# Re-Establishment of Geodetic Networks at General Commission for Survey Saudi Arabia

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**Keywords**: Geodetic Leveling Network, Absolute Gravity Network, KSA CORS,

## SUMMARY

This is a summary on the present state of geodetic activities carried out at the General Commission for Survey (GCS), Saudi Arabia. General Commission for Survey has the responsibility of defining, maintaining and providing access to the National Spatial Reference System in the Kingdom of Saudi Arabia.
The Geodetic Leveling Network constitute an essential part of a country, as it provides the necessary vertical control for all surveying and mapping purposes. The first Geodetic Leveling Network of Saudi Arabia was established by the Kingdoms Ministry of Petroleum between 1966 and 1971 as a First Order vertical network. The rapid development and reconstruction along roads where the old network was established has caused major part of the network to be destroyed. GCS aims to re-establish accurate height control throughout the kingdom by an extensive levelling campaign with second order class 1 accuracy with the same density of the original network. The tide gauge network was established at 12 locations along the Red sea and the Arabia Gulf. Tidal benchmarks were levelled at first order class 2 accuracy to the tide gauge.

This paper will focus on the preliminary results from 14,900 km of second order leveling networks with roughly 3,552 established benchmarks. Orthometric/Normal heights computed indirectly from geopotential numbers and obtained from the adjustment of Orthometric/Normal height differences resulted in almost identical results. Progress made on the 426 KSA-Continuous Operating Reference Stations for both ground type and roof type stations will be discussed, with the aim of defining the KSA Reference Frame and to provide the user community with access to NRTK. In addition, this paper will outline the status of the Absolute and Relative Gravity Network established in the Kingdom.

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## 1. INTRODUCTION

The Kingdom of Saudi Arabia is situated at the southwest of Asia and it has an area of 2 million sq. km. The Kingdom has a history of old geodetic networks established. The start of significant geodetic surveying in the Kingdom goes back to the 1930s during the first oil exploration by Aramco. The first gravity base stations established in the Kingdom was reported in the work of (Al Ghalayini, 1958), by using worden gravimeters. The ministry of petroleum and mineral resources established a geodetic leveling network between 1966 until 1971. The existing geodetic leveling network in the Kingdom is more than 40 years old and the majority of the network has been destroyed during the rapid infrastructural development in the Kingdom. Rapid growth witness in the Kingdom has brought the need for re-establishing all the geodetic networks.

Presently, the General Commission for Survey (GCS), which was recently established aims to re establish, maintain, monitor and control the national geodetic reference systems, the national vertical geodetic networks, the national tide gauge network and conduct national earth gravity network measurements as needed in the Kingdom of Saudi Arabia. GCS is the leading national organization in survey, mapping, charting, geographic information and hydrographic survey. The Geodetic mission of GCS is to develop and maintain an accurate and seamless Saudi Arabian National Spatial Reference System (SANSRS), and provide access to it for use in all survey and mapping of the kingdom.

## 2. NATIONAL VERTICAL GEODETIC NETWORKS

The Geodetic Leveling Network (GLN), is one of the essential geodetic network of the infrastructure of a country, and it provides the necessary vertical control information for all geodetic activities. Orthometric heights are necessary for all major development projects. The GLN of the Kingdom as showed in figure 1 consists of 2,668 benchmarks in 54 lines with First and Second Order leveling established at an average 6 km spacing by the ministry of petroleum and mineral resources between 1966 and 1971. Precisely, 1,952 km line was leveled with First Order Class 2 accuracy, while 13,002 km was leveled with a Second Order Class 1 accuracy. The monuments and leveling lines followed the major roads due to ease of access. The rapid development and reconstruction of the Kingdom over the past several decades involving large scale highway construction was probably the primary cause of the destruction of the major part of the vertical network. Unfortunately, 85% of these vertical network had been destroyed over time leaving the country with inadequate vertical control.

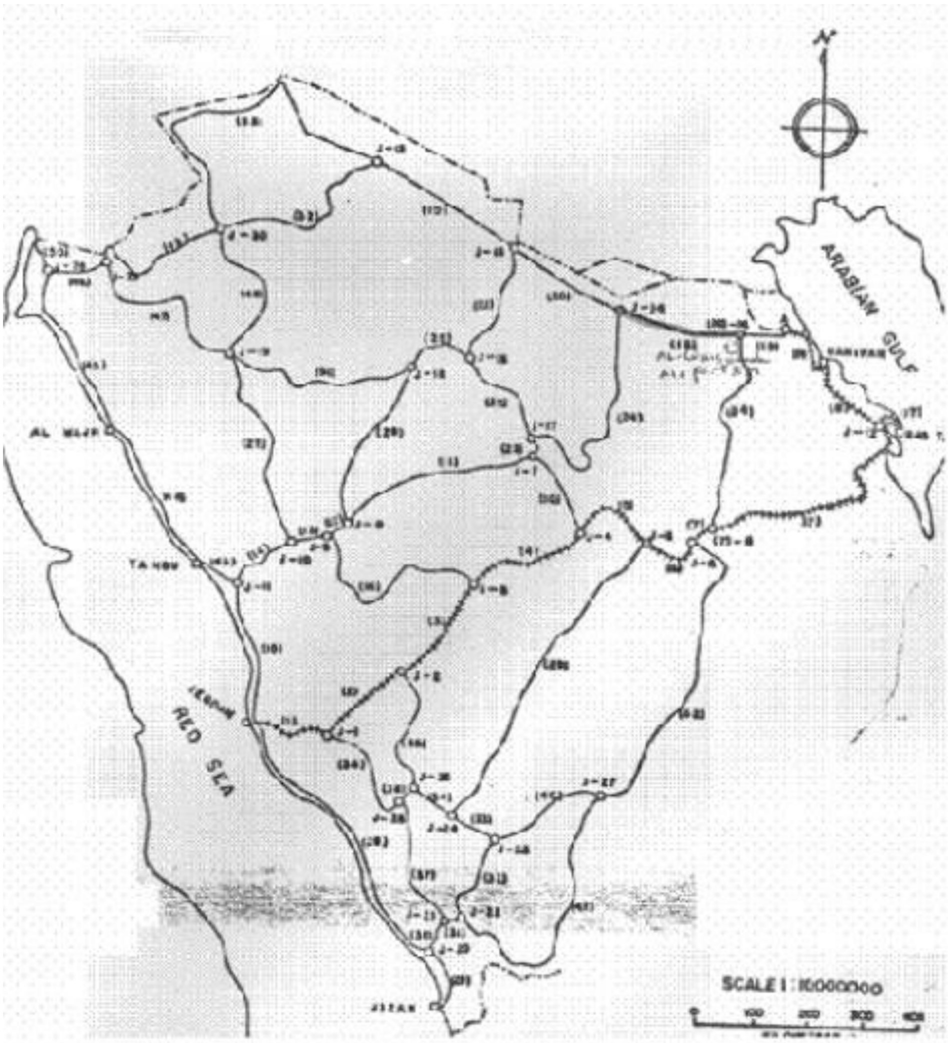


**Figure 1: First Geodetic Leveling Network of Saudi Arabia (1971)**

The General Commission for Survey (GCS) is re-establishing the GLN in four phases with a Second Order, Class I accuracies with the density of the original network and quality, suitable to serve as the basis for future development within the Kingdom. The national vertical geodetic networks being re-established by GCS will be used to realize the vertical datum for the Kingdom. All the leveling heights in the vertical geodetic network will be calculated and determined with respect to the vertical datum, The geoid is usually used as the reference surface for heights, nevertheless, the mean sea level (MSL) determined by averaging the level of water at a tide gauge over time is often used as the level surface to which heights are referred (Lu *et al.* 2014). The old vertical control network established chose the Jeddah MSL 1970 to be the reference surface. GCS has established 7 tidal stations along the Red sea and 5 stations along the Arabian Gulf. GCS will later decide the reference surface to be used after carefully monitoring all the 12 tide gauge stations.

The national vertical geodetic networks being established by GCS are based on First and Second Order leveling network. The national tide gauge network was established based on First Order-Class 2 accuracy while the national leveling network currently being established is based on Second Order-Class 1 leveling. The length of the new network is 20,443 km and double leveling runs along the kingdoms major road network. The new network comprises of 3,552 benchmarks. Trimble DiNi and Leica DNA03 digital levels were used.

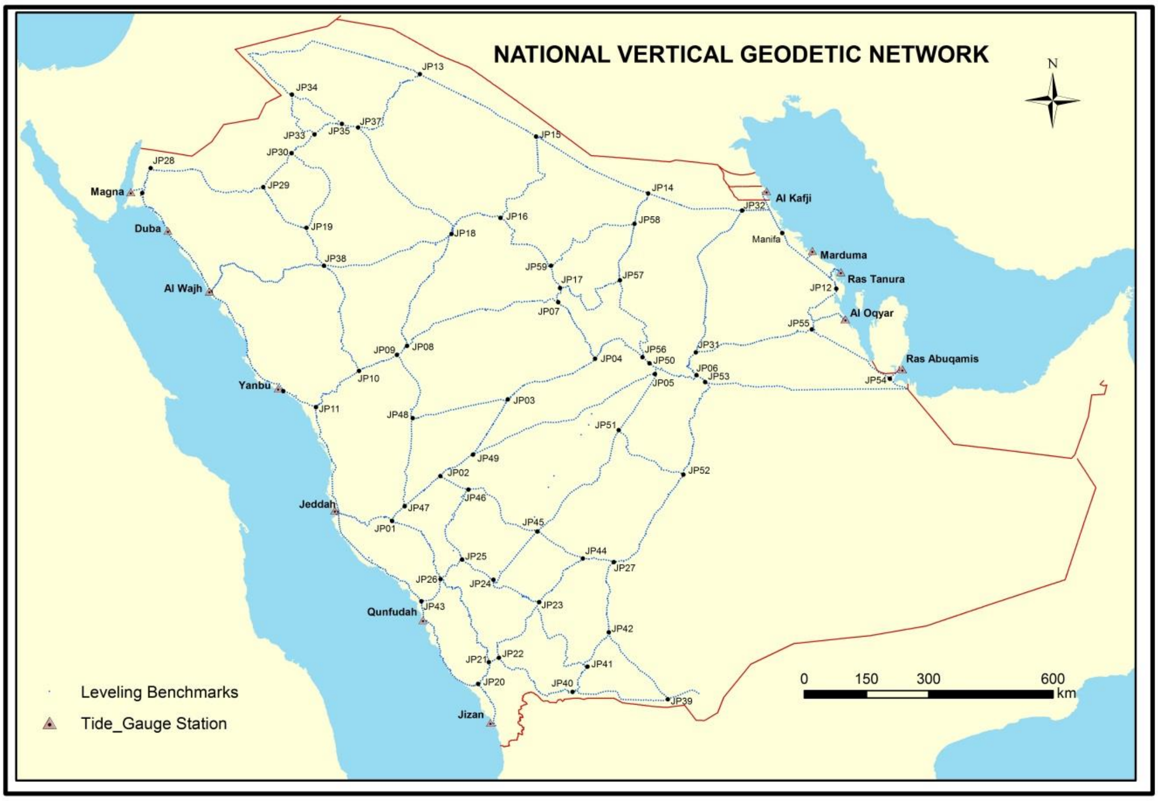


**Figure 2: Newly Established National Vertical Geodetic Network (2014)**

Following the compilation of field measurements, level data was checked, edited and adjusted afterwards to determine the heights of the monumented vertical points. These tasks were achieved by the use of geodetic software’s and in-house Matlab scripts. Translev developed by the National Geodetic Survey (NGS), was used for editing, formatting and checking digital level data. The misclosures were calculated for each section and entire levelling line of the network. Maximum allowable misclosure for Second Order/Class I is $\mp 6\sqrt{S}$. (S: shortest section length in km). The same formula was also used to calculate the loop misclosures. The recorded temperature sheets were checked for each section for forward and backward runs. They were observed with two thermometer and three temperature probes. The probes heights were at 0.5 m, 1.5 and 2.5 m above the ground (Whalen, 1981). The accuracy of the temperature probe used was ± 0.1°c.

Correction of rods calibration , scale factor, temperature variations, refraction, astronomic, curvature, normal orthometric and orthometric corrections were introduced

## 2.1. Preliminary Adjustment of the National Vertical Geodetic Network

These section discusses the preliminary least square adjustment made on 14,900 km of Second Order/Class I leveling networks from 20,443 km geodetic leveling network. Two procedures for height computations using geopotential number differences and height differences corrected by gravity effects (orthometric, normal and normal orthometric) were adapted. Least squares adjustments was carried out four times using different types of observation and geopotential numbers as well as orthometric, normal and normal orthometric heights of all benchmarks were determined separately. We took all single run observations separately in order to detect outlier observations accurately.

Firstly, geopotential number differences between sections were computed by combining corrected (except gravity effect) leveled height differences with the predicted surface gravity from the EGM2008 model. Then, Helmert orthometric height and Molodensky normal height were computed by scaling geopotential numbers with an appropriate mean gravity. Secondly, we converted leveled height differences (orthometric, normal and normal orthometric) by using the estimated gravity. The first two are the input to the subsequent adjustments. In these adjustments, heights of the benchmarks in different system are calculated directly.

In order to perform the adjustment and determine the heights of the network points, a benchmark with known height was required in order to avoid the normal equations becoming singular for datum definition, for initial approximation an old benchmark 984.722 m from previous studies was used. Geopotential number of this benchmark was calculated as 963.58763 m using estimated gravity value of the benchmark. Besides, normal height of the benchmark is also calculated from the geopotential number as 984.64504 m.
For all the adjustments, datum of the network was defined with the benchmark given above, using its appropriate height in the corresponding height system. This is a minimally constrained adjustment, because the height of one point is held fixed for a one-dimensional leveling network adjustment. The heights obtained from all adjustments should be considered as approximate due to unknown datum shift.

Orthometric/Normal heights computed indirectly from geopotential numbers and obtained from the adjustment of Orthometric/Normal height differences resulted in almost identical results. The differences were within (-0.1 to 0.2 mm) for Helmert heights and (-0.9 to 0.5 mm) for Normal heights. The same type of instruments and rods were used for all observations and the a priori variance for 1 km leveling is assumed to be same for whole network. We assumed that a priori variance for the observation is not known and we estimated a posteriori variance for the observations after least square adjustment. Thus the weight of the observation was calculated with P =1/S (km). Statistical results of all adjustments were almost identical. The normalized residuals from the least squares adjustment (a minimally constrained) was checked for detecting outlier observations. For outlier detection we used Tau (Pope) test method using $1-\alpha= 0.95$ probability level. No outlier was detected.
A posteriori (post adjustment) standard deviation was found to be 1.19 mm/$\sqrt{}$ (km) for single run, which corresponds to 0.84 mm /$\sqrt{}$ (km) for double run. This value indicates that the

preliminary established network achieved better than Second Order Class 1 leveling network standards.

## 2.2. National Tide Gauge Network

GCS established a network of accoustic wave tide gauges in 2011 at selected locations along the Arabian Gulf and along the Red Sea. Seven of these metrological-tide gauge stations was established along the Red sea, five along the Arabian Gulf and the data center is stationed at GCS headquarters in Riyadh. This network is currently providing essential data for monitoring sea level variations as well as facilitating great wealth of data for environmental studies and monitoring. The figure 3 below shows the distribution of 12 tide gauge network in the Kingdom.

The tide gauge comprises of the following features;

- Accuracy of ≤ 1 cm.
- Data transmission is in Real-Time.
- Recording interval: 1 minute.

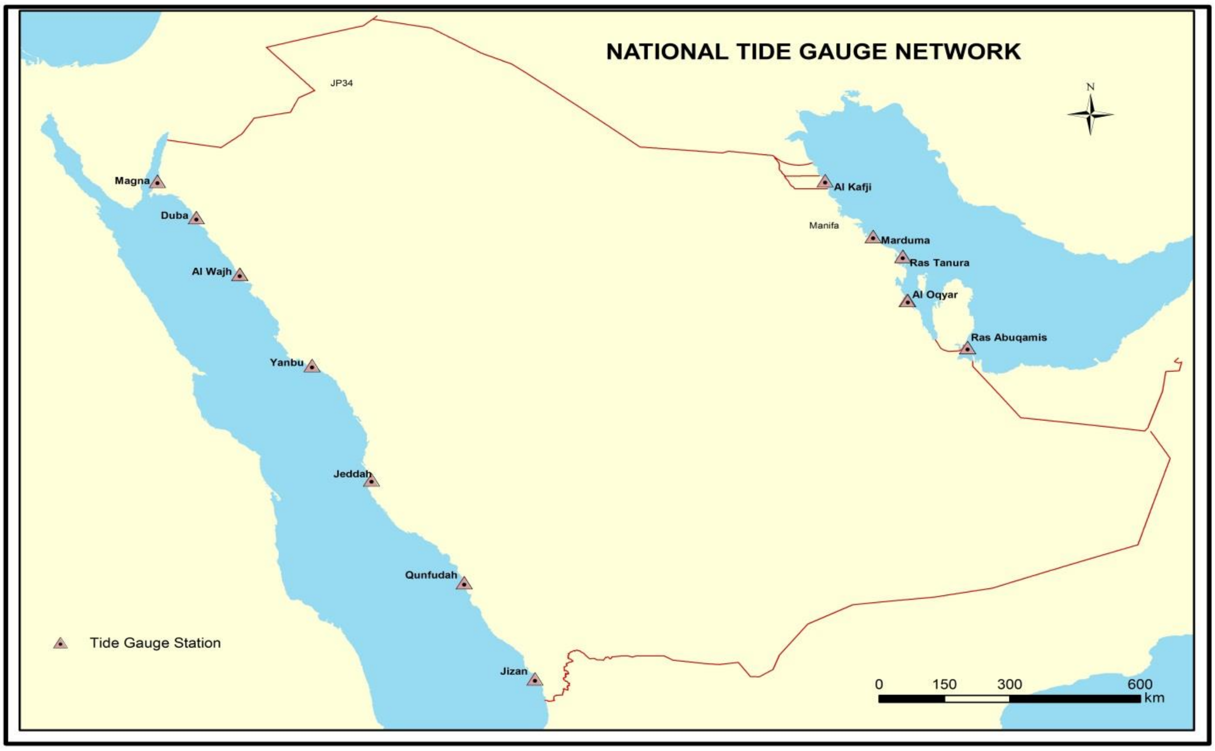


**Figure 3: The National Tide Gauge Network**

A network of benchmarks is an essential component of every tide gauge station. At each station, six geodetic benchmarks are installed. Four benchmarks are installed in vicinity of the tide gauge and the other two are installed at a maximum distance of 7 km from the tide gauge preferably on a bedrock to monitor the stability of the tidal benchmarks. One of the four benchmarks installed in the vicinity of the tide gauge is a tidal benchmark to which the tidal datums are referenced and it is installed 5 meters away from the tide gauge. It represents the primary benchmarks. First Order Class 2 levelling was used to observe between the tide gauge benchmarks and the tide gauge zero reference. Connections between tidal datum elevations and geodetic elevations were obtained after levelling between the tidal benchmarks and the geodetic network benchmarks (NGS, 1997).

## 3. NATIONAL GRAVITY CONTROL NETWORK

Flanigan and Akhrass, in (1972) reported the use of uncalibrated Lacoste-Romberg gravimeters in establishing base network of 42 base stations round the Kingdom. The primary base for the surveys was located at old Jeddah International Airport, and these stations have been destroyed. The new datum and network adopted in 1971, named The International Gravity Standardization Net 1971 (IGSN71) demanded a new tie to re-establish the gravity datum for the Kingdom. A gravity base station was established in Jeddah USGS X and tied to the IGSN71 via the IGSN71 stationed in Sudan, and Kenya (Gettings, 1985). He further points out that the four Lacoste-Romberg gravimeters used to establish the base station were calibrated to the IGSN71 scale (mgal). The Jeddah USGS X observed gravity value was 978,738.973 mgal with a standard deviation of 0.024 mgal and a standard error of the mean of 0.003 mgal based on 60 out of 64 ties. Based on USGS quality criteria, the station was first-order and has a minimum accuracy of + 0.020 mgal. Nevertheless, (Ayhan *et.al.* 2014) stated that the USGS-established base and baseline stations are presently nonexistent.

The gravity network establishment at GCS was defined in two phases. The first phase which has been completed covers the size (gravity datum, gravity level) and scale (calibration) definition of the network by using absolute gravimeters. The on-going second phase covers densification of the absolute gravity sites up to benchmarks level, and installing gravity calibration baseline for gravity survey by using relative gravimeters. This section will summarize the result from the absolute gravity phase.

The absolute gravity observation was carried out in 2013 by GCS incorporation with Micro-g LaCoste Inc., U.S.A. The observation was equipped with one A10, one FG5 and two CG5s. The network was called KSA Absolute Gravity Network (KSAAGN) as reported by Ayhan *et.al.* 2014). The network consists of 50 stations at 25 sites distributed across the kingdom as shown in figure 4. Most sites were located in rural areas, away from coastal areas as possible, (Hwang *et al.* 2002). Each site comprises of two stations; an indoor and outdoor station. Both stations were occupied by A10 (accuracy < ± 10 μGal) while seven of the sites were collocated by FG5 (accuracy < ± 3 μGal). Two CG5 gravimeters were used for measurement of vertical gradients at both inside and outside stations and ties between indoor and outdoor stations at each site. For the indoor stations, the site selection and monument construction was selected at the lowest level of the building to reduce vibrations as much as possible. A basement with a thick concrete floor is usually best. Floors with composition materials were avoided as possible, and the instrument was set up on a solid tile or concrete floor. The monument at all outdoor stations and some indoor stations is 60 x 60 x 100 cm sized concrete pillar.

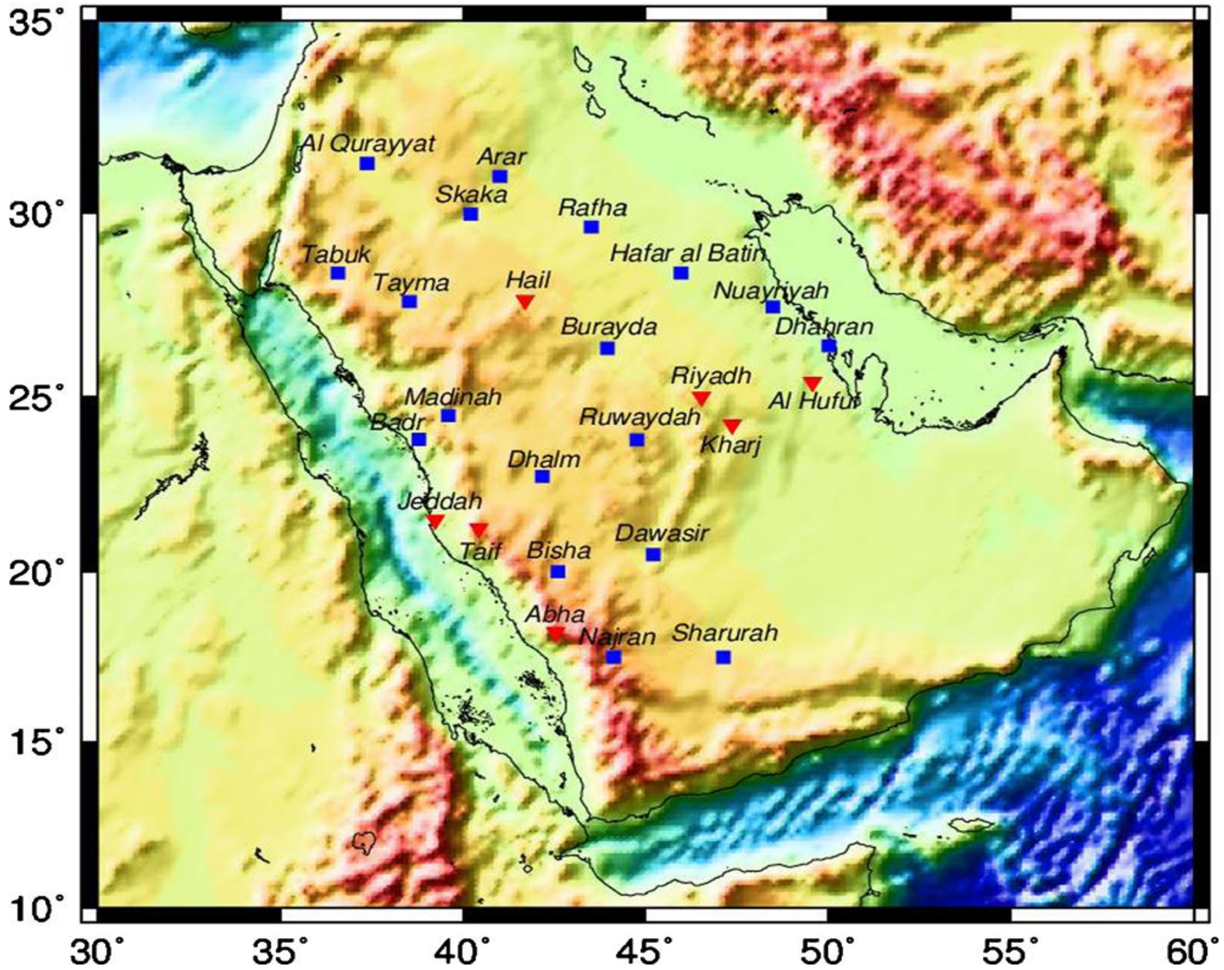


**Figure 4: Absolute gravity sites within the Kingdom. Solid blue square is A10 site; solid red inverted triangle is FG5 and A10 site**

The total uncertainties of about ±2 and ±6 μGal obtained at the FG5 and A10 stations, respectively, are enough to provide the size (gravity datum) and scale (calibration) for gravity surveys in the kingdom. A10 tie differences, having minimum -1.96 μGal and maximum 1.03 μGal, indicate slight site dependence (Figure 4.a)

Gradients at the outdoor stations deviate significantly from the free air gradient (3.086 μGal/cm) along the red sea coastal area. However, average gradient at the outdoor stations is obtained as 3.09±0.09 μGal/cm which confirms the free air gradient in general. Therefore, the Helmert orthometric height system, which depends on the free air gradient assumption, can be recommended for the kingdom (Ayhan *et.al.* 2014).

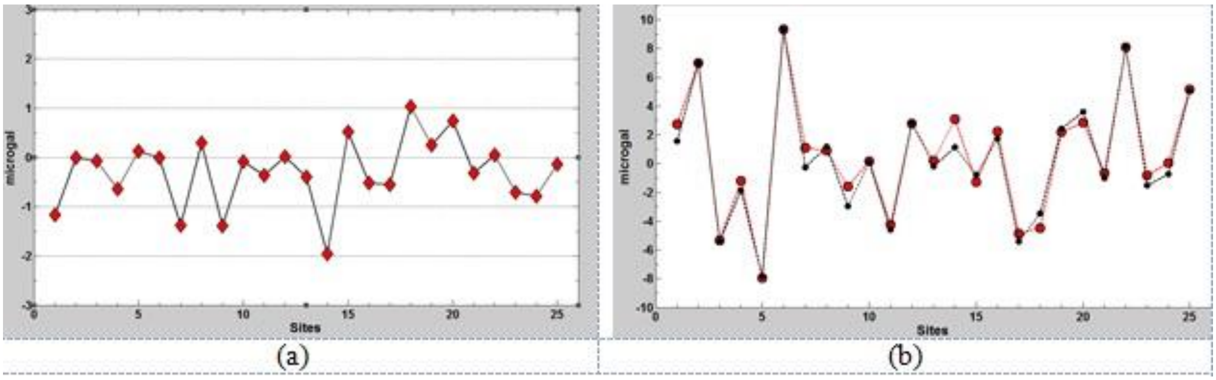


**Figure 5: a). Difference between A10 first and second order ties between indoor and outdoor stations. b). Differences between A10 and CG5 Ties. Solid red circle is 1st order gradient, black solid circle is 2nd order gradient used.**

Differences between A10 and FG5 absolute gravities at 72 cm vary between −3.8 and 9.5 µGal at seven stations. Excluding the outside stations, we obtained the differences from −3.8 to 5.5 µGal at indoor stations.

## 4. KSA CONTINUOUSLY OPERATING REFERENCE STATIONS NETWORK

GCS defines the Kingdom of Saudi Arabia's Reference Frame (KSAREF) and relates it to the International Terrestrial Reference Frame and local geodetic datum by providing its orientation, scale and shift. This section describes the ongoing establishment for the Kingdom of Saudi Arabia Continuously Operating Reference Station (KSA CORS) network.

The KSA CORS was planned to be established in phases for easy implementation and monitoring. The fundamental infrastructure of the KSA-CORS is formed by a Network Control Center (NCC) and a network of permanent reference stations. Precisely, 426 stations will be deployed, with about 1188 baselines. The minimum distance is 29 km.

The primary goals of establishing KSA CORS network is to deploy a CORS network covering the Kingdom with the aim of achieving the following;

- Define, deploy and maintain the KSAREF
- Provide a kingdom wide range of positioning services simultaneously to the user community with access to KSAREF by means of data distribution for both post-processing and in real-time. Specifically the following positioning services will be provided;
  - Access to RINEX files from the CORS sites.
  - Network Real-Time Kinematic (NRTK), with an accuracy level of centimeter at densely populated areas.
  - Real Time Network Differential GNSS, with accuracy level of decimeter at any location within the kingdom.

The CORS stations infrastructure is designed to be International Global Navigation Satellite System Service (IGS) compliant, in order to ensure high precision coordinates and velocities determination that allow a correct and precise crustal deformation monitoring and KSAREF definition and maintenance.

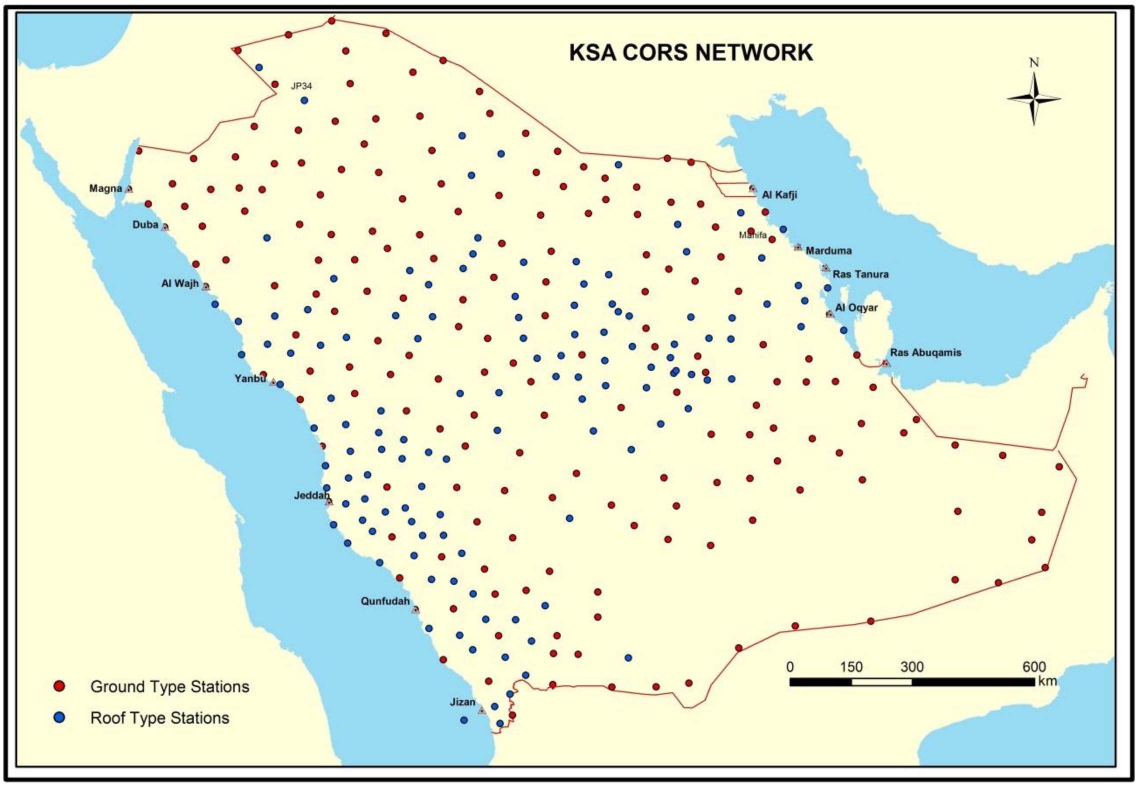


**Figure 6: KSA CORS Networks.**

The first type of monument used for KSA CORS is referred to as the Ground Type (GT), which forms a CORS geodynamic level network. The GT stations is based on ground monumentation according to the specifications defined by the IGS. The second type is referred to as the Roof Type (RT), which is established on top of a stable building with few obstructions as possible. The GT stations which is more stable will be deployed to define and maintain the reference frame, at the same time GT and RT stations will both be deployed for NRTK services. Each station comprises of a GNSS antenna and a Trimble NetR9 Ti-1 GNSS receivers. The Trimble Pivot Platform is installed at the NCC for GNSS data collection, storage, processing and distribution.

A CORS site will be deployed at collocated tide gauge stations developed by GCS and a connection will tied between both sensors by precise leveling. Inetrnational Geodetic Community is increasingly aware of the imporatance of connecting tide gauge stations with GNSS networks. GCS aims to dicriminate the sea level variations from the vertical movement of the tide gauge caused by subsidence or subplates vertical movements.

The data stored at the NCC will be distributed to users by different positioning services, on both real-time and post-process basis. Data from all stations will be combined in a network solution that makes it possible to discriminate the spatial component of ionosphere, troposphere and geometric errors that affect the GNSS signal. This technique gives users access to services that facilitate work with one receiver while getting an accurate position over the territory. Positioning services are distributed over internet and consist of downloading GNSS files and real-time services for high-precision positioning in densely populated areas. The Network Real Time Kinematic (NRTK) stations are located at densely selected area and will afford the required interstation distance of 70-90 km in order to provide centimeter accuracy positioning. The network is designed to have a redundancy geometric factor that could maintain the quality of data on a particular area in case of partial system failure. This is the capacity to provide enough number of stations without compromising the accuracy to be disseminated.

## 5. GPS - LEVELING NETWORK

The main purpose of these future project is to establish GPS leveling observation for about 50% of the newly established leveling network benchmarks including junction points and tidal benchmarks.

Analyzing gravity density plots and modeled geoid height values, as well as contour plots of free-air anomalies and Bouguer anomalies, are practical ways for users to determine which benchmarks in the project need to be occupied by GPS or where additional gravity observations are required. Contour map of geoid heights estimated from a high- resolution geoid model indicate some areas with smooth, gently sloping geoid, but this could be because there wasn't enough gravity information in the area to adequately define changes in the shape of the geoid. Ideally, GPS station with a leveling-derived orthometric height is required whenever there is a change in the slope of the geoid and wherever there is an area of sparse gravity data. After a detailed study of the density and distribution of observed gravity plot, GCS has identified roughly 50% of the benchmarks, which will be occupied with GPS to adequately evaluate the slope and changes in slope of the geoid.

# 6. CONCLUTIONS

The Geodetic mission of GCS is to develop and maintain an accurate and seamless Saudi Arabian National Spatial Reference System, and provide access to it for use in all survey and mapping of the kingdom. GCS aims to re establish, maintain, monitor and control the national geodetic reference systems, the national vertical geodetic networks, the national tide gauge network and conduct national earth gravity network measurements as needed in the Kingdom of Saudi Arabia.

GCS has currently completed re establishment of an absolute gravity network and its national tide gauge network. Work is on-going in the re-establishment of a new vertical geodetic network and relative gravity network. The new network of Continuosly Operating Reference Stations establishment is on-going. First Order Class 1 Precise leveling observations are on-going to monitor the stability of tidal benchmarks at each of the tide gauge stations.

GCS aims to compute an improved regional geoid model over the Kingdom with an accuracy better than 5cm. The process involves analysis of existing GPS, gravity, and leveling data, to fulfil the needs of the geodetic, surveying, geospatial, engineering, researchers and all other geo-information professionals across KSA.

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## BIOGRAPHICAL NOTES

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Graduated from Survey Engineering from King Saud University in 1992. He attended Army Survey Course at the School of Military Survey in the United Kingdom in 1995. He has served in the General Department of Military Survey from 1993 until 2010. He served as manager in different sections of GDMS. He is currently the deputy director for geodesy and land survey department at General Commission for Survey, Riyadh. His research interest includes geodetic surveys and data processing.

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Completed his bachelor's degree in Survey Engineering from King Saud University in 2011. He currently serves as the deputy section head for vertical geodetic network at General Commission for Survey for the past 3 years. He is currently involved with supervision of precise leveling and adjustment teams.

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