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# Comparative Analysis of Jordan Transverse Mercator (JTM) and Cassini-Soldner Projection (CASS)

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**Abstract** Jordan uses two coordinate systems; one based on the Palestine 1923 Datum, Cassini-Soldner projection (CASS), and a more recent one called "Jordan Transverse Mercator" (JTM). The JTM Projection System is based on the "International Hayford 1927" Datum. The Department of Land and Survey (DLS) is responsible for managing the cadastral maps of Jordan. Maps in the Cassini-Soldner projection cover 17% of Jordan and maps in the JTM projection cover the rest of the country. This study is devoted to compare CASS with JTM in Jordan. Adopting a reference frame was done in Jordan to support development of a spatial data infrastructure (SDI). On the other hand, depending on affine adjustment process using ArcMap, version 10.2.2, CASS projection was transformed to JTM. In conclusion, the transformation from CASS to JTM, according to the method used in this study, gave accurate results of approximately 10cm. This is a potent result that encourages the transfer of all maps from CASS to JTM.
**Keywords** *JTM; CASS; Jordan network; Jordanian Geodetic Control Network; transformation*

## 1. Introduction

### 1.1. Map Projection Properties

The distortion properties of maps are typically classified according to what is not distorted on the map. Unfortunately, there is no perfect way of representing spherical polar coordinates on a flat map. Then, no map projection can serve all purposes. Each one is good at some characteristics but bad at others. Different kinds of distortions will be introduced depending on the projection method. Map projections are classified according to what is not distorted on the map. The most important are:

a) Correct Areas, representing areas correctly. Most projections stretch area features on the map. This stretching is usually not constant across the map, so those features are close to the poles on a world map. Example: Mollweide projection.

b) Equal Distance. No map projection can correctly represent distances between all points on the map. This is important to remember that compute distance is a common application of GIS databases. For large scale mapping in a small geographic region, the errors are usually negligible. For national or global applications using small scale maps, the distances calculated by a GIS are not reliable unless the system compensates for the error introduced by Euclidean metric calculation at this scale. Moreover, equidistant projections do not display all distances correctly, but they can represent all distances accurately from one or two points to all other points, or along one or more lines. Example: Equidistant conic projection.

c) Correct Angles Conformal Projections. Angles and shapes of small areas are shown correctly on the map. Meridians and latitudes intersect at right angles. These projections are most useful in navigation. Example: Mercator projection.

### 1.2. The Universal Transversal Mercator (UTM) Reference System

One cartographic reference system that deserves more detailed study is the UTM system. It is one of the most common systems used around the world for large-scale mapping. It is based on a transverse cylindrical projection -Transverse Mercator- in which the cylinder touches the globe along a meridian. A different "local" meridian is chosen for different parts of the world. Distortions in distance, scale and shape along this tangent are very small. The UTM system consists of sixty zones of longitude.

Each zone has a width of 6 degrees longitude, 3 degrees in each direction from the tangent meridian. UTM zones are numbered sequentially from west to east, starting with one for the zone that covers 180°W to 174°W with central meridian 177°W. The zones are divided into rows, with a height of eight degrees. These are assigned letters from north to south, starting at 80° south with the letter C. No UTM zone is defined for regions beyond poles limits because distortion is very large.

Map scale is a ratio, the larger the distance on the ground, the smaller the map scale. For example, 1:1,000,000 scale map is a small scale map, 1 divided by 1 million is a very small number (0.000001). A 1:5,000 scale map is a large scale, 1 divided by 5,000 is a relatively larger number (0.0002). Thus, large scale maps focus on small areas while small scale maps show large areas.

### 1.3. Practical Considerations

Any large digital geodatabase project requires the integration of map information from many different sources. For that reason, a coordinate system and standard projection need to be chosen. Ideally, the reference system that is chosen should match the system used in other agency activities in the country. Most countries use a standard projection that is optimal for the national geographic information system.

Most GIS packages provide functions for transforming coordinates between different reference systems and for converting digital maps from longitude/latitude into a map projection or to change between projections. They also allow the user to select a geodetic datum and any other transformation parameters.

Projection and datum information are usually included in geographic maps. A problem with digital spatial data sets is that standard GIS formats do not necessarily store projection information explicitly. For example, a Department of Land and Survey (DLS) may obtain a geographic data set of roads or hydrology without any information about their map projection. If such data are combined with the digital cadastre maps, they may not match perfectly. Vertical integration is impossible unless the two data sets are brought into the same projection system (Division, 2009). Coordinates may be rigorously converted from one coordinate type to another as long as the metadata on the coordinates is known (Williamson et al., 2004).

## 1.4. The Jordanian Geodetic Control Network

Geodetic Control is a system of precisely determined geographic control points that serve as the reference for all mapping activities in a country, sometimes termed benchmarks. Jordan contains two main networks, Network 1 (Cassini) and Network 2 (JTM).

There are two existing local geodetic reference systems in Jordan: Cassini-Soldner projection and Jordan Transverse Mercator (JTM) coordinates. The first, second and third order control is maintained by RJGC while the fourth order and below is maintained by DLS. Maps in Cassini-Soldner projection cover 17% of Jordan and maps in JTM projection cover the rest of the country, (Figure 1). For heavily populated areas in Jordan, the Cassini-Soldner (PAL) projection is still in use, while desert areas and some cities use JTM projection. Continuing to work with two existing local coordinates in an international environment, where positioning, navigation and information systems relate to a global earth model, is becoming increasingly inefficient and difficult. This paper highlights the process of implementing one projection for managing, collecting, storing and applying spatial data. This will ensure compatibility across various geographic systems locally and globally. Kadir et al. (2003) highlight the importance of providing a homogeneous geodetic infrastructure as the basis for integration of spatial data for sustainable development decision making by reducing duplication and uncertainty.

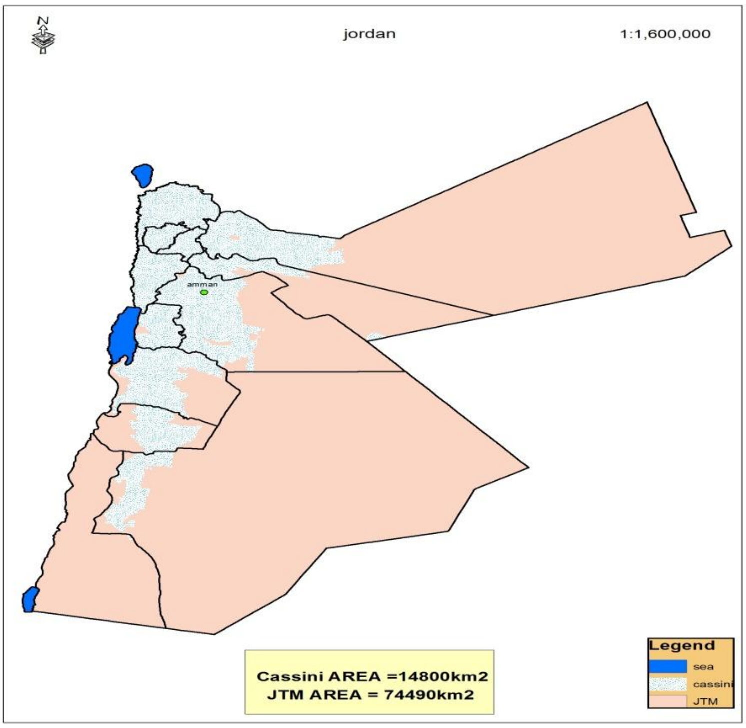


***Figure 1:*** *JTM projection and Cassini projection*

### 1.4.1. *Network (CASS)*

Began in 1922 and was completed in 1956, (Figure 2). At the period of the British Mandate, the ruling triangulation was established and maintained by the Survey of Palestine. Apart from minor extensions in Trans-Jordan, the triangulation covered the area from the coast to the Jordan River Valley and from the Syrian border in the north as far south as Lat. 31°N. No permanent triangulation had been established between this parallel and the Egyptian border. The Palestine major triangulation consisted of about 100 stations with sides of average length 15kms. The Survey of Palestine rectangular coordinates were computed on the Cassini projection. As this was not conformable, it was unsuitable for military survey purposes and a Transverse Mercator grid was therefore established to replace Cassini. The origin was a point at Jerusalem with geographical coordinates: — Lat. 31°44' 02.749". Long. 35°12'43.49". The Transjordan Triangulation Extension was initiated in 1937 by the Department of Lands and Surveys, Amman, and is based on the major triangulation of Palestine. Between Tiberias Lake and the Dead Sea, the network had 42 triangles 137M-178M. In 1941, the 36 New Zealand Survey Battery extended the Palestine triangulation down the eastern side of the Dead Sea in order to provide suitable mapping control points along the Palestine-Trans-Jordan border. This was eventually connected to the stations established by the South African Survey Company at the Gulf of Aqaba, (Gavish, 2005). Furthermore, it completed a circuit of triangulation called the Palestine-Trans-Jordan Chain (188M-211M).

The British Army contracted a civilian surveyor, Kolomoytzeff in 1942-1943 to observe a major triangulation connecting the Syrian Cadastral Primary Triangulation to the Existing work in Transjordan and it was a good network. The network had 42 triangles (1K-42K). In 1948, Jabalaltbeg Triangulation was initiated in the Jordanian-Saudi border area with 18 triangles (100TU-117TU).

In the period between 1945 and 1952, the North Eastern triangulation network was established to be the eastern facade of the South Eastern Mediterranean Network. Calculations were carried out by the Middle East Survey Directorate, and the number of network points was 22 points, holding the numbers 1A-22A. In the period between 1954 and 1955, the Jordanian-Iraqi Network has been established to unite the triangulation networks in the middle east region based on the European Datum ED 50 (global Ellipsoid), not like that used in the survey of Palestine (DLS, 2007).

In 1956, the U.S. Army Map Service (AMS) decided to eliminate all of the individual datums and grid systems of Europe, the Mid-East, and North Africa and to combine all into a single datum called the European Datum of 1950. The origin was at the Helmetturm (Helmert’s Tower) in Pottsdam, Germany where: $\Phi o$ = 52º 22’ 51.446” North, $\Lambda o$ = 13º 03’58.928” East of Greenwich, and was referenced to the International 1924 ellipsoid where $a = 6,378,388$ m, and $1/f = 297$. AMS converted all of the Palestine and Jordan surveys to the European Datum of 1950. The method used was a conformal transformation on the complex plane using UTM coordinates.

Local datum shift from Palestine 1928 Datum to European Datum 1950 is: $\Delta X = -76$ meters, $\Delta Y = +64$ meters, $\Delta Z = +442$ meters (Mugnier, 2008).

The Cassini–Soldner projection has many properties. There is no distortion in shape and area along the central meridian. Whereas on the other hand, the distortion increases with distance from the central meridian. Moreover, scale distortion increases with distance from the central meridian. Therefore, it is used primarily for large-scale mapping of areas near the central meridian. The extent on a spheroid is limited to 5° either side of the central meridian. Beyond that range, data projected to Cassini–Soldner may not project back to the same position. Transverse Mercator is often preferred due to the difficulty in measuring scale and direction on Cassini–Soldner (ESRI, 2015c).

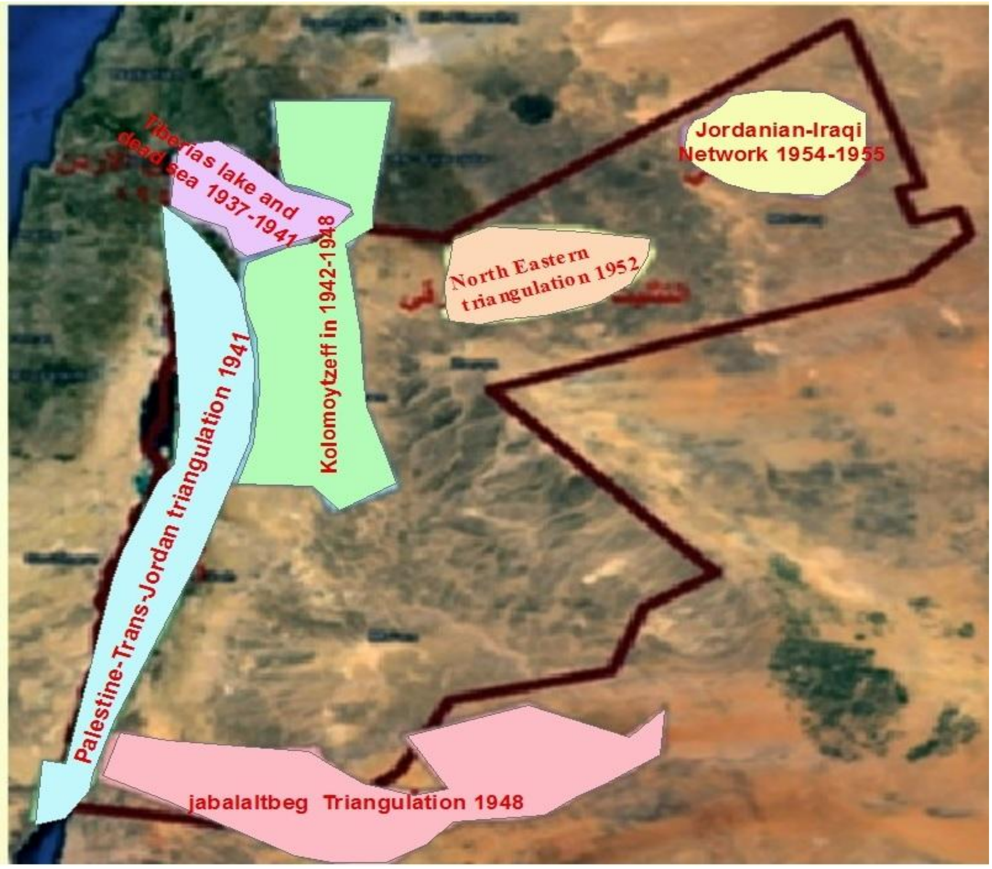


***Figure 2:*** *All networks between 1937-1956 from RJGC*

### 1.4.2. *Network (JTM)*

Created by the Royal Jordanian Geographic Centre, is considered as a modern network and the most accurate in the world. It was completed in a record period of ten years and the number of the total points surpassed 2,000 points, with relative accuracy equivalent to 1:100000.

a) **First Order Control:** was carried out by the latest scientific methods at that time, where 14 points have been observed by satellite. By using the Doppler global ways, the number of points increased to be 87 points. Traverse network has been used to link the 14 Doppler points with 20km spacing between these points on average.

b) **Second Order Control:** at this stage, 10 points have been observed astronomically in addition to the astronomical points observed in the stage of First order control in order to make a geoid map. In addition, 519 new points were added where the distances between them ranged from 8-15 km. Consequently, the number of Second order control points became 529 points.

c) **Third Order Control:** at this stage, the densification of points has been increased, with a spacing of 4-8 km, and the number of these points reached to be more than 1,400 points.

Jordan used one UTM zone through the country. In fact, Jordan is located in two zones, 36-37, in the UTM system. Since the width of Jordan from west to east is less than 6 degrees, and each zone has a width of six degrees longitude, Jordan used one zone called JTM with a central meridian of 37°.

### 1.5. Linear distortions resulting from the use of various types of projections

Distortions that concern us here are the linear distortions resulting from the use of various types of projections (Figure 3).

a) **Cassini-Soldner Projection:** It is distinguished from other types of projections used in the kingdom like transverse Mercator that the linear distortion resulting from the use of Cassini-Soldner projection is directly related to the direction, and is expressed in the following equation.

$$DP = D_0\left(1 + \frac{cos^2 V E^2}{6R^2}\right)$$

$E^2 = (XA-X_0)^2 + (XB-X_0)^2 + (XA-X_0) - (XB-X_0)$

D0 = Length (longitude) on the surface of the ellipsoid

V = Deviation angle from the north (bearing)

R = The radius of the earth

*E* = Linear eccentricity

Where, the maximum value of the distortion is when cos V = 1 which means that the measured length of the line is located in the north-south. On the other hand, the lowest distortion value of the measured line is east-west cos V = 0

b) **Palestine Transverse Mercator (PTM):** the linear distortion resulting from the use of this projection is expressed in the following equation:

$$DP = D_0\left(1 + \frac{E^2}{6R^2}\right)$$

The distortion at a certain point does not change with the direction of the line, but this distortion increases as we move away from the central meridian because of the value of scale factor = 1

c) **Jordan Transverse Mercator (JTM):** the linear distortion resulting from the use of this projection is expressed in the following equations:

$$DP = D_0 \times K$$

$$K = K_0\left(1 + \frac{E^2}{6R^2}\right)$$

K is a scale factor at the points where the distance is measured. $K_0$ is a scale factor when the central meridian in this projection = 0.9998. One of the advantages of this system is that the distortion of the signal is changeable as we move away or closer to the central meridian.

The corrections of measured horizontal distances in Jordan are illustrated in Figure 4.

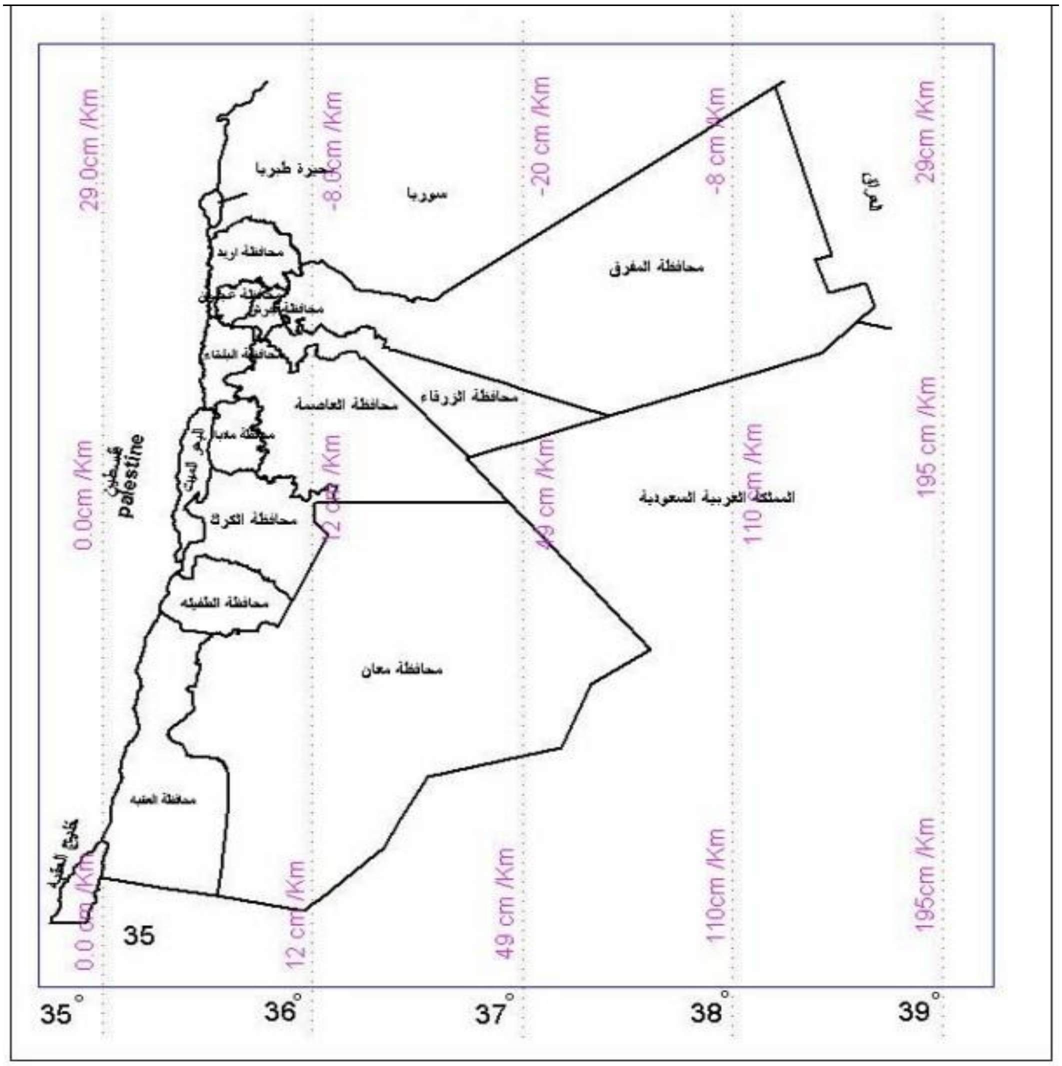


***Figure 3:*** *Linear distortion in Cassini, Palestine PTM and JTM from DLS*

## 1.6. Defining Parameters for all Projections

***Table 1:*** *All Projections Used in Jordan*

| Projection Name | Jordan Transverse Mercator | Palestine Grid (Cassini) | Palestine Belt (Transverse Mercator) |
|---|---|---|---|
| Datum | Hayford Ellipsoid1909 JGD82 | Palestine Spheroid Clarke 1880 | Palestine Spheroid Clarke 1880 |
| Central Longitude | 37.0 | 35.212 080 55 | 35.212 080 55 |
| Central Latitude | 0.0 | 31.734 096 944 44 | 31.734 096 944 44 |
| Scale Factor | 0.9998 | 1 | 1 |
| False Easting | 500000 | 170,251.555 | 170,251.555 |
| False Northing | -3000000 | 1,126,867.909 | 1,126,867.909 |

Corrections for measured horizontal distances in Jordan
because of the height reduction on mean sea level
and because of the projection distortion of Jordan Transverse Mercator (JTM)
in ppm (mm per km)

Annex 1
Page 3

| East | 500 | 510 | 520 | 530 | 540 | 550 | 560 | 570 | 580 | 590 | 600 | 610 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (km) | 500 | 490 | 480 | 470 | 460 | 450 | 440 | 430 | 420 | 410 | 400 | 390 |
| Height | | | | | | | | | | | | |
| (m) | | | | | | | | | | | | |
| - 400 | -137,2 | -136,1 | -132,4 | -126,3 | -117,6 | -106,5 | -93,0 | -77,0 | -58,5 | -37,5 | -14,1 | +11,7 |
| - 300 | -152,9 | -151,8 | -148,1 | -142,0 | -133,3 | -122,2 | -108,7 | -92,7 | -74,2 | -53,2 | -29,8 | -4,0 |
| - 200 | -168.6 | -167,5 | -163,8 | -157,7 | -149,0 | -137,9 | -124,4 | -108,4 | -89,9 | -68,9 | -45,5 | -19,7 |
| - 100 | -184,3 | -183,2 | -179,5 | -173,4 | -164,7 | -153,6 | -140,1 | -124,1 | -105,6 | -84,6 | -61,2 | -35,4 |
| 0 | -200 | -198,9 | -195,2 | -189,1 | -180,4 | -169,3 | -155,8 | -139,8 | -121,3 | -100,3 | -76,9 | -51,1 |
| 100 | -215,7 | -214,6 | -210,9 | -204,8 | -196,1 | -185,0 | -171,5 | -155,5 | -137,0 | -116,0 | -92,6 | -66,8 |
| 200 | -231,4 | -230,3 | -226,6 | -220,5 | -211,8 | -200,7 | -187,2 | -171,2 | -152,7 | -131,7 | -108,3 | -82,5 |
| 300 | -247,1 | -246,0 | -242,3 | -236,2 | -227,5 | -216,4 | -202,9 | -186,9 | -168,4 | -147,4 | -124,0 | -98,2 |
| 400 | -262,8 | -261,7 | -258,0 | -251,9 | -243,2 | -232,1 | -218,6 | -202,6 | -184,1 | -163,1 | -139,7 | -113,9 |
| 500 | -278,5 | -277,4 | -273,7 | -267,6 | -258,9 | -247,8 | -234,3 | -218,3 | -199,8 | -178,8 | -155,4 | -129,6 |
| 600 | -294,2 | -293,1 | -289,4 | -283,3 | -274,6 | -263,5 | -250,0 | -234,0 | -215,5 | -194,5 | -171,1 | -145,3 |
| 700 | -309,9 | -308,8 | -305,1 | -299,0 | -290,3 | -279,2 | -265,7 | -249,7 | -231,2 | -210,2 | -186,8 | -161,0 |
| 800 | -325,6 | -324,5 | -320,8 | -314,7 | -306,0 | -294,9 | -281,4 | -265,4 | -246,9 | -225,9 | -202,5 | -176,7 |
| 900 | -341,3 | -340,2 | -336,5 | -330,4 | -321,7 | -310,6 | -297,1 | -281,1 | -262,6 | -241,6 | -218,2 | -192,4 |
| 1000 | -357,0 | -355,9 | -352,2 | -346,1 | -337,4 | -326,3 | -312,8 | -296,8 | -278,3 | -257,3 | -233,9 | -208,1 |
| 1100 | -372,7 | -371,6 | -367,9 | -361,8 | -353,1 | -342,0 | -328,5 | -312,5 | -294,0 | -273,0 | -249,6 | -223,8 |
| 1200 | -388,4 | -387,3 | -383,6 | -377,5 | -368,8 | -357,7 | -344,2 | -328,2 | -309,7 | -288,7 | -265,3 | -239,5 |
| 1300 | -404,1 | -403,0 | -399,3 | -393,2 | -384,5 | -373,4 | -359,9 | -343,9 | -325,4 | -304,4 | -281,0 | -255,2 |
| 1400 | -419,8 | -418,7 | -415,0 | -408,9 | -400,2 | -389,1 | -375,6 | -359,6 | -341,1 | -320,1 | -296,7 | -270,9 |
| 1500 | -435,5 | -434,4 | -430,7 | -424,6 | -415,9 | -404,8 | -391,3 | -375,3 | -356,8 | -335,8 | -312,4 | -286,6 |
| 1600 | -451,2 | -450,1 | -446,4 | -440,3 | -431,6 | -420,5 | -407,0 | -391,0 | -372,5 | -351,5 | -328,1 | -302,3 |
| 1700 | -466,9 | -465,8 | -462,1 | -456,0 | -447,3 | -436,2 | -422,7 | -406,7 | -388,2 | -367,2 | -343,8 | -318,0 |
| 1800 | -482.6 | -481,5 | -477,8 | -471,7 | -463,0 | -451,9 | -438,4 | -422,4 | -403,9 | -382,9 | -359,5 | -333,7 |

| East | 620 | 630 | 640 | 650 | 660 | 670 | 680 | 690 | 700 | 710 | 720 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (km) | 380 | 370 | 360 | 350 | 340 | 330 | 320 | 310 | 300 | 290 | 280 |
| Height | | | | | | | | | | | |
| (m) | | | | | | | | | | | |
| - 400 | +40,1 | +70,9 | +104,2 | +139,9 | +178,1 | +218,8 | +261,9 | +307,5 | +355,5 | +406,0 | +458,9 |
| - 300 | +24,4 | +55,2 | +88,5 | +124,2 | +162,4 | +203,1 | +246,2 | +291,8 | +339,8 | +390,3 | +443,2 |
| - 200 | +8,7 | +39,5 | +72,8 | +108,5 | +146,7 | +187,4 | +230,5 | +276,1 | +324,1 | +374,6 | +427,5 |
| - 100 | -7,0 | +23,8 | +57,1 | +92,8 | +131,0 | +171,7 | +214,8 | +260,4 | +308,4 | +358,9 | +411,8 |
| 0 | -22,7 | +8,1 | +41,4 | +77,1 | +115,3 | +156,0 | +199,1 | +244,7 | +292,7 | +343,2 | +396,1 |
| 100 | -38,4 | -7,6 | +25,7 | +61,4 | +99,6 | +140,3 | +183,4 | 229,0 | +277,0 | +327,5 | +380,4 |
| 200 | -54,1 | -23,3 | +10,0 | +45,7 | +83,9 | +124,6 | +167,7 | +213,3 | +261,3 | +311,8 | +364,7 |
| 300 | -69,8 | -39,0 | -5,7 | +30,0 | +68,2 | +108,9 | +152,0 | +197,6 | +245,6 | +296,1 | +349,0 |
| 400 | -85,5 | -54,7 | -21,4 | +14,3 | +52,5 | +93,2 | +136,3 | +181,9 | +229,9 | +280,4 | +333,3 |
| 500 | -101,2 | -70,4 | -37,1 | -1,4 | +36,8 | +77,5 | +120,6 | +166,2 | +214,2 | +264,7 | +317,6 |
| 600 | -116,9 | -86,1 | -52,8 | -17,1 | +21,1 | +61,8 | +104,9 | +150,5 | +198,5 | +249,0 | +301,9 |
| 700 | -132,6 | -101,8 | -68,5 | -32,8 | +5,4 | +46,1 | +89,2 | +134,8 | +182,8 | +233,3 | +286,2 |
| 800 | -148,3 | -117,5 | -84,2 | -48,5 | -10,3 | +30,4 | +73,5 | +119,1 | +167,1 | +217,6 | +270,5 |
| 900 | -164,0 | -133.2 | -99,9 | -64,2 | -26,0 | +14,7 | +57,8 | +103,4 | +151,4 | +201,9 | +254,8 |
| 1000 | -179,7 | -148,9 | -115,6 | -79,9 | -41,7 | -1,0 | +42,1 | +87,7 | +135,7 | +186,2 | +239,1 |
| 1100 | -195,4 | -164,6 | -131,3 | -95,6 | -57,4 | -16,7 | +26,4 | +72,0 | +120,0 | +170,5 | +223,4 |
| 1200 | -211,1 | -180,3 | -147,0 | -111,3 | -73,1 | -32,4 | +10,7 | +56,3 | +104,3 | +154,8 | +207,7 |
| 1300 | -226,8 | -196,0 | -162,7 | -127,0 | -88,8 | -48,1 | -5,0 | +40,6 | +88,6 | +139,1 | +192,0 |
| 1400 | -242,5 | -211,7 | -178.4 | -142,7 | -104,5 | -63,8 | -20,7 | +24,9 | +72,9 | +123,4 | +176,3 |
| 1500 | -258,2 | -227,4 | -194,1 | -158,4 | -120,2 | -79,5 | -36,4 | +9,2 | +57,2 | +107,7 | +160,6 |
| 1600 | -273,9 | -243,1 | -209,8 | -174,1 | -135,9 | -95,2 | -52,1 | -6,5 | +41,5 | +92,0 | +144,9 |
| 1700 | -289,6 | -258,8 | -225,5 | -189,8 | -151,6 | -110,9 | -67,8 | -22,2 | +25,8 | +76,3 | +129,2 |
| 1800 | -305,3 | -274,5 | -241,2 | -205,5 | -167,3 | -126,6 | -83,5 | -37,9 | +10,1 | +60,6 | +113,5 |

***Figure 4:*** *Correction for measured horizontal distance in Jordan (JTM) (DLS)*

## 2. Methodology

### 2.1. Implementation and Adopting a Reference Frame to Support SDI

The concept of the SDI hierarchy, ranging from local through to global levels, needs to be built on a solid positional foundation. Without a good geodetic base, many of the problems regarding positional accuracy become more intelligible (Williamson et al., 2004).

a) Defining the distortion and homogeneity in the geodetic network, this network is computed in the Cassini-Soldner projection, which is not a conformal projection. Some triangulation points were observed by GPS (Global Positioning System). These points have coordinates in the Cassini-Soldner projection (from the office which is responsible for triangulations) and the field surveying provides its Cassini coordinates. The points are used to determine distortion and homogeneity in the geodetic network.

The triangulations are from three governorates: Irbid, Jarash, and Ajloun. We will take every one as a separate zone then we take them all together, we used Leica Geo office 8 software to calculate coordinates in different zones.

| | | | |
|---|---|---|---|
| AJ0007 | 228985.6810 | 1197031.3170 | 0.0000 |
| AJ0019 | 228983.5650 | 1195858.2780 | 0.0000 |
| IR0704 | 231942.8230 | 1197734.0610 | 0.0000 |
| JA0216 | 233223.945 | 1195025.495 | 0.0000 |
| JA0219 | 233668.961 | 1194104.523 | 0.000 |

//observation depending on three zones//

| | | |
|---|---|---|
| aj0007 | 228985.4455 | 1197031.3544 |
| aj0019 | 228983.3849 | 1195858.1782 |
| IR0704 | 231942.7064 | 1197734.1473 |
| ja0216 | 233223.5374 | 1195025.5146 |
| ja0219 | 233668.5968 | 1194104.6619 |

//observation depending on Ajloun zone//

| | | |
|---|---|---|
| aj0007 | 228985.4455 | 1197031.3543 |
| aj0019 | 228983.3849 | 1195858.1781 |
| IR0704 | 231943.0139 | 1197734.2139 |
| ja0216 | 233225.3833 | 1195026.2303 |
| ja0219 | 233670.9110 | 1194105.4507 |

//observation depending on Irbid zone//

| | | |
|---|---|---|
| aj0007 | 228985.5394 | 1197031.0945 |
| aj0019 | 228983.5827 | 1195858.1539 |
| IR0704 | 231942.7064 | 1197734.1473 |
| ja0216 | 233225.0528 | 1195026.5245 |
| ja0219 | 233670.5691 | 1194105.8803 |

//observation depending on Jarash zone//

| | | |
|---|---|---|
| aj0007 | 228983.6221 | 1197030.6662 |
| aj0019 | 228981.5136 | 1195857.6594 |
| IR0704 | 231941.0119 | 1197733.3471 |
| ja0216 | 233223.1205 | 1195025.4652 |
| ja0219 | 233668.5610 | 1194104.7111 |

***Table 2:*** *Comparison table for aj0007*

| Triangulations No | aj0007 | aj0007 | aj0007 | aj0007 | **aj0007** |
|---|---|---|---|---|---|
| Zone | From office | three zone | Ajloun zone | Irbid zone | **Jarash zone** |
| x | 228985.6810 | 228985.4455 | 228985.4455 | 228985.5394 | **228983.6221** |
| y | 1197031.3170 | 1197031.3544 | 1197031.3543 | 1197031.0945 | **1197030.6662** |

**Coordinate Differences:** if we match aj0007 from office with aj0007 from Jarash, we will see approximately 2 meters difference on coordinate.

***Table 3:*** *Comparison table for aj0019*

| Triangulations No | aj0019 | aj0019 | aj0019 | aj0019 | **aj0019** |
|---|---|---|---|---|---|
| Zone | From office | three zone | Ajloun zone | Irbid zone | **Jarash zone** |
| x | 228983.5650 | 228983.3849 | 228983.3849 | 228983.5827 | **228981.5136** |
| y | 1195858.2780 | 1195858.1782 | 1195858.1781 | 1195858.1539 | **1195857.6594** |

**Coordinate Differences:** if we match aj0019 from office with aj0019 from Jarash, we will see approximately 2 meters difference on coordinate.

***Table 4:*** *Comparison table for IR0704*

| Triangulations No | IR0704 | IR0704 | IR0704 | IR0704 | **IR0704** |
|---|---|---|---|---|---|
| Zone | From office | three zone | Ajloun zone | Irbid zone | **Jarash zone** |
| x | 231942.8230 | 231942.7064 | 231943.0139 | 231942.7064 | **231941.0119** |
| y | 1197734.0610 | 1197734.1473 | 1197734.2139 | 1197734.1473 | **1197733.3471** |

**Coordinate Differences:** if we match IR0704 from office with IR0704 from Jarash, we will see approximately 2 meters difference on coordinate.

***Table 5:*** *Comparison table for ja0216*

| Triangulations No | ja0216 | ja0216 | **ja0216** | **ja0216** | ja0216 |
|---|---|---|---|---|---|
| Zone | From office | three zone | **Ajloun zone** | **Irbid zone** | Jarash zone |
| x | 233223.945 | 233223.5374 | **233225.3833** | **233225.0528** | 233223.1205 |
| y | 1195025.495 | 1195025.5146 | **1195026.2303** | **1195026.5245** | 1195025.4652 |

**Coordinate Differences:** if we match ja0216 from office with ja0216 from Ajloun and Irbid zones, we will see approximately 2 meters difference on coordinate.

***Table 6:*** *Comparison table for ja0219*

| Triangulations No | ja0219 | ja0219 | **ja0219** | **ja0219** | ja0219 |
|---|---|---|---|---|---|
| Zone | From office | three zone | **Ajloun zone** | **Irbid zone** | Jarash zone |
| x | 233668.961 | 233668.5968 | **233670.9110** | **233670.5691** | 233668.5610 |
| y | 1194104.523 | 1194104.6619 | **1194105.4507** | **1194105.8803** | 1194104.7111 |

**Coordinate Differences:** if we match ja0219 from office with ja0219 from Ajloun and Irbid zones, we will see approximately 2 meters difference on coordinate.

Therefore, the network is not homogeneous and according to (Z. Alostah, and S. Alkhatib) the reasons for discrepancies in map-edges (in Department of Land and Survey) is the non-homogeneous network (Cassine).

Depending on the previous results, the Cassini-Soldner projection is non-homogeneous and JTM is homogeneous.

JTM

| | | | |
|---|---|---|---|
| AJ0007 | 390576.8603 | 582439.4797 | 0.0000 |
| AJ0019 | 390555.1000 | 581266.9639 | 0.0000 |
| IR0704 | 393545.0590 | 583092.4975 | 0.0000 |
| ja0216 | 394781.501 | 580363.538 | 0.0000 |
| ja0219 | 395211.315 | 579435.654 | 0.0000 |
| aj0007 | 390576.6255 | 582439.5210 | 0.0050 |
| aj0019 | 390554.9182 | 581266.8671 | 0.2241 |
| IR0704 | 393544.9438 | 583092.5858 | 0.0092 |
| ja0216 | 394781.4384 | 580364.0430 | 0.0023 |
| ja0219 | 395211.3637 | 579436.1142 | 0.0053 |

b) Geodetic Network Coverage: the JTM covers all Jordan while Cassini projection does not cover the eastern regions of the Kingdom (Figures 5 and 6).

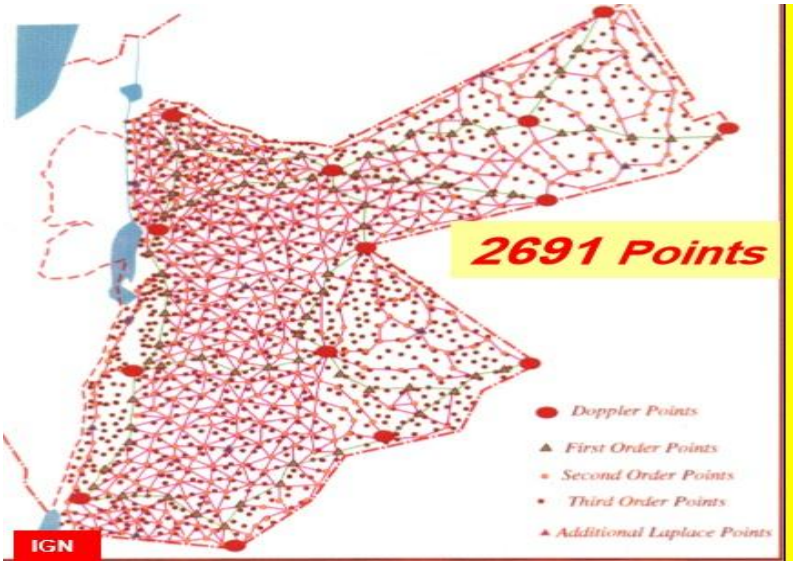


***Figure 5**: JTM Network*

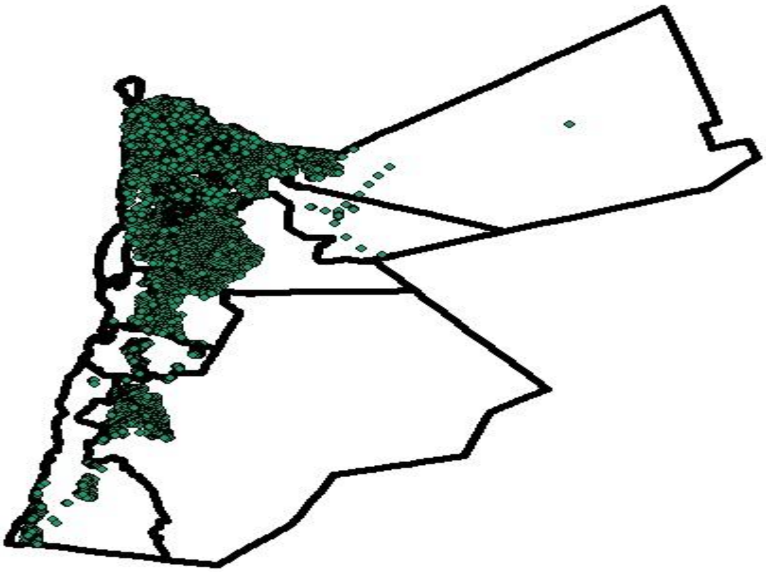

***Figure 6:** Cassini Network*

c) Jordan used one zone throughout the country. In fact, Jordan is located in the two zones 36-37 in the UTM system. Since the width of Jordan from west to east is less than 6 degrees, each zone has a width of six degrees longitude. Therefore, Jordan used one zone called JTM with the central meridian of 37°, while Cassini used two zones.

d) The national geodesic network, created by the Royal Jordanian Geographic Centre (RJGC), is considered as a modern network and the most accurate in the world. It was completed in a record period of ten years and the number of total points surpassed 2,000 points, with relative accuracy equivalent to 1:100000. In the 1930s and 1940s, the English army had established several triangulation networks, which served as a basis for both topographic and cadastral surveying.

e) The geodetic network is computed and based on a non-conformal projection “Cassini-Soldner” while JTM is a conformal projection.

f) From 1978-1988 (new) the RJGC completed the national geodetic network (JTM) (1st, 2nd and 3rd order) while Cassini triangulation network began in 1922 and was completed in 1956 (old).

*Depending on the previous points we will transform to JTM projection.*

## 2.2. Transformation

Geodetic datum transformation is the determination of a mathematical relationship to be used in transforming a set of coordinates from one geodetic datum to another (Dawod and Alnaggar, 2000). There are many ways of modelling the transformation between two datums (ICSM, 2014), but those in common use include:

**2.2.1. *Molodensky's method*** is commonly used in Geographic Information Systems (GIS) and hand-held GPS receivers. The formulae are simple, assuming that the transformation between the local and global datums can be represented by 5 parameters: a shift at the origin (the earth's centre of mass) along the earth-centred Cartesian coordinate axes ($\Delta X$, $\Delta Y$, $\Delta Z$) and the difference between the local and global ellipsoids (semi-major axis and flattening). The origin shifts can be determined by an averaging of the same differences at each of the common points and the difference in ellipsoids is a simple subtraction of the ellipsoid parameters; the errors in Molodensky's formulae: 5 metres.

***Table 7:*** *Advantages and disadvantages of Molodensky transformation*

| Molodensky Transformation | |
|---|---|
| *Advantages* | *Disadvantages* |
| • Simple derivation | • Assumes internally consistent networks |
| • Simple application | • Limited accuracy |
| • Available in GIS packages and hand-held GPS | • Derivation requires ellipsoidal heights |

**2.2.2. *The 7-parameter method*** assumes a similar relationship between the local and global datums. The common points are used in a Least Squares process to solve 7 parameters which represent the relationship between the two datums: origin shifts at the earth's centre of mass ($\Delta X$, $\Delta Y$, $\Delta Z$); rotations about each of the axes (Rx, Ry, Rz); and a scale change between the two systems, the errors in 7-parameter: 1-2 metres.

***Table 8:*** *Advantage and disadvantage of 7-Parameter Transformation*

| 7-Parameter Transformation | |
|---|---|
| *Advantages* | *Disadvantages* |
| • Improved accuracy | • Assumes consistent geodetic networks |
| • Used in many GIS packages | • Moderately complex derivation & application |

| | |
|---|---|
| | • Requires ellipsoidal heights for both global and local positions |
| | • Accuracy limited by geodetic network consistency |

The selection of a datum transformation method depends on the accuracy required and the number of commonly available points, the size of the area and the type of the network (3D or 2D or even 1D) (Mitsakaki, 2004).

We used ArcMap 10.2.2 and the parameter for JTM projection and Cassini projection depended on ArcMap (Table 9).

***Table 9:*** *the parameter for JTM projection and Cassini projection depended on ArcMap*

| Projection name | Palestine_1923_Palestine_Grid | Jordan_JTM |
|---|---|---|
| Authority | Custom | ESRI |
| Projection | Cassini | Transverse_Mercator |
| False_Easting | 170251.555 | 500000.0 |
| False_Northing | 1126867.909 | -3000000.0 |
| Central_Meridian | 35.21208055555556 | 37.0 |
| Scale_Factor | 1.0 | 0.9998 |
| Latitude_Of_Origin | 31.73409694444445 | 0.0 |
| Linear Unit | Meter (1.0) | Meter (1.0) |
| Geographic Coordinate System | GCS_Palestine_1923 | GCS_Jordan |
| Angular Unit: | Degree (0.0174532925199433) | Degree (0.0174532925199433) |
| Prime Meridian | Greenwich (0.0) | Greenwich (0.0) |
| Datum | D_Palestine_1923 | D_Jordan |
| Spheroid | Clarke_1880_Benoit | International_1924 |
| Semimajor Axis | 6378300.789 | 6378388.0 |
| Semiminor Axis | 6356566.435 | 6356911.946127947 |
| Inverse Flattening | 293.4663155389802 | 297.0 |

Transformation depends on GIS package, arc 10.2.2 and we match the transformed zone with adjacent border because it's in JTM. By this way the error has been determined.

a) Depending on **Palestine_1923_To_WGS1984_1+ Jordan_To_WGS_1984** parameter, the error is approximately 5 meters (Figure 7).

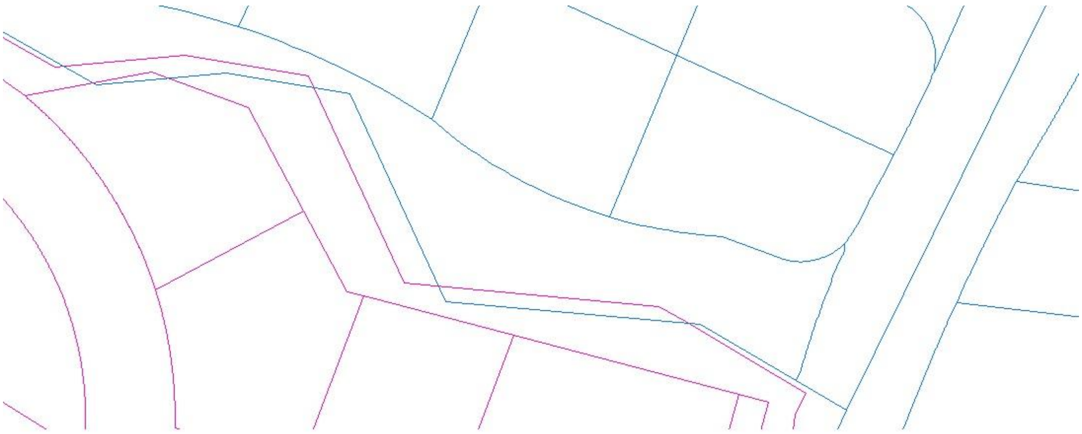

***Figure 7:*** *The error depending on* ***Palestine_1923_To_WGS1984_1+ Jordan_To_WGS_1984*** *parameter*

b) Depending on **Palestine_1923_To_WGS1984_1X+ Jordan_To_WGS_1984** parameter, the error is more than 100 meters (Figure 8).

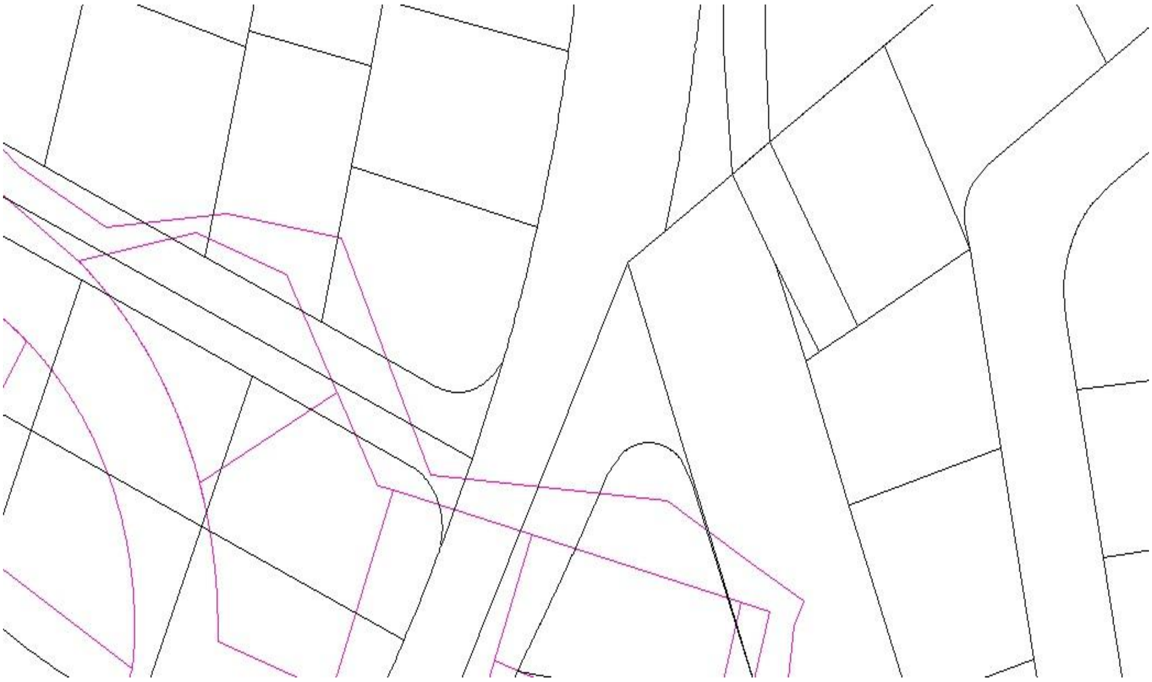

***Figure 8:*** *the error depending on* ***Palestine_1923_To_WGS1984_1X+ Jordan_To_WGS_1984*** *parameter*

c) Depending on **Palestine_1923_To_WGS1984_2+ Jordan_To_WGS_1984** parameter, the error is approximately 10 meters (Figure 9).

***Figure 9:*** *The error depending on* ***Palestine_1923_To_WGS1984_2+ Jordan_To_WGS_1984*** *parameter*

d) Depending on **Palestine_1923_To_WGS1984_2X+ Jordan_To_WGS_1984** parameter, the error is approximately 2.5 meters (Figure 10).

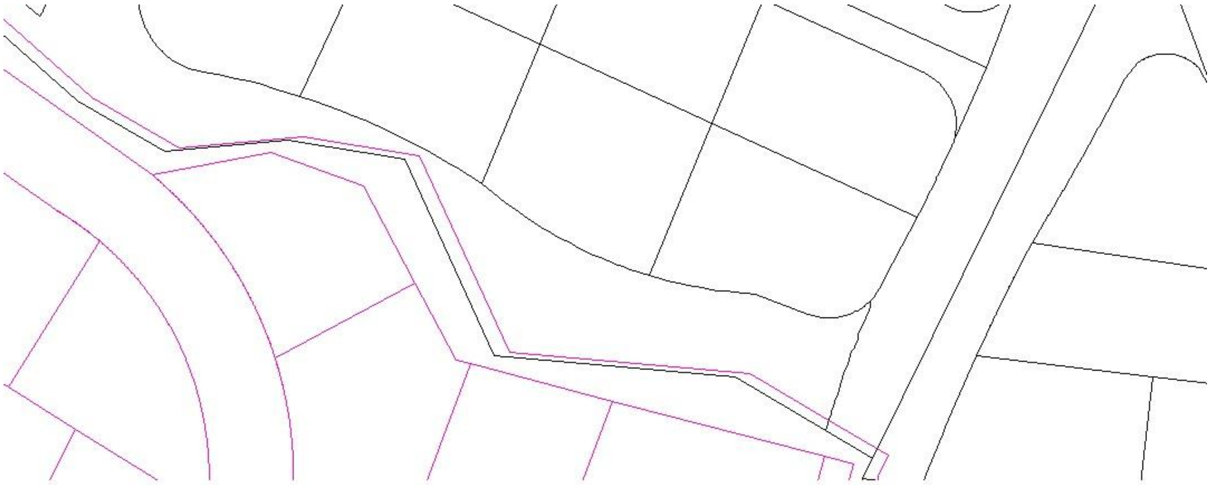

***Figure 10:*** *The error depending on* ***Palestine_1923_To_WGS1984_2X+ Jordan_To_WGS_1984*** *parameter*

***The (7 parameters) transformation will not suffice for high accuracy applications.***

***Table 10:*** *Errors (for transformation from Cass to JTM, used in arc 10.2.2)*

| Parameter for transformation from Cass to JTM, used in arc 10.2.2 (Geographic Transformation) | Errors |
|---|---|
| Palestine_1923_To_WGS1984_1+ Jordan_To_WGS_1984 | Approximately 5 meter |
| Palestine_1923_To_WGS1984_1X+ Jordan_To_WGS_1984 | Approximately 100 meter |
| Palestine_1923_To_WGS1984_2+ Jordan_To_WGS_1984 | Approximately 10 meter |
| Palestine_1923_To_WGS1984_2X+ Jordan_To_WGS_1984 | Approximately 2.5 meter |

**2.2.3.** ***Spatial Adjustment Transformations*** Transformations move or shift data within a coordinate system. For transformations, from and to locations of links are used to construct the transformation formulas. When creating links for transformations, you are trying to match the same location in the source and destination locations. Links do not have to start or end on features. The distance from and to locations can often be quite large. ArcMap supports three types of transformations: affine, similarity, and projective.

i) Affine Transformation

An affine transformation can differentially scale the data, skew it, rotate it, and translate it. Figure 11 illustrates the four possible changes.

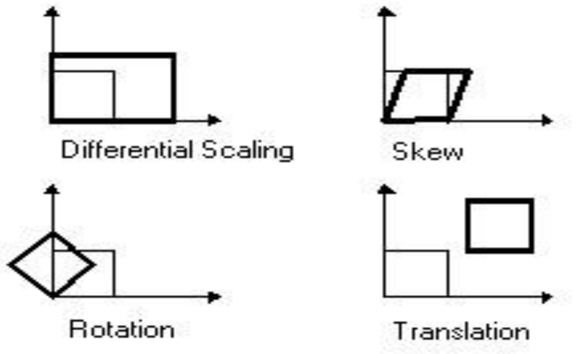


***Figure 11:*** *The four possible changes of an affine transformation*

The affine transformation function is:

x' = Ax + By + C
y' = Dx + Ey + F

where x and y are coordinates of the input layer and x' and y' are the transformed coordinates. A, B, C, D, E, and F are determined by comparing the location of source and destination control points. They scale, skew, rotate, and translate the layer coordinates.

ii) Similarity Transformation

The similarity transformation scales, rotates, and translates the data. It will not independently scale the axes, nor will it introduce any skew. It maintains the aspect ratio of the features transformed, which is important if you want to maintain the relative shape of features.

The similarity transform function is

x' = Ax + By + Cy' = -Bx + Ay + F

where
A = s * cos t
B = s * sin t
C = translation in x direction
F = translation in y direction
and
s = scale change (same in x and y directions)
t = rotation angle, measured counterclockwise from the x-axis

iii) Projective Transformation

The projective transformation is based on a more complex formula that requires a minimum of four displacement links.

x' = (Ax + By + C) / (Gx + Hy + 1)
y' = (Dx + Ey + F) / (Gx + Hy + 1)

This method is used to transform data captured directly from aerial photography (ESRI, 2015B).

In this work, we used affine adjustment to transform from the Palestine projection to the JTM projection (see Figures 12, 13 and 14). For this purpose the area of the Kingdom was divided into blocks 12x12 km. Blocks are edge matched so that points transformed at or near the boundary of multiple blocks will not result in multiple differing solutions. Depending on our study, Badran and Abunoser villages have been transferred, more than 80 observed points by GPS (Global Positioning System) have been used, and any suspect data (observations) that may contain errors or blunders are removed during the adjustment process. These points were used to determine the transformation parameters between the CASS and JTM projections. What applies to this block can be applied to all Jordan. After we finish transformation, we will get a file for transformation parameters and it's an accurate and rigorous solution.

The cadastral map in Jordan is used as a base map for most purposes such as utilities, transportation, developments plans and land use planning. The Department of Lands and Survey (DLS) is the agency responsible for both the land registration and the cadastral surveying on a national level DLS consists of 12 central directorates (in the headquarters) and 34 land registration directorates distributed all over the kingdom plus 4 registration service offices. DLS is under the umbrella of the Ministry of Finance.

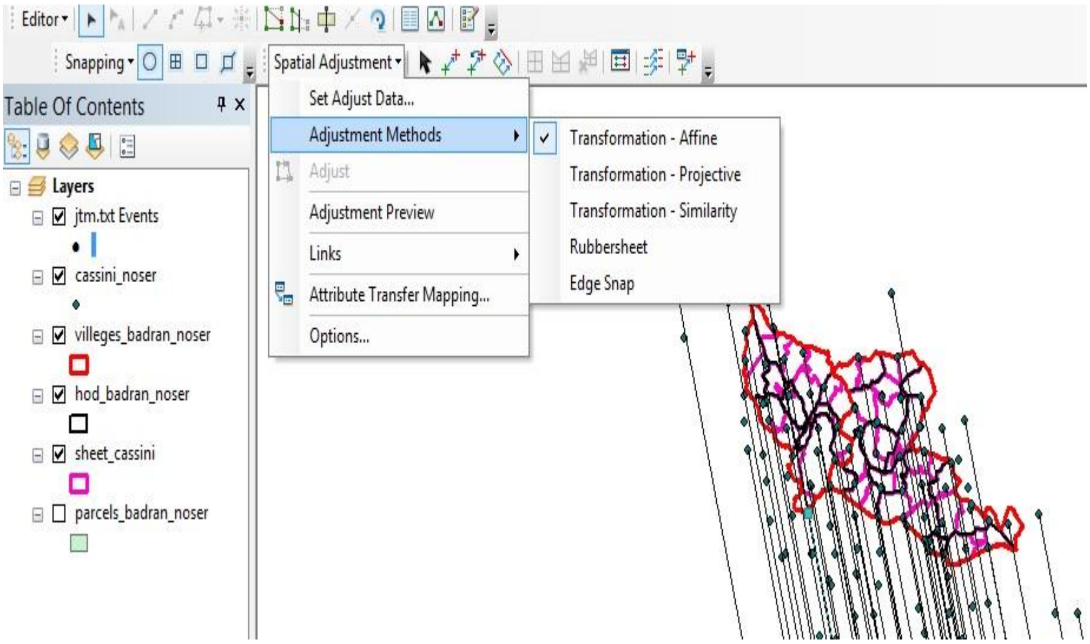


***Figure 12:*** *Affine Adjustment Process*

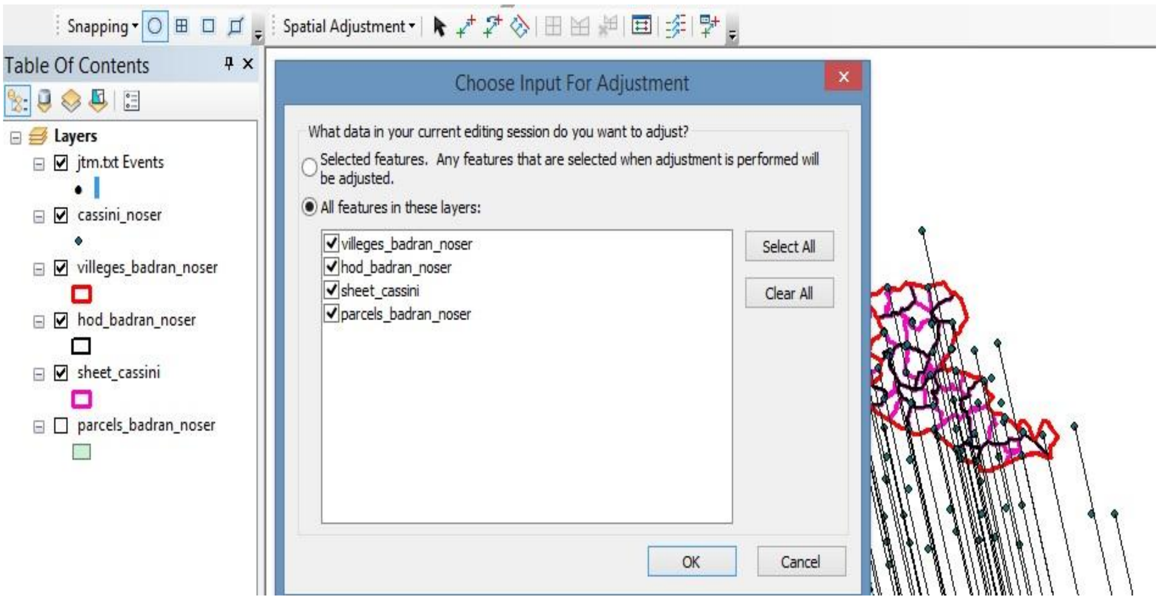


***Figure 13:*** *Selected layers for Affine Adjustment Process*

The point we have used in transformation, in Cassini-Soldner projection and Jordan Transverse Mercator (JTM). The RMS Error is 0.108 meter Table 11.

***Table 11:*** *The points were used to determine the transformation parameters between CASS and JTM projections*

| id | X Source | Y Source | X Destination | Y Destination | Residual Error |
|---|---|---|---|---|---|
| 70 | 236932.342 | 1162983.154 | 397953.507 | 548268.009 | 0.019167 |
| 66 | 238059.34 | 1163151.362 | 399083.154 | 548417.404 | 0.021836 |
| 12 | 237954.43 | 1162085.409 | 398960.511 | 547353.47 | 0.032299 |
| 35 | 239262.125 | 1162769.632 | 400279.4 | 548015.736 | 0.03598 |
| 52 | 231009.959 | 1167962.566 | 392115.136 | 553344.656 | 0.036372 |
| 50 | 237039.538 | 1163808.186 | 398074.433 | 549091.049 | 0.041181 |
| 7 | 238854.332 | 1163908.461 | 399890.646 | 549161.059 | 0.042089 |
| 32 | 234937.411 | 1161101.628 | 395927.574 | 546420.199 | 0.043251 |
| 46 | 239001.797 | 1161992.972 | 400006.182 | 547243.615 | 0.047444 |
| 40 | 231265.043 | 1167132.105 | 392356.349 | 552510.19 | 0.048618 |
| 24 | 230159.394 | 1168262.268 | 391269.712 | 553658.407 | 0.049704 |
| 17 | 239840.422 | 1164165.876 | 400880.874 | 549401.975 | 0.050494 |
| 21 | 235957.361 | 1161043.303 | 396946.409 | 546344.897 | 0.056255 |
| 25 | 237891.894 | 1164915.81 | 398945.145 | 550184.177 | 0.057839 |
| 49 | 229981.459 | 1167009.377 | 391070.937 | 552408.837 | 0.058137 |
| 11 | 232818.746 | 1161183.818 | 393810.563 | 546537.686 | 0.060566 |
| 65 | 237004.03 | 1164857.983 | 398056.418 | 550141.158 | 0.061973 |
| 36 | 238039.857 | 1160282.317 | 399015.908 | 545549.462 | 0.064502 |
| 30 | 229997.593 | 1166059.676 | 391071.254 | 551459.173 | 0.064508 |
| 33 | 236808.57 | 1166161.951 | 397882.735 | 551447.886 | 0.069579 |
| 63 | 237076.868 | 1161040.481 | 398065.705 | 546323.428 | 0.069797 |
| 39 | 243165.052 | 1161158.831 | 404154.861 | 546340.414 | 0.070088 |
| 55 | 240121.195 | 1161298.633 | 401113.848 | 546530.823 | 0.071542 |
| 34 | 241809.858 | 1160798.06 | 402793.896 | 546002.283 | 0.075225 |
| 29 | 231739.424 | 1166128.134 | 392813.947 | 551498.621 | 0.07985 |
| 27 | 236134.986 | 1164934.532 | 397188.752 | 550232.157 | 0.084909 |

| | | | | | |
|---|---|---|---|---|---|
| 2 | 233825.871 | 1162020.687 | 394831.444 | 547357.531 | 0.086189 |
| 68 | 238835.868 | 1160889.452 | 399821.924 | 546143.148 | 0.088038 |
| 28 | 235210.877 | 1163845.946 | 396246.627 | 549159.22 | 0.094924 |
| 51 | 232579.953 | 1166296.087 | 393657.151 | 551652.53 | 0.095516 |
| 19 | 244925.024 | 1157934.589 | 405860.82 | 543087.802 | 0.096019 |
| 48 | 234650.878 | 1163249.405 | 395676.773 | 548572.164 | 0.102339 |
| 60 | 238622.887 | 1160601.495 | 399604.195 | 545858.814 | 0.105039 |
| 67 | 240880.844 | 1160075.302 | 401853.018 | 545295.178 | 0.105621 |
| 53 | 234901.17 | 1164548.79 | 395948.668 | 549867.03 | 0.110886 |
| 1 | 232890.815 | 1162063.783 | 393897.23 | 547416.202 | 0.114077 |
| 5 | 234026.167 | 1162905.199 | 395046.417 | 548238.462 | 0.114235 |
| 4 | 230969.203 | 1164734.985 | 392020.667 | 550118.721 | 0.117021 |
| 44 | 234137.355 | 1163925.096 | 395174.57 | 549256.221 | 0.126696 |
| 10 | 233254.187 | 1163163.239 | 394278.834 | 548509.297 | 0.143883 |
| 3 | 231838.991 | 1163885.996 | 392875.906 | 549255.435 | 0.154067 |
| 47 | 233536.642 | 1165190.522 | 394595.004 | 550531.329 | 0.168158 |
| 61 | 230104.891 | 1163192.903 | 391130.851 | 548591.507 | 0.177628 |
| 20 | 232900.546 | 1165000.772 | 393955.834 | 550352.231 | 0.185131 |
| 14 | 226726.899 | 1169085.204 | 387851.65 | 554538.334 | 0.195029 |
| 45 | 235074.607 | 1166178.775 | 396149.144 | 551493.596 | 0.21568 |
| 6 | 236555.057 | 1168231.25 | 397663.551 | 553520.795 | 0.228909 |
| 43 | 228526.689 | 1170361.844 | 389672.469 | 555784.579 | 0.246911 |
| | | | | **RMS** | **0.108392** |

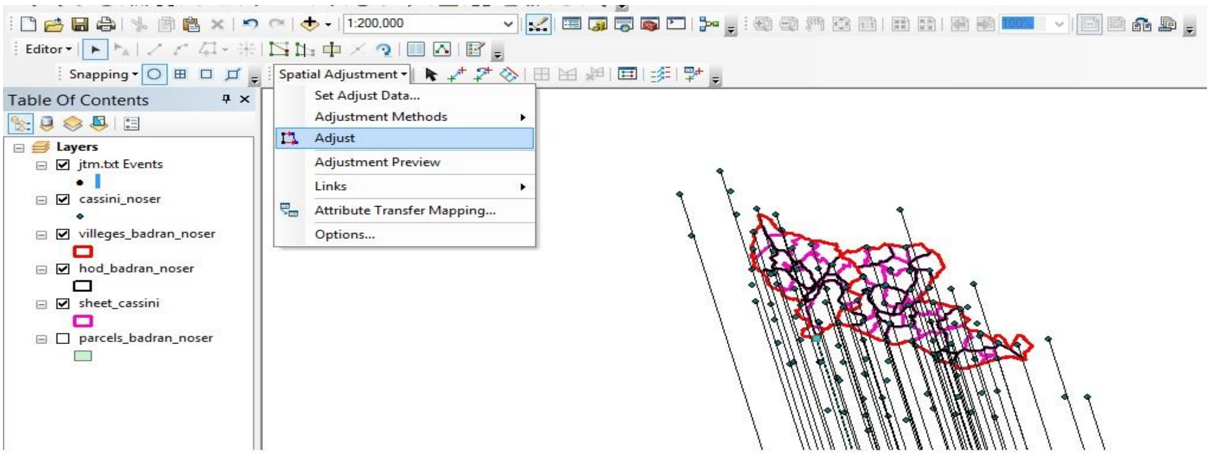


***Figure 14:** Affine Adjustment Process after selected layer*

We match the transformed zone with the adjacent border because it's in JTM and its approximate match Figure 15.


***Figure 15:*** *the result after applied an affine transformation process*

## 3. Results and Discussion

a) In this study, CASS was demonstrated as a non-homogeneous projection. On the other hand, the JTM was a homogeneous projection. Moreover, the JTM was more comprehensive than CASS, where JTM covers all Jordan while Cassini projection does not cover the eastern regions of the Kingdom.

b) Depending on GIS the package, ArcMap 10.2.2, the lowest error in transformation was approximately 2.5 meter, therefore, it not suitable for accurate data like cadastre and topographic maps.

c) Depending on Affine Adjustment (block 12*12 km), the RMS error was 10 cm, which is an adequate result and suitable for accurate data like cadastre and topographic maps.

d) The homogeneity, comprehensiveness, and accuracy of the JTM projection taken together to prove that the JTM projection is more suitable for surveying work than the CASS projection. This supports the Department of Land and Survey in Jordan to transform from CASS to JTM to build the Jordan Digital Cadastral Data Base (JDCDB).

e) According to this study, the discrepancies between organisations might be eliminated by using the JTM projection as one reference system in Jordan.

## 4. Conclusions

The ideas presented in this paper are so far just ideas - not official policy. However, the Department of Land and Survey proposes the development of building the Jordan Digital Cadastral Data Base (JDCDB). The original maps are in Cassini-Soldner projection which is a non-homogeneous datum and doesn't cover all Jordan using two zones (1922-1956). Therefore, transforming all the (20000) maps to JTM fulfils the overall goal of establishing JDCDB to participate in building National Geographic Information System (NGIS).

The JTM projection will have the flexibility to provide a stable spatial foundation for Jordan for the foreseeable future. Many users of the survey system seek stability in coordinates. This is an understandable desire given the limitations of spatial data processing today. JTM can provide a complete and adaptable coordinate system with the stability that users seek, because JTM is a uniform, precise, homogeneous geodetic network, and highly accurate, with 6° zones, a central meridian of 37° and scale factor in the central meridian of 0.9998. Moreover, the transformation from CASS to JTM, according to the method used in our study, gave accurate results of approximately 10cm. This encourages the transfer of all maps from Cass to JTM. Spatial data infrastructure (SDI) depends on a base of the homogeneous network, and for the maximum benefit of the data, there should be no confusion about its positional accuracy, and in Jordan we are looking to build Jordan Spatial Data Infrastructure (JSDI).

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