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Investigating the Geometrical Problems Related to the Redifinition of the Egyptian Geodetic Datum

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Abstract- **Ain Shams University proposed, on 2006, the DMT software package which can transform any digital map from the old system to another in few seconds. This software has some limitations that should be overcome to convey the current operational requirements. Furthermore, the transformation of these maps from EGD30 into WGS84 will certainly produce some geometrical problems in the features existing in the maps. Of these geometrical problems, which has great importance, is the deformation or distortion in the geometric area property of the features. Hence, the purpose of this investigation is to update the DMT solution for transforming the digital maps from the old datum into the new one. Moreover, the geometrical problems, especially the area distortion, associated with this transformation, will be investigated. Therefore, new software, named M-DMT (Modified-Digital Map Transformer), has been developed using the Visual Basic.Net programming language which can transform the map existing in a digital DXF format from any mapping system into another accurately in few seconds. It can transform the map between ETM and UTM for all involved zones, between ETM and MTM for all included zones, and between UTM and MTM for all included zones as well. The transformation in this software is achieved based upon many datum transformation approaches such as Bursa, Molodensky, 2-D poly-zone, or 3-D surface polynomial. The user of this software can create a set of transformation parameters based on any of these transformation approaches. The M-DMT can transform the map point by point with the same accuracy as that of the transformation parameters used.**

In addition, the deformation in the area property of the polygon features constituting the map, due to the transformation from ETM into UTM and from ETM into MTM based on the poly-zone and ESA transformation parameters, is to be studied. The behavior of this distortion is investigated taking into mind three factors which are the location of the feature, the area of the polygon, and the geometry of the polygon. The study involves the distortion behavior all over Egypt; besides the maximum and minimum distortion values are noticed. Finally, new reliable software, named the DISTORTION CALC program, is developed, by which the deformation in area encountered during transforming the map from ETM into UTM or from ETM into MTM can be predicted anywhere in Egypt.

Key words- **Map transformer software ; (M-DMT) software ; Area distortion behavior ; Area deformation ; Coordinate system transformation; Area distortion calculator software ;Coordinate system transformation software ; Redefinition of the Egyptian Datum.**

I. INTRODUCTION

The basic geodetic datum used locally in Egypt is known as EGD30, whose reference ellipsoid is a non-geocentric ellipsoid of Helmert 1906. The map projection system used in Egypt is the Egyptian Transverse Mercator system (ETM). In other words, all the geodetic control networks (with different orders of accuracy) and the associated produced maps (with different scales) in Egypt have been established by the Egyptian Survey Authority (ESA) relative to EGD30 and the related grid system (ETM). On the other hand, there is a global geocentric geodetic datum known as WGS84 whose reference ellipsoid is known as GRS80 [1]. The map projection system related to WGS84 geodetic datum is known as the universal Transverse Mercator system (UTM) [2].

There is no doubt that the GPS techniques are more accurate, more efficient, time saving, weather independent, with high productivity, and more rapid compared to the traditional techniques. They need less expertise for operation, less man power, and no intervisibility between stations is required. Also, GPS positioning does not suffer from the problem of error accumulation [3], [4]. This makes GPS surveying techniques, related to WGS84, to be superior over the other traditional techniques. WGS84 can be considered as a unified geodetic datum for the entire world. Furthermore, ETM projection systems have many disadvantages [5], [6].

ESA decided to replace the current EGD30 and associated projection system (ETM) with the WGS-84 and associated projection system (UTM) [6]. In addition to that, ESA has been proposed a new projection system called the Modified Transverse Mercator (MTM) which is related to the global positioning system WGS-84. In this way, ESA will produce all the surveying operations, control points, and maps relative to the new datum (WGS-84) and its associated grid systems (UTM & MTM). For this purpose, ESA established a High Accuracy zero order GPS Reference Network (HARN), known as the New Datum, based on the new global satellite positioning system GPS measurements [7].

That replacement of the Egyptian geodetic datum will result in many problems to be faced. First of all, ESA has a huge data, of a great historical and economical value, related to the old datum. These data are the traditional triangulation networks with different orders and the associated topographic maps, existing as hard copy or soft copy, with different scales. Besides, many private firms and organizations have already carried out their own mapping operations relative to the old datum. Then, to preserve those historical and economical efforts, the mapping system of all those huge old data should be transformed to the new one. In addition to that, further extensions of the old maps using the modern GPS technology can be executed easily. This means that combining the terrestrial data and the satellite data will be possible. For these reasons, ESA formed a joint committee with respective researchers at Ain Shams University, to carry out many investigations concerning the consequences of such decision on the past, present, and future surveying work in Egypt[5], [8]. From these important investigations are those made by [El-Tokhey, 2000] and [Mogahed, 2006] which have introduced a new transformation parameters sets [9], [10]. In addition, new software, named DMT, was developed for transforming the map from the old datum into the new one in few seconds [9].

However, the DMT program needs to be updated. It is designed only to transform the mapping system from ETM Red zone to UTM-36N zone only based on the poly-zone transformation parameters only. The transformation from the ETM system to the MTM one is not available. In addition to that, the inverse transformations; from UTM into ETM and from MTM into ETM and from MTM into UTM and vice versa, are not completed. Unfortunately, after the transformation of the mapping systems either using the DMT or any other methodology, some problems will arise. In other words, there may be distortions in positions, scale, areas, distances, shapes, orientations, or angles. Then, geometric problems will arise due to the redefinition of the Egyptian geodetic datum. Of the geometrical problems, the area distortion is of great importance, because the cadastral issues and the taxes management depend on the areas of parcels.

All the above problems, associated with the transformation to the adopted new WGS84 datum, have been the basic motivation behind undertaking the present investigation. Therefore, there are three objectives of the current research. The first is updating and developing the current DMT software to be capable for transforming the maps among the various projection systems through all zones involved in each one. Also, it is intended for the software to permit the datum transformation based on any transformation approach not only a single transformation parameters set. The second is investigating the deformation in the feature area that occurred due to transforming the mapping system from ETM into UTM and MTM based on both the poly-zone and ESA parameters. Finally, the third objective is developing a new program for computing and predicting the distortion which may occur in the feature area when transforming the map from the old datum into the new one anywhere in Egypt.

II. DEVELOPING THE M-DMT SOFTWARE:

The DMT software, produced previously on 2006 using the Fortran language, has been redeveloped and updated, using the Visual Basic.Net language, to be more applicable, faster, and reliable having the name of M-DMT(Modified Digital Map Transformer). In this context, this last program can be operated for many geodetic investigations especially those concerning the Datum transformations. As mentioned before, the old version of the DMT software has many limitations, and the newly developed software is proposed to overcome them. The M-DMT software consists of two parts, the first deals with the graphical maps and the second concerns with the individual geodetic points. In the first part of the M-DMT software, the input map, to be transformed, can exist in any version of CAD DXF format and outputs the result map also in any version of CAD DXF format that is available easily todays. The output digital map has the same layer properties as the input digital map such as line colors, line thickness…..etc. The software can transform, in few seconds, the map from ETM system including all zones, RED, PURPLE and BLUE, into the UTM system including all zones used for Egypt, UTM-36N and UTM-35N, and also into MTM with the all constituting zones, MTM-1, MTM-2, MTM-3, and MTM-4. As well, it involves the inverse transformation of the map, from UTM into ETM and from MTM into ETM including all mapping zones for each system. The transformation between the UTM and MTM systems, taking into account all their constituting zones, are not ignored in this software. The transformation can be carried out in any customized transformation parameters based on any one of the four datum transformation approaches, which are Molodensky, Bursa, surface polynomial, and the 2-D poly-zone method.

In the second part of this software, the coordinates of the geodetic points can be converted between the various positioning formats, e.g. curvilinear (φ, λ, h), Cartesian formats (X, Y, Z), and planar grid coordinates (Easting, Northing). This part of the software enables the user to create its own Ellipsoid, Projection system, or transformation parameters based on any datum transformation approach. Therefore, this software can be used for any further geodetic investigations in future. Hence, this M-DMT software will be the basic tool for conducting this investigation. Figure (1) illustrates the flow chart of the user main interface of the M-DMT package; Figure (2) shows the package main window from which any application of the software can be launched.

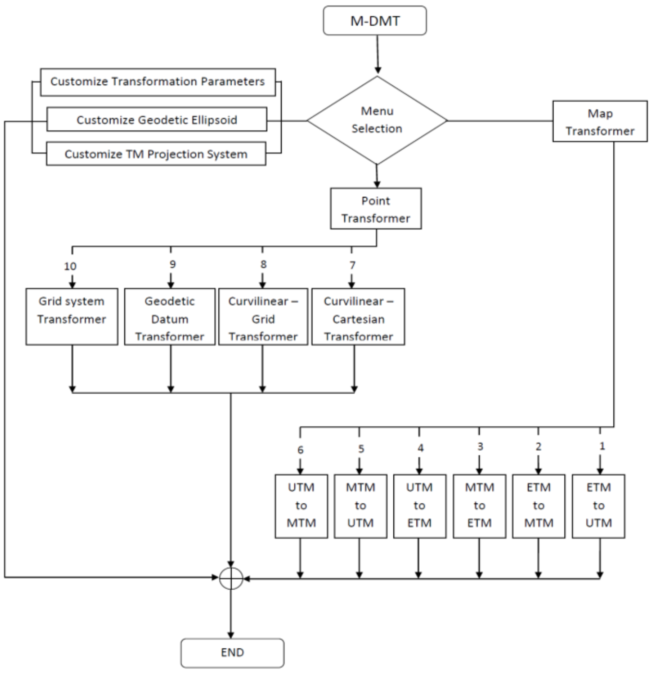

Figure (1) the flow chart of the user main interface of the M-DMT package

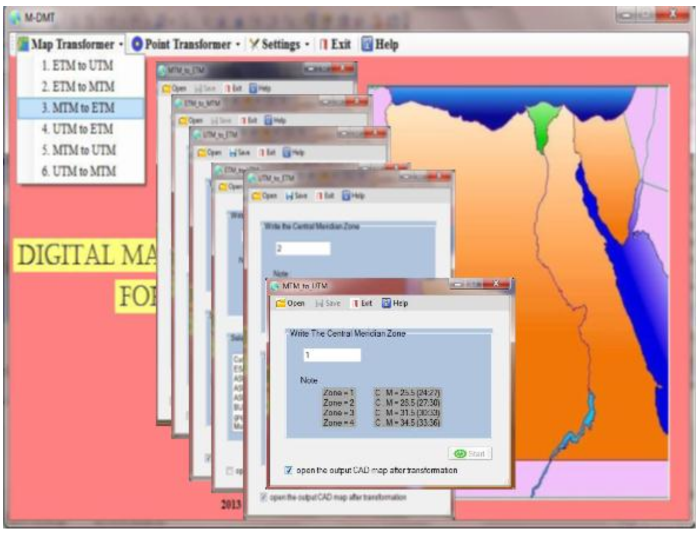

Figure (2) the package main window from which any application of the software can be launched

III. METHODOLOGY OF INVESTIGATION

In studying the area deformation occurred when transforming the map from ETM into UTM or from ETM into MTM, there are many zone-to-zone transformation possibilities. From figure (3), one should note that, the map having the projection system of ETM RED BELT may be transformed either into UTM-36 or UTM-35. This decision is made according to the map location in the ETM projection system; if the map lies between the 30o E and 33o E longitude, the appropriate UTM zone to which this map will be transformed is UTM-36. On the other hand, if the considered map lies between the 30o E and 29o E longitude, its appropriate corresponding UTM zone is the zone 35N. Similarly, the ETM PURPLE mapping zone corresponds to the zone 35N in UTM system, and the BLUE zone of the ETM system corresponds to the zone 36N in UTM system.

Also, there are five possibilities when transforming a map from ETM into MTM as shown in figure (4). The map having the projection system of ETM RED BELT may be transformed either into MTM-2 or MTM-3. This decision is made according to the map location in the ETM projection system; if the map lies between the 30o E and 33o E longitude, the appropriate MTM zone to which this map will be transformed is MTM-3. On the other hand, if the considered map lies between the 30o E and 29o E longitude, its appropriate corresponding MTM zone is the zone 2. Similarly, the map having the projection system of ETM Purple BELT may be transformed either into MTM-1 or MTM-2. This decision is made according to the map location in the ETM projection system; if the map lies between the 25o E and 27o E longitude, the appropriate MTM zone to which this map will be transformed is MTM-1. Otherwise, if the considered map lies between the 27o E and 29o E longitude, its appropriate corresponding MTM zone is the zone 2. Finally, the ETM Blue mapping zone corresponds to the zone 4 in MTM system.

For each zone-to-zone transformation possibility, mentioned above, three factors will be taken into mind during studying the area distortion, which are the position of the polygon, the area magnitude of the polygon, and the geometry of the polygon as follows:

In studying the relationship between the position and the distortion that may be encountered during transforming a map from the old system ETM into the new one UTM or MTM, a polygon of certain area and of a rectangular shape is selected to accomplish this study. For finding the overall behavior of the distortion through the zone under study, the study polygons are arranged in a grid form throughout the study zone, see figure (5).

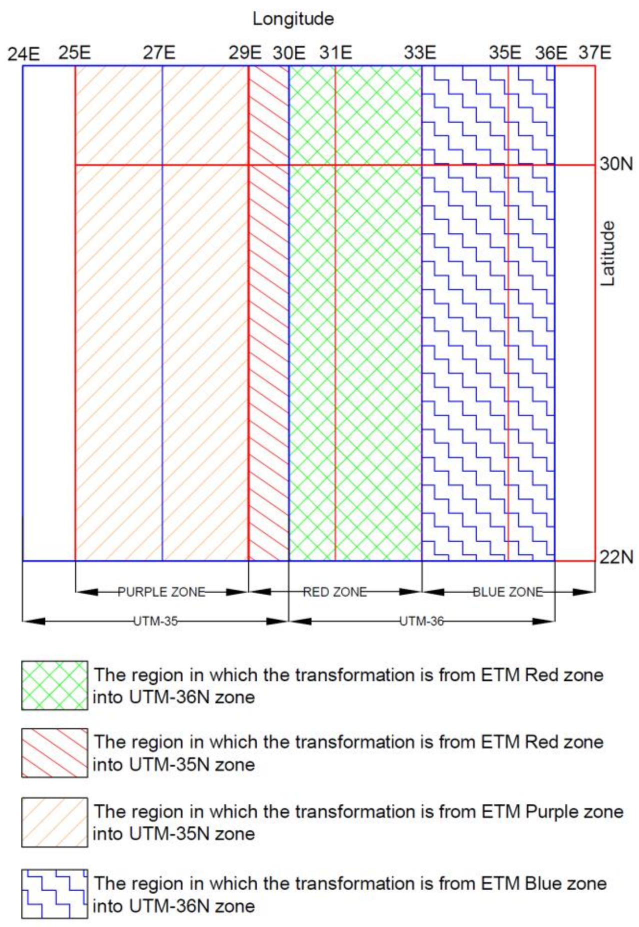

Figure (3) portrays the ETM system zones and their corresponding UTM system ones, (zone to zone transformation convenience)

These gridded polygons are transformed in the M-DMT software from the old system into the new one, also, using the poly-zone parameters in case of the first part and the official ESA parameters in case the second part. A new grid file is created, in which the data is the differences between the geometric area values of those polygons, relative to the ETM, and their corresponding ones relative to the UTM positioned at the x and y coordinates of the geometric centers of the corresponding polygons. The overall trend of the distortion can be overviewed by a contour graph manipulated from that latter grid file obtained. At this stage of study, the area and geometry properties of the polygons are kept constant, and only the position property is variable during the investigation.

In studying the relationship between the area magnitude of the polygon and area deformation that may be seen after the datum transformation, a group of the symmetrical study polygons, mentioned above, having the same geometric center, however having different area values, see figure (6), are transformed from the old datum to the new one using the two transformation parameters sets.

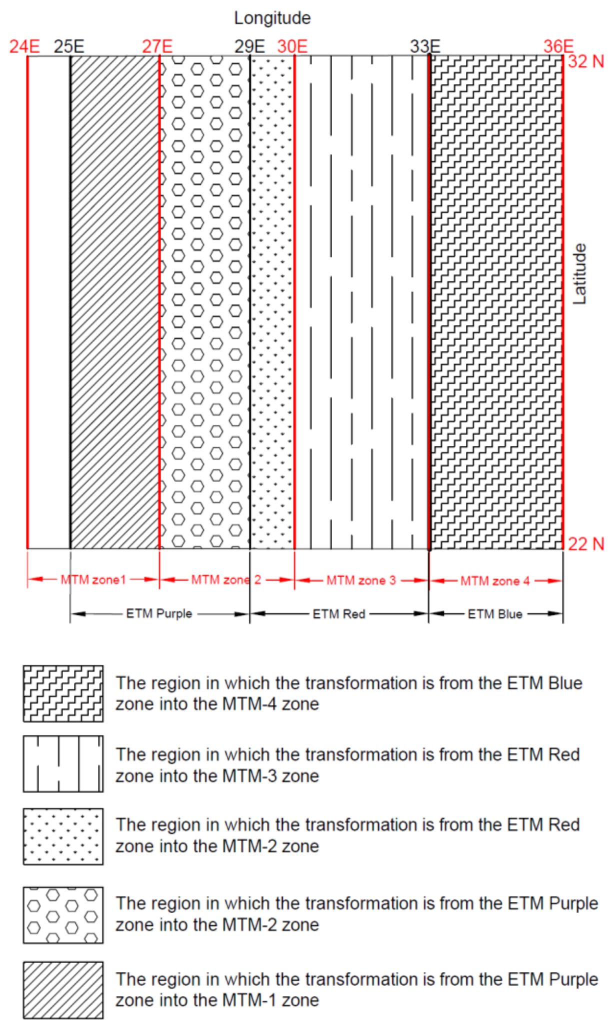

Figure (4) portrays the ETM system zones and their corresponding MTM system ones, (zone to zone transformation convenience)

This means that the position and geometry properties of the polygons will be kept constant, and only the area property will be variable during the study. The differences in area values between each rectangle in the old system and its counterpart in the new one are computed and filled in a table. Then, a graph demonstrating these results, in turn, the studied relation is presented.

In studying the effect of the geometry of the polygon on the area distortion percent, a group of polygons each of which have various complicated irregular geometry and having the same area values and the same geometric center of the rectangle best fitted to each irregular polygon, see figure (7). This means that the position and area properties of the polygons will be kept constant, and only the geometry property will be variable in the investigation here.

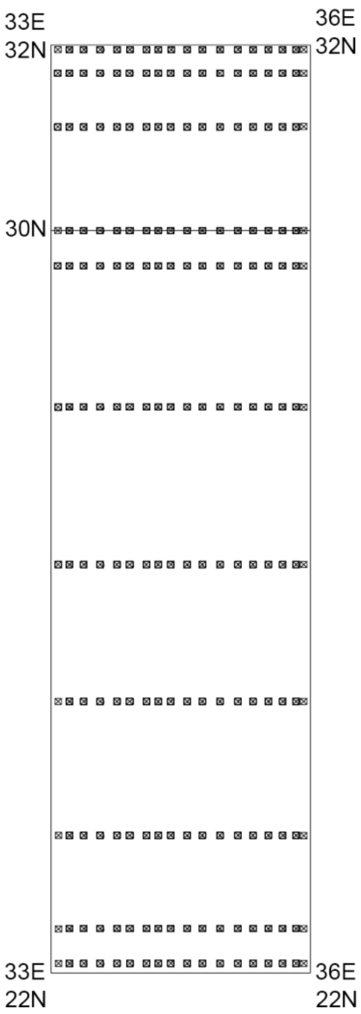

Figure (5) the grid form of the study polygons in case of investigating the area distortion

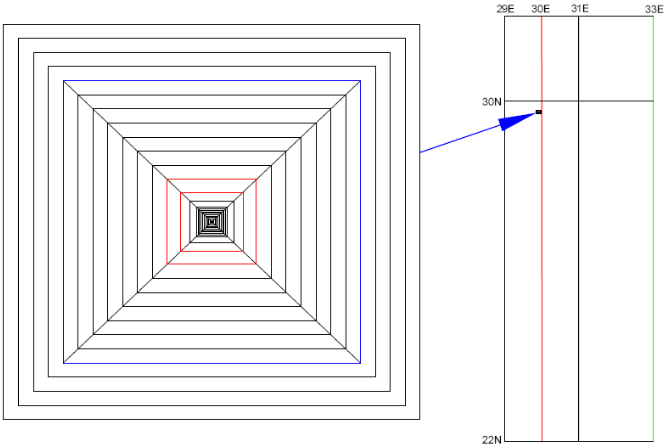

Figure (6) a group of rectangles having different areas and have the same geometric center positioned at a certain location

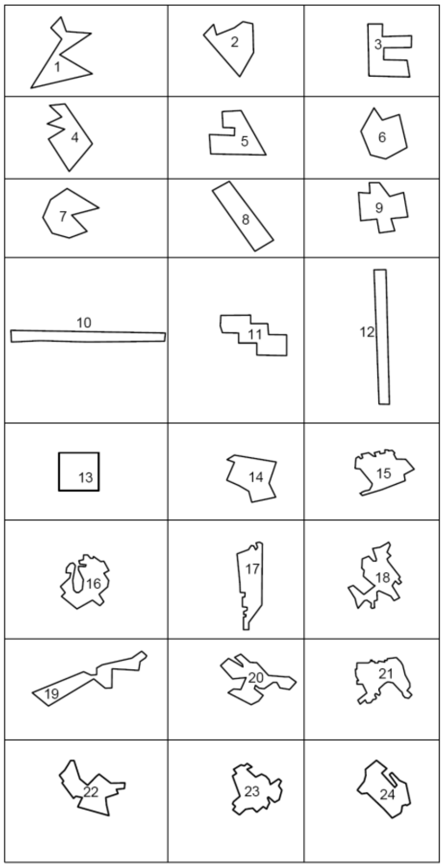

Figure (7) displays the irregular geometric figures used in studying the relationship between the area distortion and the geometry of the polygon

These polygons are transformed from the old mapping system into the new one using the two transformation parameter sets, poly-zone and ESA parameters, by which the proposed software is designed. Also, the distortion values are observed and filled in a table, in addition a statistical graph is introduced to depict the sought relation.

IV. ANALYSIS OF THE OBTAINED RESULTS OF INVESTIGATING THE AREA DISTORTION DUE TO THE TRANSFORMATION FROM ETM INTO UTM BASED ON THE POLY-ZONE AND ESA PARAMETERS

The area distortion due to the transformation from the ETM mapping system into the UTM one is mainly dependent upon the position through the grid system. In this context, the relation between the area distortion and position of the polygon may be modeled by the 2D surface polynomial model, to interpolate the distortion value anywhere. Therefore, a new simple program is developed, called Distortion Calc., using the VB.net programming language, to enable its users for predicting the distortion in the geometric area of the polygons in a map that may be encountered after transforming the map from ETM into UTM systems.

As shown in figure (8), always, the area deformation decreases from East to West until it reaches zero value, then it increases in the same direction. Excluding from this behavior, the transformation from ETM Purple into UTM-35N, where the two projection systems have the same central meridian which is 27° E and the distortion occurred here is only due to the change of the geodetic datums (from Helmert 1906 to WGS-84) and the change of the mapping scale factor, in turn, the deformation change, here, is mainly affected by the control points in this region. The distortion values through this part are very close to each other and they do not rapidly vary with position as in the other possibilities of transformation, figure (9). In this context, one can conclude that the distortion variation with position is mainly dependent upon the change of the characteristics of the two projection systems, especially the central meridian, between which the transformation is performed. In most zone to zone transformation cases, the area deformation decreases very slowly from North to South, excluding from that the transformation from Red into UTM-35N, where the deformation increases from North to South.

The distortion variation is fast in the East-West direction and very limited in the North-South direction, this emphasizes that the deformation in area occurred during the transformation is mainly dependent on the change of the properties of the two projection systems involved in the transformation. That is due to the fact that, the distortion occurred due to the mapping operations varies as one goes from the central meridian of the projection system.

Table (1) introduces the maximum, minimum, standard deviation and the mean values of the area deformation due to the transformation from ETM into UTM based on both the poly-zone and ESA parameters. There are slight differences in the distortion values when using whether the poly-zone or the ESA transformation parameters in the same location. So, the slight differences in these distortion values of both methods indicate that the transformation parameters contribute in the area distortion values due to the transformation. Note that the poly-zone parameters are not valid for the western desert, so no statistical values are obtained for the case of Purple into UTM-35 N transformation.

As shown in figure (10), for all possibilities of transformation, which are from Red zone into UTM 36N, from Red zone into UTM-35N, from Blue zone into UTM 36N, or from Purple zone into UTM 35N, the area distortion value is independent of the area magnitude of the transformed geometric polygon.

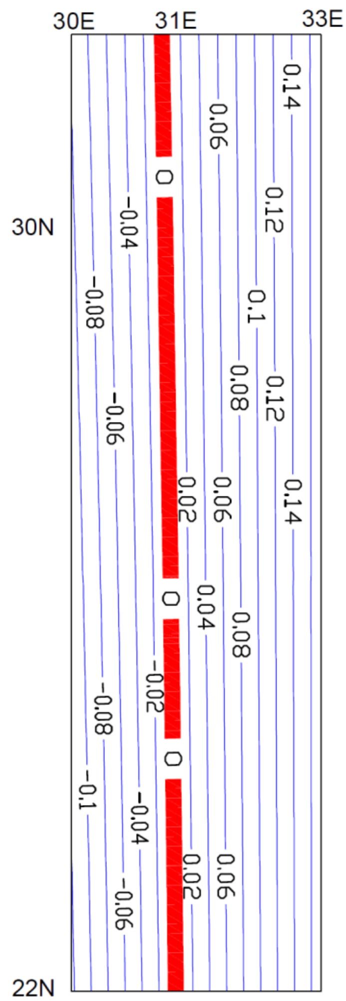

Figure (8) portrays the general behavior of the area distortion change in case of investigating the transformation from ETM RED into UTM 36N

So, the area magnitude of the polygon existing on the map should not be taken into account when computing the area deformation due to the datum transformation. In other words, the area deformation percentage will be nearly constant for all various polygons having different areas and locating in the same position.

As shown in figure (11), the area deformation does not depend on the geometry of the polygon under study. The area distortion values of the regular-geometry features do not greatly differ from those of the irregular-geometry features and the differences may be neglected from the practical point of view. The area distortion values for the polygons, having the same location and vary in geometry, are deviated randomly from the sample mean by little values, but lying through a very narrow range (about 0.002 %). Then, the polygon geometry can be ignored when considering the area deformation due to the datum transformation of the maps.

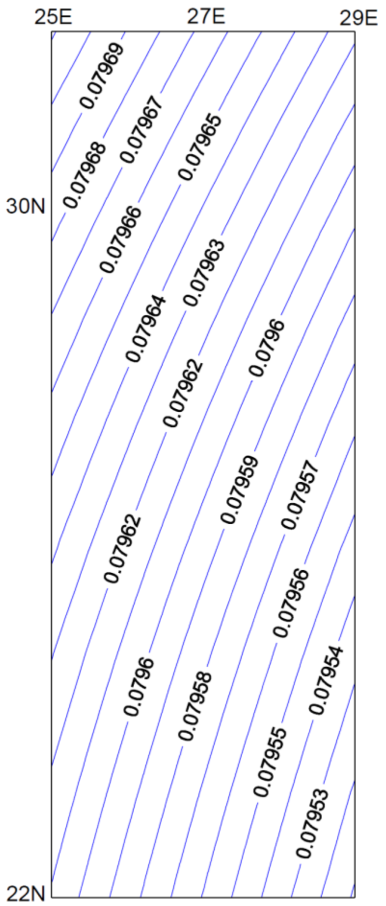

Figure (9) displays the general behavior of the area distortion change (%) in case of investigating the transformation from ETM Purple into UTM 35N

		Poly-zone	ESA parameters
Red into UTM-36	Maximum (%)	0.18	0.17
	Minimum (%)	0	0
	St. Deviation (%)	0.0518	0.0501
	Mean (%)	0.0819	0.0757
Red into UTM-35	Maximum (%)	0.15	0.13
	Minimum (%)	0	0
	St. Deviation (%)	0.0370	0.0338
	Mean (%)	0.0634	0.0519
Blue into UTM-36	Maximum (%)	0.18	0.17
	Minimum (%)	0	0
	St. Deviation (%)	0.0492	0.0453
	Mean (%)	0.0828	0.0750
Purple into UTM-35	Maximum (%)	---------	0.0797
	Minimum (%)	---------	0.0795
	St. Deviation (%)	---------	0.00004
	Mean (%)	---------	0.0796

Table (1) portrays the maximum and minimum values of the area deformation due to the transformation from ETM into UTM based on both the poly-zone and ESA transformation parameters

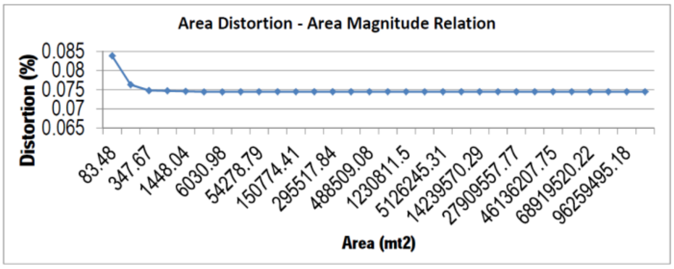

Figure (10) the relationship between the area distortion and the area magnitude in case of the transformation from ETM into UTM

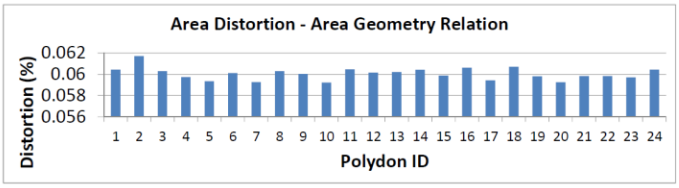

Figure (11) the relationship between the area distortion and the geometry in case of the transformation from ETM into UTM

V. ANALYSIS OF THE OBTAINED RESULTS OF INVESTIGATING THE AREA DISTORTION DUE TO THE TRANSFORMATION FROM ETM INTO MTM BASED ON THE POLY-ZONE AND ESA PARAMETERS

The area distortion due to the transformation from the ETM mapping system into the MTM one is mainly dependent upon the position through the grid system. In this context, the relation between the area deformation and position of the polygon may be modeled by the 2D surface polynomial model, to interpolate the distortion value anywhere. Also, Distortion Calc. program is developed to enable its users for predicting the distortion in the geometric area of the polygons in a map that may be encountered after transforming the map from ETM into MTM systems.

As shown in figure (12), always, the area deformation decreases from East to West until it reaches zero value, then it increases in the same direction. In other words, for each zone to zone transformation possibility, there is a North-South line along which the area deformation is zero; the ETM and MTM area values of the polygon are identical. This line is not identical with any central meridian of the two projection systems used.

The distortion variation is fast in the East-West direction and very limited in the North-South direction, this emphasizes that the deformation in area occurred during the transformation is mainly dependent on the change of the properties of the two projection systems involved in the transformation. That is due to the fact that, the distortion occurred due to the mapping operations varies as one goes from the central meridian of the projection system.

As shown in figure (13), for all possibilities of transformation, which is from Red zone into MTM-2, from Red zone into MTM-3, from Blue zone into MTM-4, from Purple zone into MTM-1, or from Purple zone into MTM-2, the area distortion value is independent of the area magnitude of the transformed geometric figure. So, the area magnitude of the polygon existing on the map should not be taken into account when computing the area deformation due to the datum transformation. In other words, the area deformation percentage will be nearly constant for all various polygons having different areas and locating in the same position.

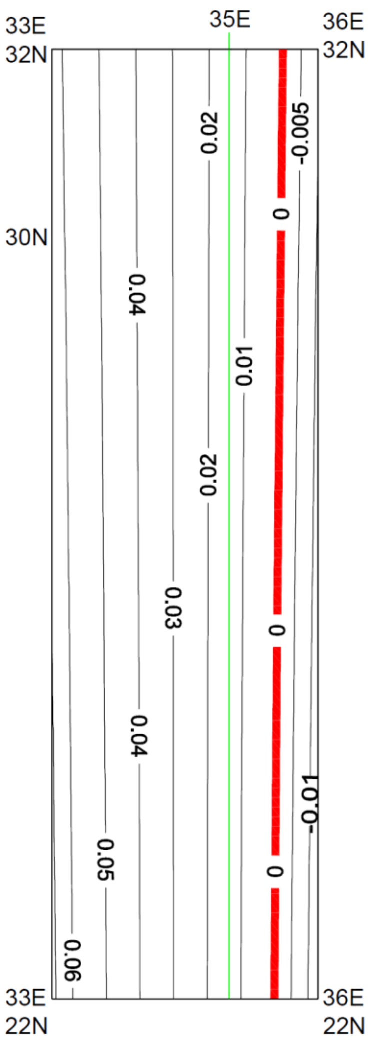

Figure (12) displays the general behavior of the area distortion change in case of investigating the transformation from ETM BLUE into MTM-4

As shown in figure (14), the area distortion does not depend on the geometry of the polygon under study. The area distortion values of the regular-geometry features do not greatly differ from those of the irregular-geometry features and the differences may be neglected from the practical point of view. The area distortion values for the polygons, having the same location and vary in geometry, are deviated randomly from the sample mean, but lying through a very narrow range (roughly 0.0006 %). Then, the polygon geometry can be ignored when considering the area deformation due to the datum transformation of the maps.

Table (2) introduces the maximum, minimum, standard deviation and the mean values of the area deformation due to the transformation from ETM into MTM based on both the poly-zone and ESA parameters. There are slight differences in the distortion values when using whether the poly-zone or the ESA transformation parameters in the same location. So, the slight differences in these distortion values of both methods indicate that the transformation parameters contribute in the area distortion values due to the transformation.

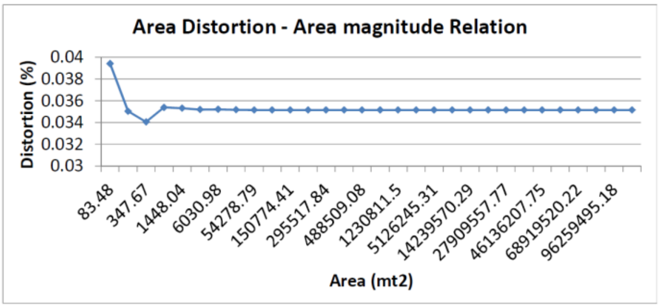

Figure (13) displays the relationship between the area distortion and the area magnitude in case of the transformation from ETM into MTM

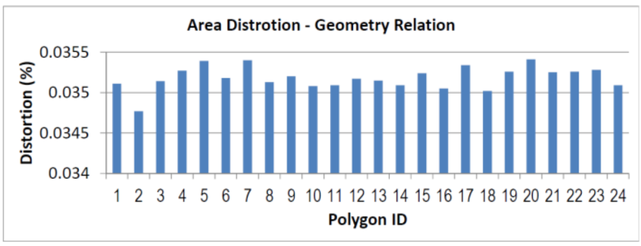

Figure (14) displays the relationship between the area distortion and the geometry of the polygons in case of the transformation from ETM into MTM

		Poly-zone	ESA parameters
Red into MTM-3	Maximum (%)	0.065	0.061
	Minimum (%)	0	0
	St. Deviation (%)	0.0193	0.0191
	Mean (%)	0.0289	0.0277
Red into MTM-2	Maximum (%)	0.10	0.10
	Minimum (%)	0	0
	St. Deviation (%)	0.0331	0.0326
	Mean (%)	0.0473	0.0468
Blue into MTM-4	Maximum (%)	0.065	0.061
	Minimum (%)	0	0
	St. Deviation (%)	0.0188	0.0187
	Mean (%)	0.0277	0.0272
Purple into MTM-1	Maximum (%)	---------	0.11
	Minimum (%)	---------	0
	St. Deviation (%)	---------	0.0321
	Mean (%)	---------	0.0460
Purple into MTM-2	Maximum (%)	---------	0.10
	Minimum (%)	---------	0
	St. Deviation (%)	---------	0.0296
	Mean (%)	---------	0.0430

Table (2) portrays the maximum and minimum values of the area deformation due to the transformation from ETM into MTM based on both the poly-zone and ESA transformation parameters for all transformation possibilities

The maximum and minimum values of the deformation occurred in the polygon area due to the transformation from ETM into MTM are less with respect to those occurred due to the transformation from ETM into UTM. That is because the zones widths of the MTM system, 3° width, are small than that of the UTM system, 6° width. In this context, the MTM projection system gives less geometrical problems than the UTM one.

VI. CONCLUSIONS

According to the above discussions and results of the present investigation, there are several conclusions that could be extracted throughout the thesis work, which will be enumerated below.

- Reliable software, named M-DMT, is developed to be capable for transforming any map, existing in a DXF format, among the various coordinate systems familiar in Egypt such as ETM, UTM, and MTM in few seconds. Also, it can transform the individual geodetic points among the different geodetic positioning formats, such as curvilinear, plane, and Cartesian coordinates.
- Due to the transformation from ETM into either UTM or MTM, the features existing in a map will have deformation in its area property. The behavior of this distortion is mainly dependent upon the position of the feature and it is independent of the size or geometry of the features.
- The behavior and values of the area deformation when the transformation based on the poly-zone transformation parameters is greatly near to that when the transformation is based on the seven ESA transformation parameters. However, there exist slight differences between them. Then, one can conclude that the transformation parameters used will also affect the geometrical problems during the transformation process.
- The area distortion resulting from the transformation from ETM into MTM is less than that resulting from the transformation from ETM into UTM. In this context, it is recommended to use the MTM system for mapping in Egypt.
- Reliable software, named Distortion Calc., is developed to be capable for interpolating the deformation which occurs in the area property of the map features during the transformation into UTM or MTM.

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