Simple Model for Improving the Accuracy of the Egyptian Geodetic Triangulation Network

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SUMMARY

The existing Egyptian geodetic network, which dates back to the first decade of the twentieth century, has been studied and adjusted in two and three-dimensions by several researchers. All previous trials showed that there is some kind of distortion due to the inaccurate treatment, adjustment and lake of geoid information. GPS is used extensively in the last decade. GPS is very accurate in its relative (surveying) mode. GPS is used in many projects in Egypt and the coordinates of many triangulation stations are precisely determined in the World Geodetic System 1984 (WGS-84). The idea of this research is to use the available precise coordinates, at some stations of the Egyptian triangulation network, in defining the distortion in the network and to establish a correction model to improve the accuracy of the local network without readjusting the network.

تتطلب التنمية الاقتصادية لأي دولة إنشاء شبكة حديثة من النقط الجيوديسية ، وتعتبر هذه الشبكات هي الأساس لإنشاء الخرائط والمشروعات الهندسية الكبيرة. وتوجد فوائد عديدة لهذه الشبكات من أهمها: دراسة تحركات القشرة الأرضية ، ترسيم الحدود الدولية ، دراسة تغير سطح البحر وكذلك تعيين مدارات الأقمار الصناعية. وتتطلب كل هذه التطبيقات العديدة شبكات جيوديسية تتميز بالدقة العالية.
وتتكون شبكات التحكم الجيوديسية المصرية من شبكتين رئيسيتين وقد تم ضبط الشبكة الأولى بواسطة هيئة المساحة المصرية في البعدين الأفقيين كل قطاع على حدة باستخدام طريقة المعادلات الشرطية كإحدى طرق الضبط بنظرية أقل مجموع لمربعات الأخطاء وبدون أي معلومات عن الجيويد وقد أدى ذلك إلى حدوث تشوهات في إحداثيات نقط التحكم. أما بالنسبة إلى الشبكة الثانية فلم تقم هيئة المساحة بضبطها. وقد تمت عدة محاولات لضبط شبكات التحكم الجيوديسية إما جزئيا أو كليا سواء في البعدين الأفقيين أو في الثلاث أبعاد بواسطة باحثين بالجامعات المصرية.
استخدمت الأقمار الصناعية فى العقود الأخيرة لايجاد الاحداثيات بدقة عالية عن طريق مستقبلات خاصة بها و من أشهر هده النظم النظام العالمى للاحداثيات GPS . استخدم هدا النظام فى عدة مشروعات فى مصر وتم تحديد احداثيات العديد من النقاط فى الشبكة المصرية بدقة عالية. هدا البحث هو محاولة لتحديد نقاط الضعف فى الشبكة المصرية عن طريق احداثيات ال GPS المتاحة ثم عمل نمودج بسيط لزيادة دقة الشبكة المصرية ودلك بدون اعادة ضبط الشبكة والمعروف بصعوبته.

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1. INTRODUCTION

In classical geodesy, the geodetic control networks provide a fundamental base for mapping, cadastral applications and large engineering projects. However, in modern geodesy and geodynamics, these geodetic control networks have several other benefits such as: the determination of crustal movements, which is useful in monitoring the earthquakes, plate boundary determination, studying the sea surface topography and its variation with time, the computation of the orbits of the artificial geodetic earth satellites, and improving the knowledge of the earth's gravity field [Mather, 1977]. These recent applications require very high accuracy for the network coordinates.

1.1 The Egyptian Geodetic Control Network

Between 1853 and 1859 a survey of Egypt was made but did not depend on a triangulation scheme [Shaker, 1982]. Later, many attempts were made for constructing a geodetic triangulation, but they were not of higher order. In 1907 it became possible to begin a new work for establishing a geodetic triangulation frame for Egypt, which is considered to be the first national network to be established in Africa [Moritz, 1981]. From the cost point of view, it was decided to carry out the network along the Nile Valley only [Shaker, 1982]. The main reason to carry it out was to fix, with a great possible accuracy, fundamental control-stations to be a base for the cadastral survey and national mapping of the country. Egyptian network was extended to Sudan and other African nations. The first order geodetic horizontal control network of Egypt contains two main networks, Network (1) and Network (2), [Cole, 1944]. Figure (1) shows the first order triangulation networks.

1.1.1 Network (1)

It started in the year 1907 and was finished in 1945. It consists of ten sections contain 195 stations and the general form as (T) shape, with initial point on the Mokattem hills to the east of Cairo, Figure (2). The nearly horizontal part from (T) shape contains five sections covering the north area from Al-arish in the East to Al-salom in the West and passing through Cairo region. The nearly vertical part from (T) shape contains the other five sections covering the cultivated area of the Nile valley from Cairo to Adindan near Sudanese borders. Each section starts from a base line and ends at another base line. Station Z5 (Adindan) in the south is the origin of the Sudanese geodetic network.

1.1.2 Network (2)

In 1952, the Egyptian Survey Authority (ESA) set out a plan for observing the second geodetic Network (2) to cover South Sinai, the area of the Red sea, and to cover also part of the Western Desert, in order to cultivate and inhabit these areas [Elhussainy, 1982]. Network (2) was constructed and observed from 1955 and finished in 1968. This network consists of 207 stations forming three basic blocks which are divided into 13 sections. The two Networks were linked by 19 common stations in different regions, Figures (1) and (3).

1.2 Description of Treating Network 1 and Network 2

The geodetic observations of Network 1 and Network 2 were taken while the geoid in Egypt was unknown. So the gravimetric reductions to the collected observations were neglected. The gravimetric reductions are needed to relate the observations to the ellipsoidal (geodetic) gravity field which the observations will be computed in. The Network 1 is adjusted section by section, not as one block, so the errors in the network are not homogeneously distributed. The coordinates of Network 2 stations are just computed from the collected observations without gravimetric reductions and without any kind of adjustment. Therefore it is expected that Network 1 has some distortions and inconsistency. It is expected also that Network 2 has more distortions and inconsistency.

1.3 Some GPS Networks in Egypt

GPS surveys for producing geodetic control points have been performed within the Egyptian Survey Authority (ESA) through the Finnish Project in the Eastern Desert (Finmap), the American Project in the Delta and along the River Nile with some extensions in the Eastern Desert. In addition, the Survey Research Institute (SRI) established some GPS points. Some other GPS control points were available from the German Project in Aswan area. A High Accurate Reference Network (HARN) is observed in 1995 and a new Egyptian Datum is based on it. GPS observations were taken at triangulation stations in a project belongs to the Aviation Authority. The National Research Institute for Astronomy and Geophysics (NARIAG) established two GPS networks to follow the crustal movements in Sinai and Greater Cairo area in the years 1994 and 1995 respectively.

2- The Used Data

The used data in this research are the geodetic coordinates of 32 first order triangulation stations from Network 1 and Network 2, Figure (4). The coordinates of those stations are defined in both datums, the Egyptian Local Datum (LD) and WGS-84. The coordinates in the Egyptian datum are obtained from the Egyptian Survey Authority (ESA). Twenty six stations belong to Network 1 and six stations belong to Network 2. The coordinates of 27 stations in WGS-84 are obtained from the High Accurate Reference Network (HARN) and the National Agricultural Cadastral Network (NACN) through (ESA). The other 5 stations are obtained from the Civil Aviation Authority project. Those 5 stations are modified to the HARN coordinates in [Saad A.A, 1998]. Coordinates of 16 points from the adjustment of [Awad, 1997] are used in evaluating the results of this work.

2. METHODOLOGY

The following steps are followed in the computations to verify the goal of this research:
To illustrate the differences between the coordinates of the Egyptian datum and WGS-84 over the territory of Egypt, the differences in latitudes and longitudes at the available stations are computed. The differences are tabulated in Tables from (1) to (4) for latitudes, longitudes, and their horizontal resultants. Those differences are illustrated in Figures (5), (6), and (7) respectively. This was done to interpret the behavior of the differences all over the country and to see if they are dependent on the section and position of the stations.

In order to investigate the distortion in the local coordinates of the Egyptian datum, WGS-84 coordinates are changed to their corresponding coordinates in the Egyptian local datum by using the well known datum shift equations, [Heiskanen and Moritz, 1967]:

$$\partial\varphi = (\cos\varphi i.p \cos\varphi + \sin\varphi\ i.p \sin\varphi \cos\Delta\lambda)\ \partial\varphi\ i.p - (\sin\varphi \sin\Delta\lambda \cos\varphi\ i.p)\ \partial\lambda\ i.p + (\sin\varphi\ i.p \cos\varphi - \cos\varphi\ i.p \sin\varphi \cos\Delta\lambda)\ ((\delta h / a) + (\delta a / a) + \sin 2\varphi\ i.p * \delta f) + 2\cos\varphi (\sin\varphi - \sin\varphi\ i.p)\ \delta f \quad (1)$$

$$\cos\varphi\ \partial\lambda = (\sin\varphi i.p \sin\Delta\lambda)\ \partial\varphi\ i.p + (\cos\Delta\lambda\ \cos\varphi i.p)\ \partial\lambda\ i.p - [(\cos\varphi i.p \sin\Delta\lambda) * (\delta h / a) + (\delta a / a) + \sin 2\varphi\ i.p * \delta f)] \quad (2)$$

Where :

φ and λ are the latitude and longitude of the point to be shifted in the old datum
φ i.p and λ i.p are the latitude and longitude of the Initial Point in the old datum
$\delta\varphi$ i.p = φ i.p new – φ i.p old, $\delta\lambda$ i.p = λ i.p new – λ i.p old, δa = a new – a old
δf = f new – f old, $\Delta\lambda = \lambda$ point – λ i.p, δh = h new- h old
$\partial\varphi$ to be added to WGS-84 latitude to produce the local datum latitude.
$\partial\lambda$ to be added to WGS-84 longitude to produce the local datum longitude.
Equations (1) and (2) are based on a spherical approximation, i.e. they considered;

$$M = N = M+h = N+h = a$$

Where N and M are the radii of curvature in prime vertical and meridian respectively, (a) is the semi-major axis of the adopted ellipsoid, and (h) is the ellipsoidal height of the point. [Abd-Elmotaal and El-Tokhey, 1995] derived full equations without spherical approximation. They also derived equations for computing the effect of the spherical approximation. They also computed this effect allover the area of Egypt. They obtained 10 and 11cm as a maximum effect on latitudes and longitudes respectively. Therefore this approximation will not significantly affect the results in this research.

So, every station will have two coordinate values, one is original local coordinates and the other is WGS-84 shifted to the local datum. Here, the original coordinates are named (LD) and WGS-84 shifted coordinates are named (LD-1).

To show the distortion in the network, the differences in latitude, longitude, and their resultant between (LD) and (LD-1) coordinates are computed. Those distortions are in Tables (5 to 8), and illustrated in Figures (8), (9), and (10).

The obtained distortions in latitudes ($\Delta\varphi$) and longitudes ($\Delta\lambda$) are modeled using 1st, 2nd, and 3rd order polynomials and the best fitting polynomials are chosen. This was to modify the local coordinates of the network where their accuracy can be simply improved using the available GPS coordinates. The used polynomials were as follows:

$\Delta\varphi = a0 + a1L + a2\alpha$ (1st order)

$+ a3L2 + a4L\alpha + a5\,\alpha\,2$ (2nd order)

$+ a6L3 + a7\,L2\,\alpha + a8L\,\alpha\,2 + a9\,\alpha\,3$ (3rd order)

……………. (3)

$\Delta\lambda = b0 + b1L + b2\,\alpha$ (1st order)

$+ b3L2 + b4L\,\alpha + b5\,\alpha\,2$ (2nd order)

$+ b6L3 + b7\,L2\,\alpha + b8L\,\alpha\,2 + b9\,\alpha\,3$ (3rd order)

………… (4)

Where $\Delta\varphi$ and $\Delta\lambda$ are in meters,

(L) is the distance of the point from the initial point F1, in meters and

(α) is the azimuth of the line between the point and F1, in degrees.

The obtained polynomials are then applied to the coordinates of the points in (LD) to obtain their corresponding coordinates in (LD-1)

Finally, the coordinates of sixteen points from the adjustment of [Awad, 1997] are used in evaluating the results of the proposed improving model.

4. COMPUTATIONS AND RESULTS

The available stations are devided into four groups in the tables of the results. Group 1 starts from the Initial point F1 in the North and goes to the South beside the Nile, its points belong to Network 1. Group 2 includes the stations in the East-West direction, they belong to Network 1. Group 3 includes three points in the Eastern Desert and belongs to Network 2. Group 4 contains three points in the Western Desert and belongs to Network 2.

4-1 Differences between WGS-84 and Local Coordinates

The differences in latitudes and longitudes between WGS-84 and local systems are computed. Their resultants are also computed.

4-1-1 Coordinate Differences in Group 1 (North-South Direction)

Table (1): Differences between local and WGS-84 coordinates in North-South sections from group 1-Network 1.

Point	Dist. From F1 (km)	Azimuth to F1 (Deg)	Diff-phi (m)	Diff-lam (m)	Result-Diff (m)
F1	0.00	-------	18.02	180.90	181.79
O1	19.8	161	17.63	180.82	181.68
A2	112.6	186	15.95	178.71	179.42
L2	209.5	193	14.47	176.30	176.89
S2	298.6	194	13.17	175.16	175.65

B3	299.7	182	12.51	176.06	176.50
A3	306.7	180	12.57	176.10	176.55
T2	309.8	189	12.76	175.41	175.87
M3	459.5	169	10.44	176.98	177.29
B4	504.7	165	10.50	177.82	178.13
A4	505.0	164	10.40	177.71	178.01
P4	672.0	165	8.93	177.82	178.04
A5	681.1	167	8.74	177.47	177.69
E5	747.2	168	7.75	178.20	178.37
L5	808.2	176	6.60	177.23	177.35
O5	843.2	178	6.17	176.81	176.92
Q5	859.5	179	6.04	176.72	176.82
Y5	867.1	178	5.92	176.79	176.89
R5	877.9	178	5.76	176.78	176.87

Latitude differences: Looking at Table (1) and Figure (5), the latitude differences are decreasing to the south direction. They start with 18 meters at the initial point F1 and reduce till 5.76 meters at the extreme south with more than 12 meters range. The range is somehow big value compared with the average of the differences. The latitude datum shift Equation (1) depends mainly on the latitude of the concerned point. Latitudes of the used stations range from 22º to 32º N.

Longitude Differences: Looking at Table (1) and Figure (6), the differences themselves are in direct proportion with the longitude differences from F1. The differences range from 175.16 to 180.90 meters, it means that the range is small relative to the average of the values. The longitude datum shift Equation (2) depends mainly on the logitude difference from F1, which is not big value in most of the cases in Group 1 points.

Horizontal Resultant Differences: Looking at Table (1) and Figure (7), the resultant differences are undulating through those five sections but their rates with respect to the distances from F1 are increasing to the South. The longitude differences are affecting the resultants because they are much bigger than their corresponding latitude differences.

4.1 Coordinate Differences in Group 2 (East-West Direction)

Table (2): Differences between local and WGS-84 coordinates in East-West sections from group 2-Network 1.

Point	Dist from F1 (km)	Azimuth to F1 (Deg)	Diff-phi (m)	Diff-lam (m)	Result-Diff (m)
F1	0.00	-------	18.02	180.90	181.79
F6	17.3	70	17.91	181.23	182.11
O1	19.8	161	17.63	180.82	181.68

E7	68.7	252	18.53	179.2	180.16
A6	128.4	85	17.19	181.89	182.70
N7	140.3	279	20.36	178.92	180.07
D8	242.4	292	21.94	178.67	180.01
X8	427.9	290	24.39	176.39	178.07
Z9	584.3	285	25.36	174.64	176.47

Latitude Difference: From Table (2) and Figure (5), the latitude differences are increasing from the East to the the West direction. They start with 17.19 meters at the east (A6) and reach 25.36 meters at the extreme west (Z9) with nearly 8 meters range. The 8 meters range here is less than the 12 meters range in the North-South case because the change in latitudes in the North-South case is bigger than that of the East-West case.
Longitude Differences: The differences in longitudes are increasing from the East to the West direction. They range from 181.89 meters at the East (A6) to 174.64 meters at the West (Z9). The range is small relative to the average of the differences. The range here is bigger than that of the North-South direction because the longitude difference from F1 here is bigger than that of North-South direction. Again the longitude difference depends on the East-West distance from F1.

Horizontal Resultant Differences: In the East-West direction, again the behavior of the longitude differences are affecting the resultants behavior because they have bigger values than their corresponding latitude differences.
4-1-3 Coordinate Differences in Group 3 (Eastern Desert Points)

Table (3): Differences between local and WGS-84 coordinates in Eastern Desert (Network 2).

Point	Dist from F1 (km)	Azimuth to F1 (Deg)	Diff-phi (m)	Diff-lam (m)	Result-Diff (m)
B11	313.0	139	11.25	181.64	181.99
B20	535.8	146	9.08	180.83	181.06
B19	788.8	149	11.19	174.36	174.72

Latitude differences at the three points in the Eastern Desert do not show a trend.
Longitude differences at the three points in the Eastern Desert increase from the East to the West direction but with irrigular rate.

The horizontal resultant differences are affected mainly by the longitude differences because they have bigger values than their corresponding latitude differences.

4.2 Coordinate Differences in Group 4 (Western Desert Points)

Table (4): Differences between local and WGS-84 latitudes in Western Desert (Network 2).

Point	Dist from F1	Azimuth to F1	Diff-phi	Diff-lam	Result-

	(km)	(Deg)	(m)	(m)	Diff (m)
C17	519.6	221	23.96	150.62	152.51
I15	530.2	200	12.91	164.33	164.84
A16	664.4	188	1.39	167.23	167.24

For the latitude differences, the three points in the Western Desert show a trend in the north south direction, the rate here is different from the rate of group 1.

For the longitude differences, on the opposite of the Eastern Desert case, longitude differences at the three points in the Western Desert decrease from the East to the West direction.

For the horizontal resultant differences, again the behavior of the longitude differences are affecting the resultants behavior because they have bigger values than their corresponding latitude differences.

4-2 Distortions in the Local Coordinates of the Network

Recalling that WGS-84 coordinates are datum shifted to the local datum and the resulted coordinates are named (LD-1), the original local coordinates are named (LD). The disortions in the local coordinaes are obtained as the differences between (LD-1) and (LD) coordinates. Distortions in latitudes and longitudes are computed, tabulated, and illustrated as well as their resultants. The available data points are devided into 4 groups as follows:

4-2-1 Distortions in Group 1: North-South Direction (Network 1)

The distortions in latitudes, longitudes, and horizontal resultants of the local datum at the available points in the North-South direction are computed and tabulated as follows:

Table (5): Distortions at the available stations in North-South sections
from group 1-Network 1.

Point	Dist from F1 (km)	Azimuth to F1 (Deg)	Δφ (m)	Δλ (m)	Resultant (m)
O1	19.8	161	0.14	-0.16	0.22
A2	112.6	186	1.34	0.28	1.37
L2	209.5	193	2.53	0.92	2.70
S2	298.6	194	3.46	0.55	3.50
B3	299.7	182	3.23	0.15	3.23
A3	306.7	180	3.03	0.06	3.03
T2	309.8	189	3.44	0.30	3.45
M3	459.5	169	2.91	-1.99	3.52
B4	504.7	165	2.03	-2.92	3.55
A4	505.0	164	2.05	-2.71	3.40
P4	672.0	165	1.94	-4.69	5.08

A5	681.1	167	2.19	-4.87	5.34
E5	747.2	168	2.66	-6.16	6.71
L5	808.2	176	4.28	-6.89	8.11
O5	843.2	178	4.72	-7.13	8.55
Q5	859.5	179	4.79	-7.30	8.73
Y5	867.1	178	4.77	-7.39	8.79
R5	877.9	178	4.85	-7.50	8.93

Latitude distortion: Looking at Table (5) and Figure (8), latitude distortions in the first five sections of Network 1 are undulating. They increase through Sections 1 and 2 then decrease through Sections 3 and 4 then increase again through Section 5. The maximum value is obtained at the extreme south (R5) with 4.85 meters value.

Longitude distortion: Looking at Table (5) and Figure (9), the longitude distortion in the first five sections of Network 1 is increasing to the south direction until point (L2), then it decreases starting from (S2) till the extreme south (R5) with value –7.5 meters. It is noticed that the points lying East of (F1) are shifted to the East direction and the points lying to the West of (F1) are shifted to the West direction. The longitude distortion in Sections 1, 2, and 3 is less than its corresponding latitude distortion, while in Sections 4 and 5 the opposite is true. Station (T2) shows somehow irregular behavior with the other points. It could be said that until 500 km approximately and in both directions North-South and East-West from F1, the longitude distortion is bigger than the latitude distortion at the same point. After 500 km, the longitude distortion becomes less than the latitude distortion at the same point.

Horizontal resultant distortion: From Table (5) and Figure (10), the horizontal distortion in the first five sections of Network 1 increases with the distance to the south except the area between (S2) and (A4). The relative horizontal distortion at the south of Network 1 reaches 1: 100,000. The horizontal distortion can be interpreted as scale and orientation distortions. The scale distortion increases to the south direction until the base line A3-B3, then it is somehow stable till the base line A4-B4, and then increases till the extreme south of the network. From F1 and to the south till the base line A3-B3, the orientation distortion goes to south direction with little inclination to the east. From M3 the orientation distortion goes to the south-west direction till the extreme south.

4.3 Distortions in Group 2: East-West Direction (Network 1)

Table (6): Distortions at the available stations in East-West sections from group 2-Network 1.

Point	Dist from F1 (km)	Azimuth to F1 (Deg)	Δφ (m)	Δλ (m)	Resultant (m)
F6	17.3	70	-0.08	-0.07	0.11
O1	19.8	161	0.14	-0.16	0.22
E7	68.7	252	0.23	0.68	0.71
A6	128.4	85	-0.93	0.42	1.02

N7	140.3	279	-0.20	0.90	0.92
D8	242.4	292	0.04	1.30	1.30
X8	427.9	290	0.66	2.31	2.40
Z9	584.3	285	2.11	2.16	3.01

Latitude distortion: The latitude distortion increases from the East (A6) to the West direction, then it is dropped at (N7) and increases again till the extreme West with 2.11 meters value. It is also undulating like the north-south direction.

Longitude distortion: From Table (6) and Figure (9), starting from F1, the longitude distortion is increasing to the east direction through Section 6 and increasing also towards the west direction through Sections 7 and 8. The reduction happened at (Z9) needs more data to be clarified, whether it is specific to the point itself or it is concerning the points between (X8) and (Z9), Section 9. Longitude distortion in Sections 7, 8, and 9 is greater than its corresponding latitude value. The longitude and latitude distortions are nearly in balance in Section 6. From F1 and going to the west direction, the longitude distortion is greater than its corresponding latitude value until X8. Longitude and latitude distortions are nearly equal at Z9. the same notice is true from F1 and going to the south direction until M3 regarding that both M3 and X8 have roughly the same distance from F1. Starting from the base line A4-B4 in the south direction, the longitude distortion became smaller than its corresponding latitude value.

Horizontal resultant distortion: From Table (6) and Figure (10), the horizontal distortion increases from (F1) in both east and west directions. The scale distortion increases to the west direction until the extreme west Z9. From F1 and to X8, the orientation distortion goes to east direction with little inclination to the south. At Z9 it goes to the south-east direction.

4.4 Distortions in Group 3: Eastern Desert (Network 2)

Table (7): Distortions at the available stations in Eastern Desert (Network 2).

Point	Dist from F1 (km)	Azimuth to F1 (Deg)	Δφ (m)	Δλ (m)	Resultant (m)
B11	313.0	139	2.19	-2.59	3.39
B20	535.8	146	1.69	-3.95	4.29
B19	788.8	149	-3.24	-6.16	6.96

Latitude distortion: The latitude distortion at the three points in the Eastern Desert decreases to the south direction, Figure (8).

Longitude distortion: The longitude distortion in Sections 23 and 20, parallel to the Red Sea, is increasing in its magnitude with the north-east direction, Figure (9).

Horizontal resultant distortion: The three points in the Eastern Desert increase in their horizontal distortion to the direction south-east, Figure (10).

4.5 Distortions in Group 4: Western Desert (Network 2)

Table (8): Distortion at the available stations in Western Desert (Network 2).

Point	Dist from F1 (km)	Azimuth to F1 (Deg)	Δφ (m)	Δλ (m)	Resultant (m)
C17	519.6	221	-4.86	20.77	21.33
I15	530.2	200	3.32	7.41	8.12
A16	664.4	187	12.31	3.47	12.79

Latitude distortion: The latitude distortion at the three points in the Western Desert increases to the south direction till it reaches 12.31 meters at (A16) which is big value compared to the other groups, Figure (8).

Longitude distortion: The longitude distortion in the three points in the Western Desert decreases with the south-west direction. The value at (C17) is relatively big compared to the values at the other points in the network, Figure (9).

Horizontal resultant distortion: The horizontal distortion in the Western Desert points has big values and has no trend, Figure (10).

5. IMPROVING THE ACCURACY OF THE LOCAL NETWORK

It is well known that the existed error (distortion) in the local network is classified into gross, systematic, and random errors. The trial here, to improve the accuracy of the network, deals with the systematic part. In the last section, the latitude and longitude distortions at the available stations are calculated according to the concept of this research. Those stations will be treated here as markeres through out the other network stations. First, second, and third order polynomials are suggested to fit the distortion values as function of the distance of the station from the initial point (F1) and also the azimuth of the line between the station and (F1). The model is suggested to be generalized to all the network stations for improving their accuracy in latitude and longitude. The available stations are only enough for modeling the North-South direction (Group 1) in 1st , 2nd , and 3rd orders. They are enough for modeling the East-West direction (Group 2) only in 1st and 2nd orders.

5.1 Modeling Group1 (North-South Direction)

First, second, and third order polynomials are applied to the data points and the coefficients are computed, the residuals (at the data points) of the solutions are also computed. The residuals at check points are computed when there are available points. The results were as follows:

Table (9): Latitude residuals of the fitting polynomials for Group1 (North-South direction)-solution points

point	Azimuth (Deg)	Dist (km)	Latitude Residuals (m)		
Solution Points			1 st order	2nd order	3rd order
O1	161	19.8	0.26	-0.02	-0.01
A2	186	112.0	-0.64	-0.01	0.03
L2	193	209.5	-0.34	0.09	-0.06
S2	194	298.6	0.16	-0.06	0.04
A3	180	306.7	0.66	-0.09	-0.03
M3	169	459.5	0.66	0.17	0.01
A4	164	505.0	-0.04	0.06	0.06
A5	167	681.1	-0.84	-0.27	-0.17
E5	168	747.2	-0.71	0.10	0.09
L5	176	808.2	0.11	-0.01	0.07
O5	178	843.2	0.27	0.01	0.06
Q5	179	859.5	0.20	-0.14	-0.10
R5	178	877.9	0.25	0.17	-0.01
Abs sum			**4.68**	**1.2**	**0.74**
lavgl			**0.36**	**0.09**	**0.06**
Stdv			**0.25**	**0.07**	**0.04**

From the above table, the third order polynomial fits the solution points better than the other two polynomials. The third order polynomial fitted the data with 1 cm as minimum, 17 cm maximum, and 5 cm average.

The latitude residuals at four check points are computed to investigate the quality of the proposed polynomial in the north-south direction (the first five sections) and the results were as follows:

Table (10): Latitude residuals at check points of the fitting polynomials for Group1 (North-South direction)-check points.

Point	Azimuth (Deg)	Dist (km)	Latitude Residuals (m)		
check Points			1 st order	2nd order	3rd order
B3	182	299.7	0.75	0.05	0.20
B4	165	504.7	-0.13	-0.14	-0.18
P4	165	672.0	-0.91	-0.10	0.07
Y5	178	867.1	0.22	0.08	-0.02
Abs sum			**2.01**	**0.37**	**0.47**
lavgl			**0.50**	**0.09**	**0.11**

Point	Azimuth (Deg)	Dist (km)	Latitude Residuals (m)		
Stdv			**0.33**	**0.03**	**0.07**

For the check points, the second and third order polynomials gave nearly same results. For the check points, the third order polynomial gave 20 cm as maximum residual, therefore it could be said that the latitudes of the first five sections in the local network can be improved within those 20 cm. It should be mentioned that this conclusion is drawn from the available used data in this research.

The longitude residuals are computed at the solution points and the results were as follows:

Table (11): Longitude residuals of the fitting polynomials for Group1 (North-South direction)-solution points.

Point	Azimuth (Deg)	Dist (km)	Longitude Residuals (m)		
Solution Points			1 st order	2nd order	3rd order
O1	161	19.8	-1.32	0.01	0.01
A2	186	112.0	-1.12	-0.14	-0.04
L2	193	209.5	0.20	0.15	0.07
S2	194	298.6	0.71	-0.12	-0.06
A3	180	306.7	0.98	0.21	0.04
M3	169	459.5	1.06	-0.10	-0.01
A4	164	505.0	1.06	-0.03	-0.09
A5	167	681.1	0.59	0.17	0.27
E5	168	747.2	-0.06	-0.02	-0.15
L5	176	808.2	-0.53	-0.33	-0.14
O5	178	843.2	-0.51	-0.07	0.03
Q5	179	859.5	-0.55	-0.01	0.04
R5	178	877.9	-0.51	0.29	0.03
Abs sum			**9.2**	**1.65**	**0.98**
lavgl			**0.70**	**0.12**	**0.07**
Stdv			**0.36**	**1.14**	**0.07**

From Table (11), the third order polynomial fits the solution points better than the other two polynomials. The third order polynomial fitted the data with 1 cm as minimum, 27 cm maximum, and 7 cm average.

Table (12): Longitude residuals of the fitting polynomials for Group1

(North-South direction)-check points

Point	Azimuth (Deg)	Dist (km)	Longitude Residuals (m)		
check Points			1 st order	2nd order	3rd order
B3	182	299.7	0.90	0.17	-0.01
B4	165	504.7	0.80	-0.30	-0.30
P4	165	672.0	0.77	0.35	0.30
Y5	178	867.1	-0.52	0.17	0.03
Abs sum			**2.99**	**0.99**	**0.64**
lavgl			**0.74**	**0.24**	**0.16**
Stdv			**0.13**	**0.07**	**0.14**

For the check points, the third order polynomial gave better results than the other two polynomials. For the check points, the third order polynomial gave 30 cm as maximum residual, therefore it could be said that the longitudes of the first five sections in the local network can be improved within those 30 cm. Again it should be mentioned that this conclusion is drawn from the available used data in this research.

5.2 Modeling Group 2 (East-West Direction)

First and second order polynomials are established to the data points and the coefficients are computed, the residuals (at the solution points) are also computed. The results were as follows:

Table (13): Latitude residuals of the fitting polynomials for Group2 (East-West direction)-solution points.

Point	Azimuth (Deg)	Dist (km)	Latitude Residuals (m)	
Solution Points			1st order	2nd order
F6	70	17.3	0.39	0.01
O1	161	19.8	0.52	-0.03
E7	252	68.7	0.37	0.10
A6	85	128.4	-0.82	0.00
N7	279	140.3	-0.31	-0.16
D8	292	242.4	-0.40	0.09
X8	290	427.9	-0.36	-0.02
Z9	285	584.3	0.61	0.00
Abs sum			**3.78**	**0.41**

IavgI			**0.47**	**0.05**
Stdv			**0.02**	**0.00**

From the above table, the second order polynomial fits the solution points better than the first order one. The second order polynomial fitted the data with 0.0 cm as minimum, 16 cm maximum, and 5 cm average. There are no available redundant points to be used for checking the solutions.

Table (14): Longitude residuals of the fitting polynomials for Group2 (East-West direction)

Point	Azimuth (DEG)	Dist (km)	Longitude Residuals (m)	
Solution Points			1st order	2nd order
F6	70	17.3	0.06	0.04
O1	161	19.8	-0.32	-0.11
E7	252	68.7	0.08	0.22
A6	85	128.4	0.13	-0.01
N7	279	140.3	-0.02	-0.07
D8	292	242.4	-0.01	-0.21
X8	290	427.9	0.37	0.23
Z9	285	584.3	-0.29	-0.08
Abs sum			**1.28**	**0.97**
IavgI			**0.16**	**0.12**
Stdv			**0.01**	**0.00**

From the above table, the second order polynomial fits the solution points better than the first order one. The second order polynomial fitted the data with 1 cm as minimum, 23 cm maximum, and 12 cm average. There are no available redundant points to be used for checking the solutions.

In Group 1 solutions, the maximum latitude residuals at solution and check points were 17 and 20 cm respectively and for longitude residuals they were 27 and 30 cm respectively. So, the residuals at the check points are not far from the residuals at the solution points. The same could be concluded for Group 2 (Sections 6, 7, 8, and 9) where there are no check points.

5.3 Comparing the Results of the Proposed Model and Rigorous Adjustment

Awad performed a rigorous adjustment trials of the geodetic triangulation network in Egypt [Awad, 1997]. Both Network 1 and Network 2 were adjusted as one block and a geoid model was used. The coordinates of sixteen stations from this adjustment are available for this research. The WGS-84 shifted coordinates (LD-1) can be considered as the best accurate coordinates in Egypt. The differences between (LD-1) coordinates and both Awad and the proposed model coordinates are computed. The differences are computed to show which is nearer to the accurate reference (LD-1), the traditional adjustment or the proposed model. It should be mentioned that this comparison is made using the available 16 stations.

Table (15): Coordinate differences between LD-1, Awad and the proposed model

	(LD-1) – (Awad)		(LD-1) - Model	
Point	Latitude diff. (m)	Longitude diff. (m)	Latitude diff. (m)	Longitude diff. (m)
O1	-0.10	0.16	-0.01	0.01
A3	-1.56	-0.17	-0.03	0.04
B3	-1.75	-0.25	0.20	-0.01
M3	-0.82	1.03	0.01	-0.01
A4	-0.11	1.84	0.06	-0.09
B4	-0.09	2.11	-0.18	-0.30
A5	-0.36	4.22	-0.17	0.27
O5	-3.96	6.25	0.06	0.03
Q5	-4.11	6.42	-0.10	0.04
A6	0.90	-0.60	0.00	-0.01
F6	0.06	0.08	0.01	0.04
E7	-0.22	-0.52	0.10	0.22
N7	-0.07	-0.72	-0.16	-0.07
D8	-0.76	-1.61	0.09	-0.21
X8	-1.90	-3.26	-0.02	0.23
Z9	-2.74	-3.90	0.00	-0.08

Without statistics of the values in the table, it is clear that the proposed model is closer to the accurate reference than the rigorous adjustment at the available stations.

6. CONCLUSIONS

The case of the geodetic triangulation network in Egypt is clarified in the introduction of this research and the goal of the research is defined. The coordinates of the available stations in WGS-84 have much accuracy than the corresponding coordinates in the local datum. Some studies showed that the accuracy of the coordinates in Network 1 of Egypt is around 1:100,000 while that of HARN coordinates is 1:10,000,000. So, the available 32 common points in this research can be used to improve the accuracy of the local network. The research included three main parts. The first part is illustrating the differences in latitudes and longitudes between WGS-84 and the local datum at the available 32 common stations. The second part is computing the distortion in latitudes and longitudes at the available stations which are distributed over large part of the country. The third part is interpreting those distortions and modelling them in a simple model. Depending on this simple model, latitude and longitude of any local network station could receive correction to improve its accuracy. Finally, a comparison between both [Awad, 1997] adjustment and the proposed model against the accurate reference (LD-1) is made. The results of this work showed that:

- The latitudes of Network 1 can be improved to approach the datum shifted WGS-84 accurate values with about 20 cm in its maximum case.
- The longitudes of Network 1 can be improved to approach the datum shifted WGS-84 accurate values with about 27 cm in its maximum case.
- The proposed model is much closer to the accurate reference than the rigorous adjustment <u>at the available stations</u>.
- It should be mensioned that those results are obtained through the available common stations.
- More points with high accurate WGS-84 coordinates are needed to assure those results and to make them more realistic.

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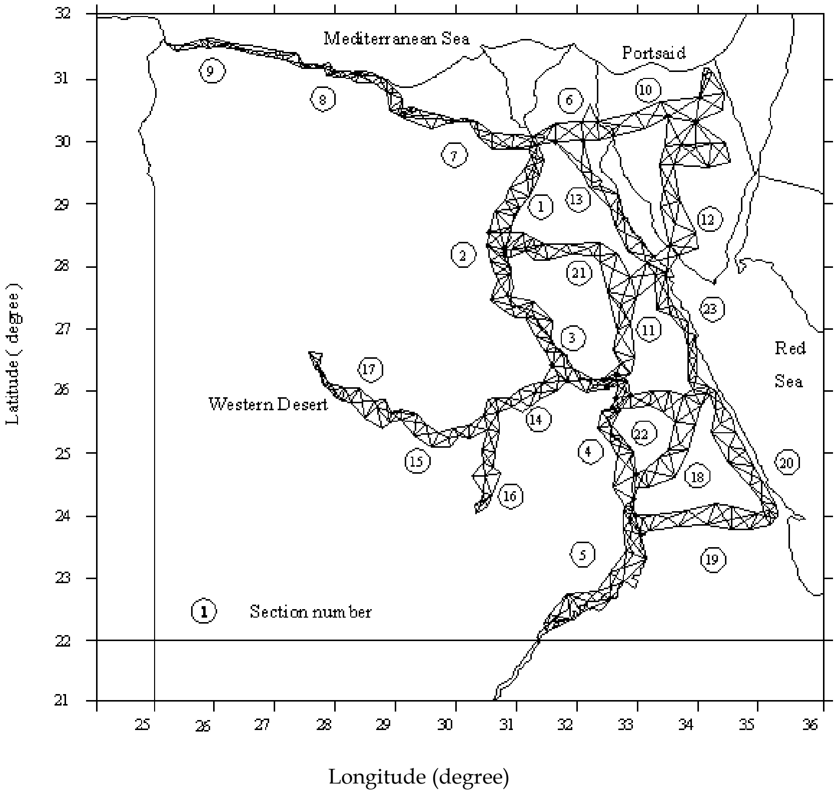
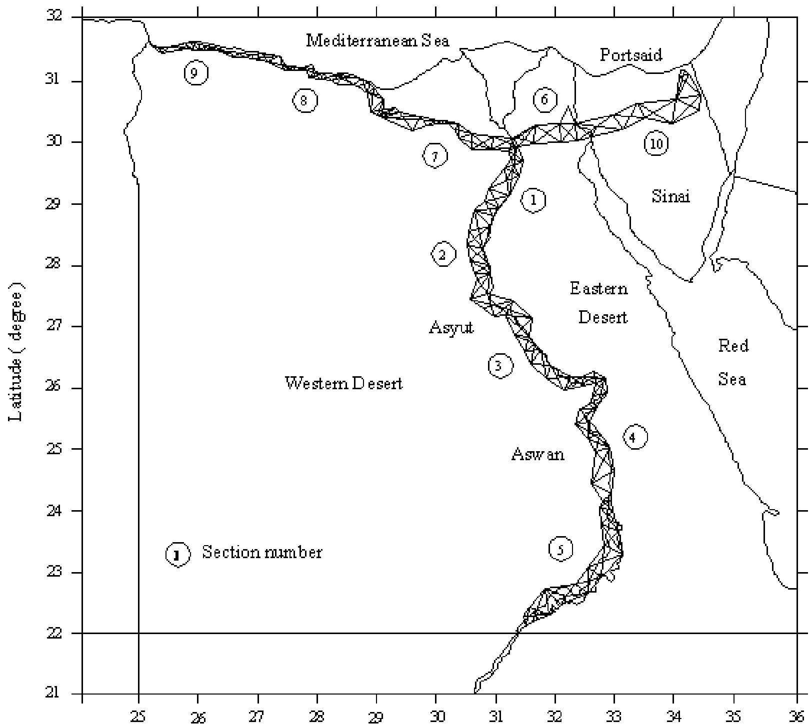
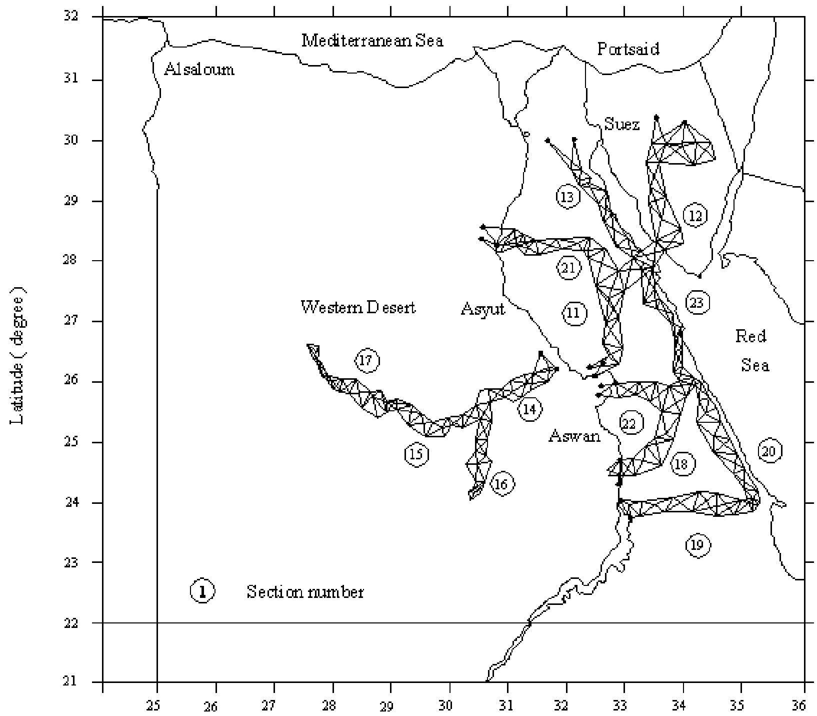


Figure (1): The Egyptian First Order Triangulation Networks.



Longitude (degree)

Figure (2): Network 1 of the Egyptian First Order Triangulation.



Longitude (degree)

Figure (3): The Egyptian First Order Triangulation Network.

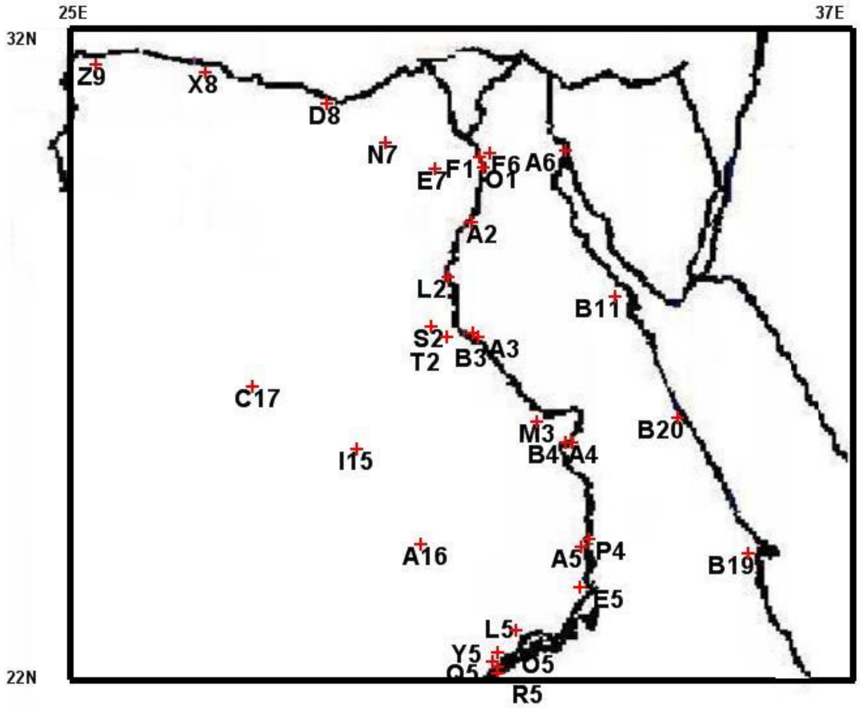


Figure (4): The Available Data Points Used in the Research.

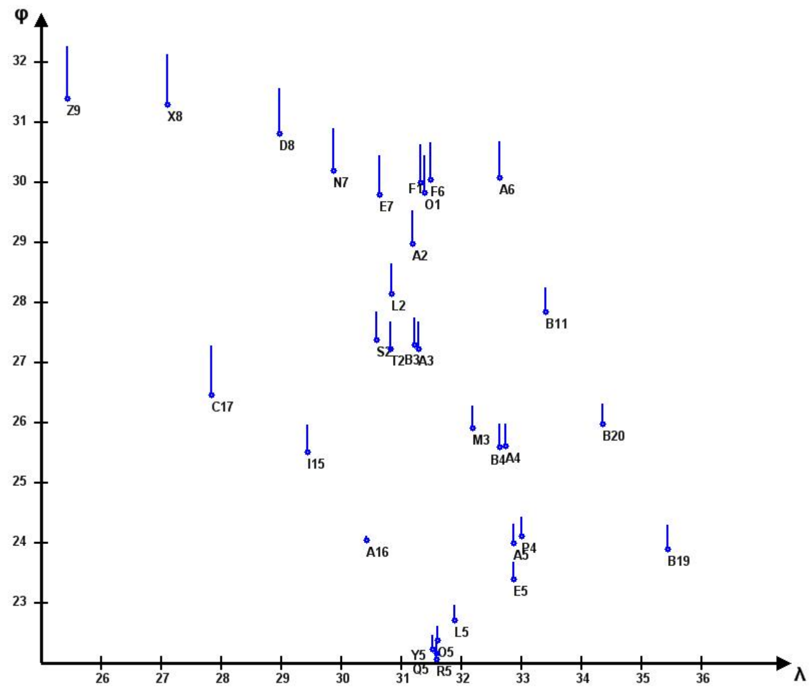


Figure (5): Latitude Differences Between the Egyptian Datum and WGS-84.

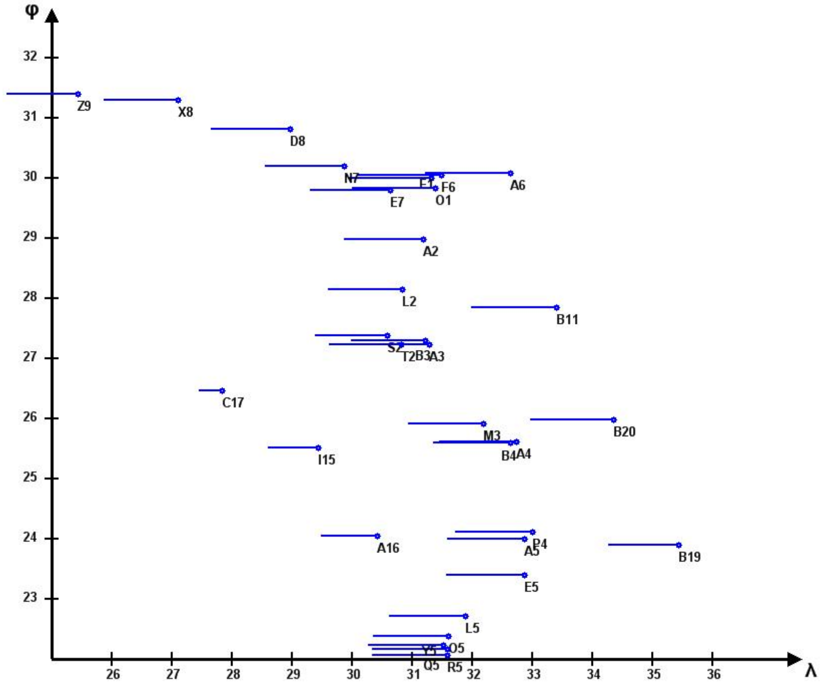


Figure (6): Longitude Differences Between the Egyptian Datum and WGS-84 (Represented after subtracting 140 m from every value).

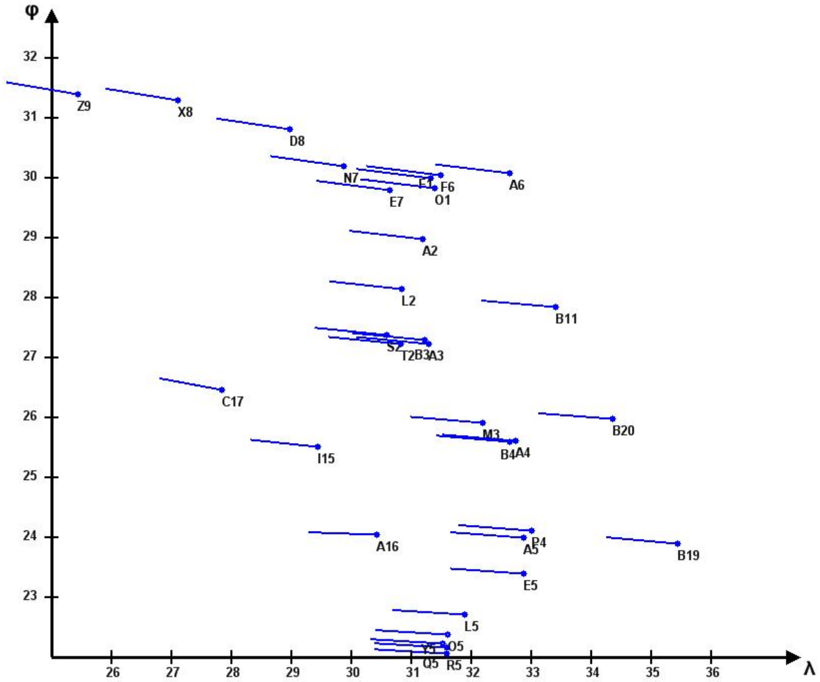
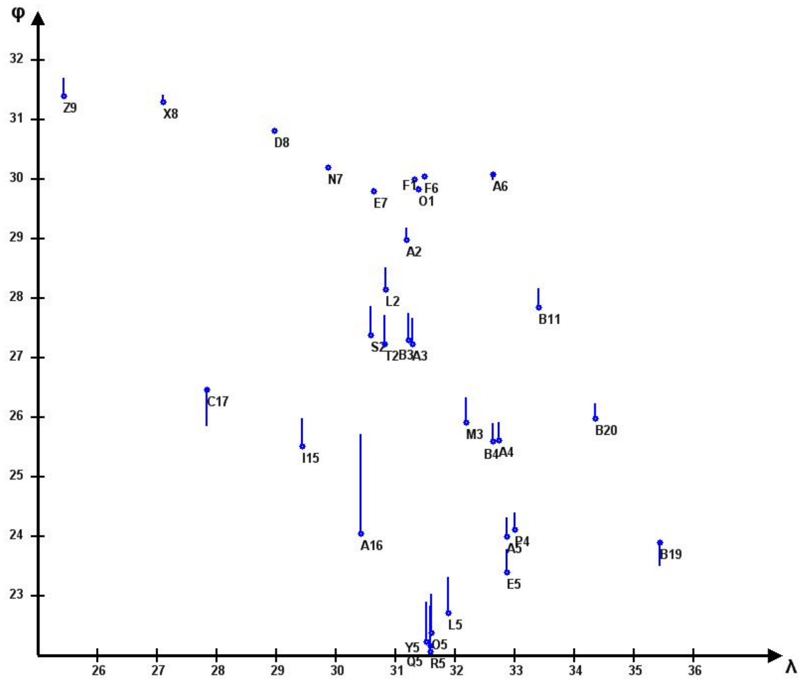


Figure (7): Horizontal Resultant Differences Between the Egyptian Datum and WGS-84.



Figure(8): Latitude Distortion in the Egyptian Datum at the Available Data Points.

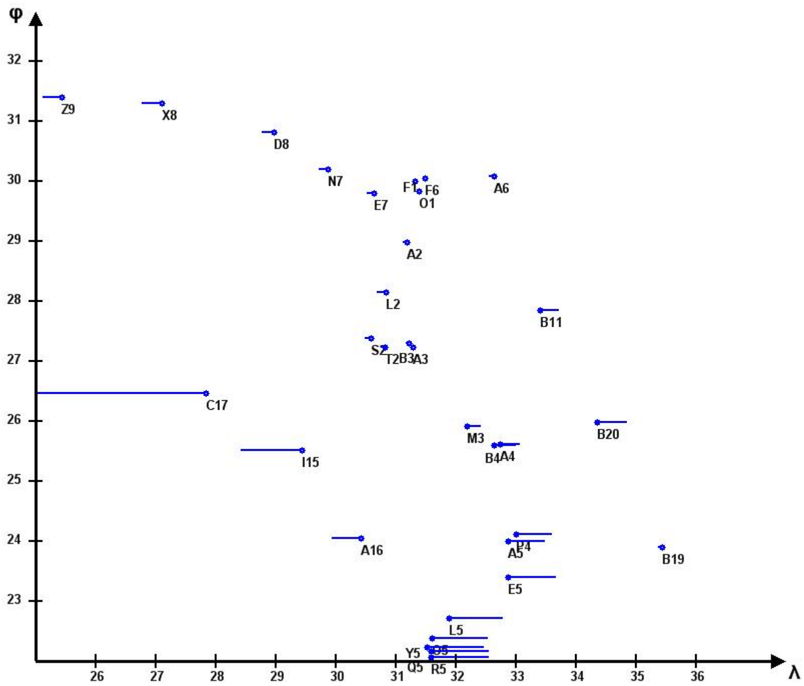
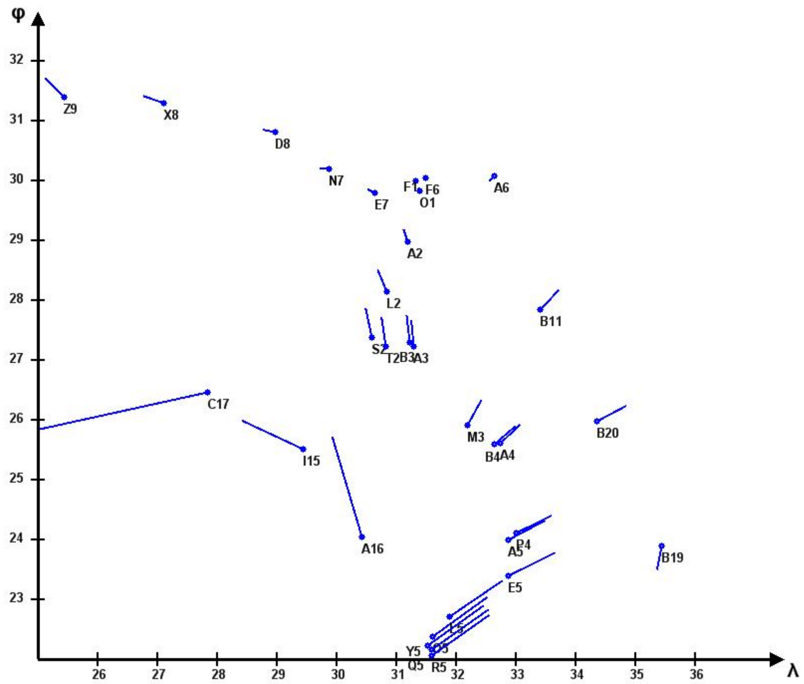


Figure (9): Longitude Distortion in the Egyptian Datum at the Available Data Points.



Figure(10): Horizontal Resultant Distortion in the Egyptian Datum at the Available Data Points.

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