295	-0.076	
NORMALIZED RESIDUES	-0.007	-0.001	0.009		-0.014	0.026	-0.017	
STANDARD ERROR OF UNIT WEIGHT		0.0082				0.0239		

1J: Kakamega County and Siaya County

	KAKAMEGA COUNTY				SIAYA COUNTY			
	1^{ST} REF	2^{ND} REF	3^{RD} REF	NEW STATION	1^{ST} REF	2^{ND} REF	3^{RD} REF	NEW STATION
EASTING	29801.88	26097.39	31106.48		643300.8	645794.1	643300.8	
NORTHING	694993.3	695094	693200.8		6699.82	5804.35	9496.95	
ABSOLUTE GRAVITY VALUE (mGal)	977554.6	977549.9	977551		977623.2	977617.5	977626.7	
1967-1980	0.83160173	0.831601327	0.831601885		0.831600087	0.8316600066	0.831600176	
HONKASALO TERM	0.037097538	0.037098112	0.037097317		0.03709875	0.037099907	0.03709975	
UPDATED GRAVITY VALUE (mGal)	977555.4687	977550.7687	977551.8687		977624.0687	977618.3687	977627.5687	
WEIGHTED DIAL READING	418.225 ±0.0725	395.950 ±0.029	400.463 ±0.025	364.603 ±0.048	512.149 ±0.1445	483.067 ±0.1	528.533 ±0.2	513.874 ±0.1011
POSSIBLE GRAVITY VALUE OF NEW STATION (mGal)	977514.9262 ±27.6503	977514.4277 ±18.0181	977514.5232 ±0.3457		977624.4069 ±0.3396	977624.4093 ±5.9670	977624.694 ±2.840	
ABSOLUTE GRAVITY OF NEW STATION (mGal)				**977514.5232**		**977624.4109**		
STANDARD DEVIATION				**0.0042**		**0.0239**		
RESIDUES	-0.2004	0.132	-0.083		0.004	0.002	-0.283	
NORMALIZED RESIDUES	-0.019	0.022	-0.012		0.0119	0.001	-0.0998	
STANDARD ERROR OF UNIT WEIGHT		0.0222						

1K: Kiambu County

	KIAMBU COUNTY			
	1ST REF	2ND REF	3RD REF	NEW STATION
EASTING	281852	284053		
NORTHING	9880413	9884816		
ABSOLUTE GRAVITY VALUE (mGal)	977580.9	977581.9		
1967-1980	0.831627849	0.831625836		
HONKASALO TERM	0.037060364	0.037063228		
UPDATED GRAVITY VALUE (mGal)	977581.7687	977582.7687		
WEIGHTED DIAL READING	519.545 ±0.199	525.600 ±0		
POSSIBLE GRAVITY VALUE OF NEW STATION (mGal)	977583.7629 ±1.9709	977583.576 ±0.7987		
ABSOLUTE GRAVITY OF NEW STATION (mGal)				**977583.602**
STANDARD DEVIATION				**0.0210**
RESIDUES	-0.161	0.026		
NORMALIZED RESIDUES	-0.082	0.033		
STANDARD ERROR OF UNIT WEIGHT		0.0623		

Appendix II: First order gravity network base station data

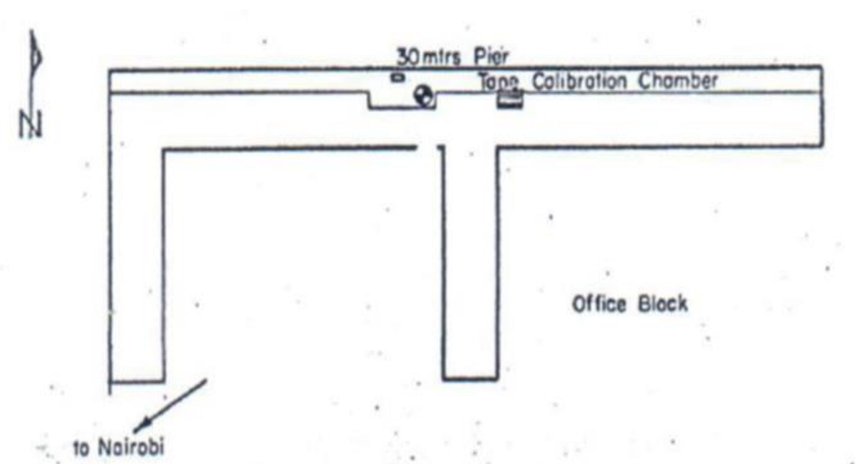
2A: Nairobi first order gravity base station

GRAVITY BASESTATION			
LATITUDE 01° 14.9'S (1)		STATION DESIGNATION	
LONGITUDE 36° 51.4'E (1)		Nairobi	
ELEVATION 1636.1 METERS (1)		COUNTY/STATE Kenya/central	
REFERENCE CODENUMBERS		ADOPTED GRAVITY VALUE	
ACIC 0199-0		g = 977 539.80 mGals	
IGB 35716A			
GW 71			
GITH 32		Estimated Accuracy	month/year
		± 0.3 mGals	7/70

DESCRIPTION AND/OR SKETCH

Observation were made at Nairobi at the Field Survey Headquarters Survey of Kenya

The site is located in the basement of the main building in the Tape calibration room, which runs the full length of the building, against the north wall of the building. Reading were taken in the alcove near the 30 meter pier on the concrete floor, about one foot west of the east wall of the alcove and about six feet south of the north wall of the wall.



(1)

REFERENCE SOURCE
(1) 01172

2B: Kisumu first order gravity base station

GRAVITY BASESTATION			
LATITUDE 0^0 06'S (1)		STATION DESIGNATION Kisumu	
LONGITUDE 34^0 45' E (1)			
ELEVATION 1143.6 METERS (1)		COUNTY/STATE Kenya	
REFERENCE CODENUMBERS		ADOPTED GRAVITY VALUE	
ACIC 3470-2		g = 977,607.97 mGals	
ORSTOM 256			
		Estimated Accuracy	month/year
		± 0.3 mGals	10/70

DESCRIPTION AND/OR SKETCH

On the veranda of the Railway Dak Bungalow. The bungalow is between the railway station and Lake Victoria and is 600m north-northeast of the steamer pier; bungalow is occupied by "immigration office" (1951). Station is on the veranda, on side facing the railway station, at the left end of the veranda, as one enters the corner on the bungalow side. (2)

REFERENCE SOURCE
(1) 00279
(2) 00129

2C: Mombasa first order gravity base station.

<table>
<tr><th colspan="4">GRAVITY BASE STATION</th></tr>
<tr><td colspan="2">LATITUDE
04^0 04' S (1)</td><td colspan="2" rowspan="2">STATION DESIGNATION

Mombasa</td></tr>
<tr><td colspan="2">LONGITUDE
36^0 44' E (1)</td></tr>
<tr><td colspan="2">ELEVATION
METERS</td><td colspan="2">COUNTY/STATE
Kenya</td></tr>
<tr><td colspan="2">REFERENCE CODE NUMBERS</td><td colspan="2">ADOPTED GRAVITY VALUE</td></tr>
<tr><td>ACIC 0321-2</td><td></td><td colspan="2" rowspan="3">g = 978,033.55 mGals</td></tr>
<tr><td>ORSTOM 270</td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td><td>Estimated Accuracy</td><td>month/year</td></tr>
<tr><td></td><td></td><td rowspan="2">± 0.3 mGals</td><td rowspan="2">9/70</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="4">DESCRIPTION AND/OR SKETCH

Treasury square; municipal offices; Room 9. (2)</td></tr>
<tr><td colspan="4">REFERENCE SOURCE
(1) 00279 (2) 00129</td></tr>
</table>