

Spatial Correction of Cadastral Maps Based on Satellite Imagery

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Abstract - It is well known that most of the cadastral maps and property plans in Iraq are preserved in paper form, with the majority dating back to the 1930s. These maps are widely used for various purposes, such as urban planning, sewage networks, and electricity networks. However, most of these maps suffer from some distortion and wear, with some being torn and taped due to the nature of the paper material and its handling, resulting in severe physical distortion. To address these issues, it is necessary to convert these maps into a digital format and perform corrective processing to mitigate the effects of past errors. Scanning alone is insufficient as it introduces many errors. Recently, fast and accurate computer software has become available that can process data from these maps and paper drawings, including addressing the wear they have undergone, and update them to meet the needs of local authorities developing and investing in these maps and implementing development projects. This process is also essential for establishing a digital foundation for the database. Geographic Information System (GIS) applications are widely used to enhance and assist decision-makers in making decisions that align with their purposes and application scenarios.

Keywords: Cadastral maps, Geographic Coordinate, digitization, Spatial correction.

I. INTRODUCTION

Spatial correction of cadastral maps using satellite imagery is one of the most significant modern techniques in the field of Geographic Information Systems (GIS) and land management. Cadastral maps, which document property boundaries and ownership, are crucial tools for urban planning and resource management. However, the spatial accuracy of these maps may be insufficient due to environmental factors and temporal changes. This is where the importance of utilizing satellite imagery comes into play, as it provides accurate and up-to-date data that contributes to the correction and updating of cadastral maps, thereby enhancing the quality of spatial information used in planning and management.

Additionally, integrating satellite imagery with traditional data enhances the accuracy and analysis of geographic information. Modern satellite technologies, such as remote

sensing and high-resolution imagery, allow for the acquisition of detailed information about the Earth's surface, which can be used to correct spatial errors present in traditional maps. This integration of advanced technology with traditional data contributes to building a more accurate and efficient geographic database, positively impacting urban planning and resource management processes in general.

Therefore, this study examines the spatial applications of Geographic Information Systems based on the following axes:

1. Inputs of cadastral maps.
2. Mechanism for converting paper maps into digital maps.
3. Matching errors after correcting the spatial location of cadastral maps.
4. Digital processing of matching errors.

II. INPUTS OF CADASTRAL MAPS

2.1 Scanning of Cadastral Maps

The spatial data of a paper map (cadastral map) can be converted into a digital pixel format using scanning devices. This process involves measuring the amount of light reflected from the paper map, which is then stored within the image cells (pixels). Small surfaces on the map reflect light at varying levels depending on the grayscale degree of the map, ranging from a maximum value for white surfaces to a minimum value for black surfaces, with graduated values in between. These reflections are then stored on a computer.

One of the advantages of this method is that it allows for rapid conversion, enabling subsequent processing. The scanning process of the map takes only a few minutes, after which the data can be stored on a hard disk or computer. The digital map can then be displayed on a screen and further processed as needed [1].

2.2 Methods of Geometric Coordinate Transformation

Spatial components and their data are derived from various sources such as paper maps, satellite imagery, and field measurements. The coordinates of these point elements constitute the fundamental data for their spatial or geographic definition. However, these coordinates are often referenced to different datums depending on their source. The coordinates

captured by a digitizing device are referenced to a coordinate system known as the digitizer coordinate system, which must be transformed into a cartographic coordinate system or the geodetic coordinate system used in the region [1].

To utilize these coordinates effectively and apply spatial analysis results to derive accurate information based on spatial data, it is crucial that these coordinates are referenced to a single datum. There are several methods for the geometric correction of spatially uncorrected maps in GIS software:

1. Geographic Coordinate System (GCS) Input
2. Projected Coordinate System (PCS) Input
3. Overlay Maps Method

Transformation methods are crucial in the digitization and updating of maps using GIS software. They are used to address the following issues [1]:

1. **Transforming Coordinates of Spatial Elements:** The coordinates of spatial elements obtained using a digitizer or scanner from diagrams or paper maps need to be transformed into the adopted coordinate system. The scanner converts paper maps into digital data within its own local coordinate system, which cannot be directly used in the adopted system.
2. **Reducing Distortions in Maps and Plans:** Relying on paper maps as the primary source of spatial data often introduces distortions due to the expansion and contraction of the paper. This results in changes to the map scale, in addition to scale changes caused by copying and imaging processes.
3. **Correcting Distorted Maps:** A distorted map can be considered a version of the original map but with a different coordinate system. Since these distorted maps often contain known coordinate points unaffected by incidental distortions (such as polygon vertices or geodetic points), these points can be used to mitigate distortions and restore the map to its original coordinate system as accurately as possible.

2.3 Study Inputs (Data)

2.3.1 Cadastral Map Data for the Study Area

Cadastral maps hold significant importance as they are the officially and legally recognized documents in boundary disputes. They are also crucial for ensuring property rights, whether public or private. Thus, the accuracy of these maps is of paramount importance. Their relevance extends to the design, updating, and development of urban planning for cities, as they encompass all natural features and elements present in the area. Cadastral maps are invaluable to decision-

makers, urban planners, researchers, and all users of geographic information.

Given this, it has become imperative to correct cadastral maps, standardize their scale, and store them in a digital format. Digitization and standardization significantly mitigate issues related to land use maps and property ownership, thereby enhancing the reliability and utility of cadastral information (Figure 1).



Figure 1: Traditional Map (Cadastral Map) [2]

2.3.2 Satellite Imagery Data

The QuickBird satellite imagery data, owned by the American company Digital Globe, represents a significant advancement in remote sensing capabilities. QuickBird was launched on October 18, 2001, aboard a Boeing Delta II rocket, and annually collects over 75 million square kilometers of imagery. It is renowned for its high spatial resolution of 60 cm, making it particularly suitable for detailed studies. The characteristics of this imagery are detailed as follows (Figure 2):

- Agency: National Aeronautics and Space Administration (NASA)
- Launch Date: First satellite launched on 18/10/2001
- Sensor System Name: BGIS 2000 sensor
- Spatial Resolution (Pan): 61 cm (nadir) to 72 cm (25° off-nadir)
- Temporal Resolution: Variable days, depending on latitude (30° off-nadir)
- Radiometric Resolution: 11-bit per pixel (2048 levels)
- Spectral Resolution:
 - Pan: 450-900nm
 - Blue: 450-520nm
 - Green: 520-600nm
 - Red: 630-690nm
 - Near IR: 760-900nm
- Coverage Area: 16.5 km * 16.5 km

- Orbital Characteristics: Sun-synchronous orbit
- Orbital Speed: Approximately 7.1 km/s (560 km/hour)



Figure 2: Satellite Image (QuickBird) [3]

2.3.3 Software Used

A set of applications is developed to organize the process of data input into computers, store, analyze, and display the data to meet specific requirements. Geographic Information System (GIS) software comprises various components, including spatial data programs (such as software for converting vector data to raster data, digital image processing of satellite or aerial imagery, and database entry programs), database management systems for descriptive (attribute) data, and external tabular data linked to mapped phenomena. Additionally, GIS software includes spatial analysis tools for optimal land use distribution, conducting various spatial measurements, and performing statistical analyses.

This approach aligns with the concise overview of computational engineering work, utilizing both hardware and software specific to digital technologies, as detailed in Table 1. This table provides a methodology for converting any paper map into a digital map referenced to a coordinate system specific to the study area.

Table 1: Software Used for Converting a Paper Map to a Digital Map Referenced to a Coordinate System

No.	Software that can be used	Devices Used	Summary of Work
1	ACD See	Colored Scanner	Convert the map to a digital format in jpg file extension (raster digital map)
2	GPS	GNSS Receiver (Navigation Type)	Study the location of the paper map, identify ground control points in reality and at the corners of the map, and record the coordinates of the newly established points.
3	ERDAS IMAGINE VER2015	Computers	Transform the map from a digital format to a coordinate system-referenced format (raster

			digital map with real coordinates) using geometric correction techniques.
4	ARC MAP GIS 10.8.1	Computers	Draw or construct vector spatial data from the corrected map image according to the actual locations of features and in accordance with cartographic standards for thematic data and the year of the paper map's production.
5	ARC MAP GIS 10.8.1	Computers	Build attribute databases for the drawn features based on the available data.
6	ARC MAP GIS 10.8.1	Computers	Construct new vector spatial data from the coordinates of points taken via GPS.
7	ARC MAP GIS 10.8.1	Computers	Build attribute databases for the newly created vector spatial data.
8	ERDAS IMAGINE VER2015 & ARC MAP GIS 10.8.1	Computers	Update cadastral maps using remote sensing data from the year 2021.
9	ARC MAP GIS 10.8.1	Computers	Finalize the outputs and save the final project on the computer, making it accessible for review at any time.

Source: From the work of the researcher

2.3.4 Global Positioning System (GPS)

The Global Positioning System (GPS) consists of a network of satellite receivers that determine the coordinates of a specific point based on its position relative to satellites, achieving a high degree of accuracy [4]. This system was utilized to identify all features within the study area and to record ground control points using Differential GPS (D.G.P.S) technology.



Figure 3: Using a D.G.P.S Device to Determine a Set of Points in the Mosul District, Ulmash Subdistrict

Source: Field study conducted by the researcher

III. MECHANISM FOR CONVERTING PAPER MAPS TO DIGITAL MAPS

The process of converting any paper map or diagram from a static state to a digital format on a computer requires referencing this phase to a coordinate reference system. This necessitates a specialized study of the specific triangulation network for the area surrounding the study region and at the national level. It also requires knowledge of the reference surface level of the country and the selection of ground triangulation points for areas with known features, whose coordinates can be read using various location determination methods, including the previously mentioned global positioning system using satellites. The geometric shape must then be determined to link the locations of data on paper maps with their counterparts on the ground in the study area. These precise operations are conducted using digital data processing software. The process can be summarized in the following steps:

3.1 Preparation and Processing of Cadastral Maps

The paper map of the study area is digitized using a scanner and saved in TIF format. These maps were obtained from government offices and originally produced by the General Survey Directorate in Baghdad. The maps are very old (black and white) and were initially produced in 1938, with a print update in 2015. According to the amended Real Estate Registration Law No. 43/1971, Article 25/2, property registration relies on the following maps: the settlement map (cadastral map). Additionally, the Ministry of Justice's Instructions No. 2/1989 regarding the preservation of documents state the following: cadastral maps, village maps, and city maps must be preserved to prevent damage and stored in any form, as per the aforementioned law [5-7].

3.2 Preparing the Geographic Information System (GIS) Environment

It is essential to determine the reference framework of the map image, specifically whether it is based on a particular datum, and to identify the ellipsoid model and the type of coordinate system. This is crucial as it fundamentally relies on the desired final scale of the outputs within the ArcMap (GIS) environment. Selecting an appropriate coordinate system, particularly a projected coordinate system, is necessary to ensure accurate representation and analysis of the spatial data (Figure 4).

coordinate system=projected coordinate system=UTM=WGS_1984_UTM_Zone_38N

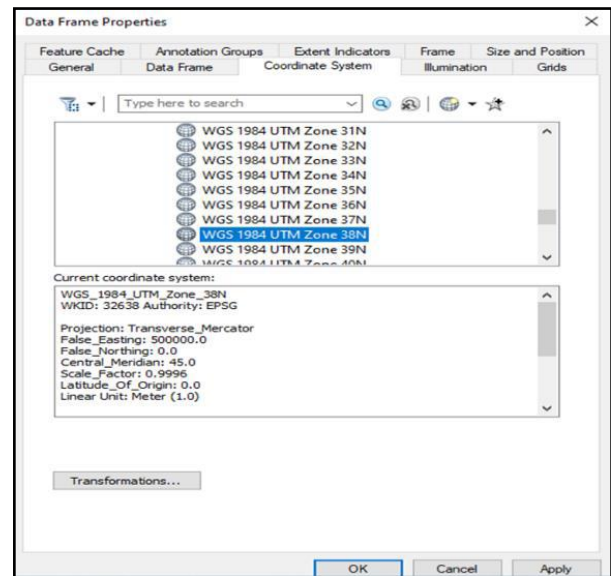


Figure 4: Geographic Coordinate Systems Used in Geographic Information Systems [2]

Source: Based on the outputs of ArcGIS 10.8.1

3.3 Spatial Correction of Cadastral Maps

After converting the map to TIF format (Tag Image File Format), a high-quality graphics format often used for storing digital images with support for multiple colors, layers, and pages, it is opened using ArcGIS 10.8.1 software. The map is then georeferenced and aligned with the UTM (Universal Transverse Mercator) coordinate system through the process of georeferencing. This involves using the coordinates from the intersections of the grid lines on the map. The true coordinate values for each grid intersection are entered as indicated on the map, as shown in Figure 5 below. Upon completion of this process, the image is rectified and saved to the computer, resulting in a coordinate-corrected image in the UTM system.

Georeferencing = insert point = Rectify

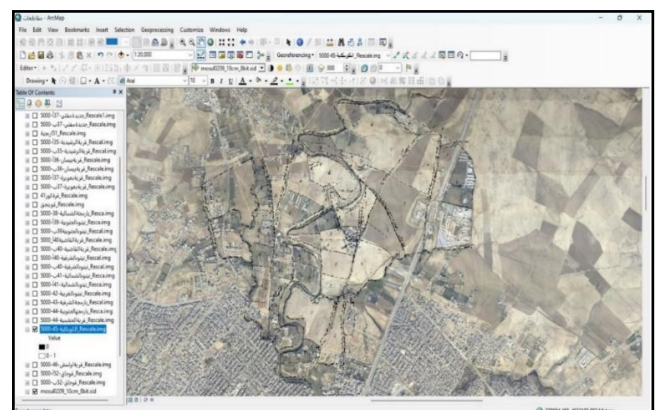


Figure 5: Spatial Correction of the Cadastral Map [2]

3.4 Boundary Spatial Correction

In this stage, the technique used for correction involves whether D.G.P.S readings of selected points in the field are matched with their counterparts on the map. Additionally, it includes matching natural and cultural landmarks such as district boundaries, roads, irrigation channels, drainage, valleys, archaeological mounds, the Tigris River, and known valleys in the city (Khosr River, Shor Valley) with high-resolution satellite imagery of the study area. This ensures the accurate correction of cadastral maps (Figure 6).

Georeferencing = Transformation = Spline = Rectify

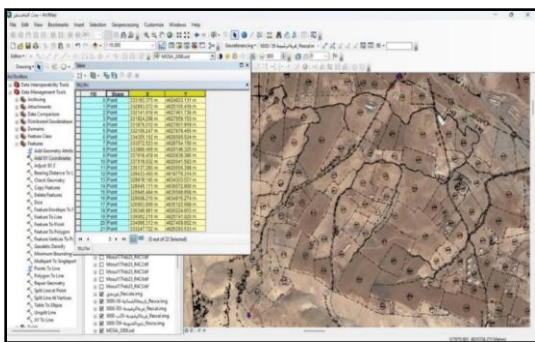


Figure 6: Spatial correction form (6) for delineating provinces [2]

IV. SPATIAL MATCHING ERRORS AFTER SPATIAL CORRECTION OF CADASTRAL MAPS

4.1 Error models of natural features

First: Delineation of the Tigris River: Through the process of matching cadastral maps with satellite imagery, spatial matching errors have been identified. Significant discrepancies are observed between the boundaries of the Tigris River in the satellite imagery and its representation in the cadastral map of Northern Yarmouk Province (Figure 7).



Figure 7: Issue of boundary alignment for the Tigris River [2]

Second: Defining the boundaries of the Tigris River: Through the process of matching the cadastral map with the satellite imagery, we find a discrepancy between the boundaries of the Tigris River and the satellite imagery. See the model for the Qara Koz region, Figure (8).



Figure 8: The issue of boundary alignment for the Tigris River [2]

Third: Alignment of Wadi Networks: Through the process of matching the cadastral map with the satellite imagery, we find a discrepancy between the wadi networks and the satellite imagery. See the model for the Rashidiya region, Figure (9).



Figure 9: The issue of alignment of wadi networks [2]

Source: Based on the outputs of the (ArcGIS 10.8.1) software

Fourth: Alignment of High Areas, Hills, and Earthen Embankments: Through the process of matching the cadastral map with the satellite imagery, we find a discrepancy between the high areas, hills, and earthen embankments and the satellite imagery. See the model for the Jileh Bilbil Tapa region, Figure (10).



Figure 10: The problem of matching high areas, hills, and ancient earthen dams [2]

4.2 Error Models for Human Features

First: The problem of matching between map scales: It is observed from the two previous images that there is a

mismatch in the boundaries of the districts. This is due to the difference in the scales at which the two maps were designed, with the first having a scale of 1:10,000 and the second 1:50,000. This makes matching the boundaries difficult, and at the same time, causes generalization or lack of distinction for small features drawn at a small scale. Figure (11)



Figure 11: The difference between the boundaries of the Yarmja Northern District, scale 1:5000, and the Harakia and Forests, scale 1:10000 [2]

Second: The Issue of Contiguous Boundaries between Districts:

There is a discrepancy in the boundaries of districts that are drawn to the same scale. This mismatch can be attributed to several factors, including the deterioration of map sections due to poor storage conditions and the exposure of these sections to climatic influences such as shrinkage and expansion. Additionally, humidity can alter the dimensions of the maps. These maps were also created using traditional methods, which are fraught with various technical problems that can generally affect the accuracy of the maps. See Figure (12).

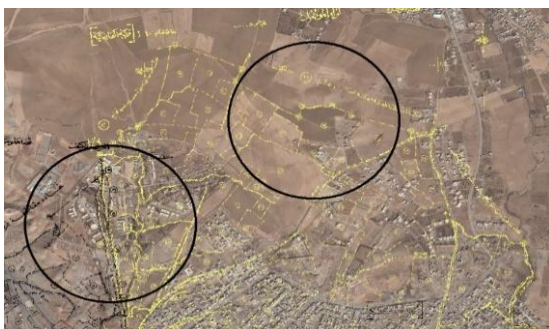


Figure 12: The Difference in Contiguous Boundaries and Matching Problems Between AlQadyah A and AlQadyah B. [2]

Third: The Issue of Displacement of Certain Landmarks:

From figure (13), it is evident that the road connecting the cities of Ramadi and Fallujah does not align with its actual location in reality. This misalignment leads to numerous surveying and technical errors in determining property and land tenure boundaries. Therefore, it has become essential to

correct cadastral maps, standardize their scale, and store them digitally. This approach significantly mitigates issues related to land use and property maps.



Figure 13: Displacement of Certain Features from Their Actual Location [2]

V. DIGITAL PROCESSING OF MATCHING ERRORS

To illustrate the digital processing of matching errors for cadastral maps, a model was used to perform spatial correction on one of the maps from the study area, specifically the map of Kobuklia District as an application model. This model was adopted as a work plan for the remaining maps. The map has a scale of (1:5000) and is prepared according to the Clarke 1880 projection system. Spatial correction was carried out based on the coordinates provided with the map and the satellite imagery of the study area for the year 2023, which was prepared according to the WGS84 system. See Figure (14).

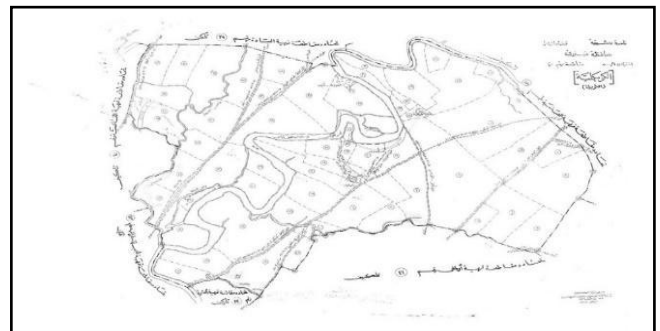


Figure 14: Image of the Kobuklia Cadastral Map Prepared According to the Clarke 1880 System [8]



Figure 15: Satellite Imagery of the Study Area for the Year 2023 Prepared According to the WGS84 System [3]

The following steps were adopted to implement the alignment between the cadastral map and the satellite imagery, conducting field calculations of points to derive results applicable to other cadastral maps of Mosul District. This experience can also be extended to other cadastral maps in Nineveh Governorate or Iraq.

5.1 Spatial Correction According to the Geographic Coordinate System

Twenty random points were selected after correcting the cadastral map and converting it from paper to digital format according to the coordinates provided with the cadastral map. These points were entered into the UTM Calculator program and converted from the geographic system based on GCS_Clarke_1880 to the geographic system based on GCS_WGS_1984. The difference between the two systems was calculated, representing the shift of the points from the Clarke_1880 system to the north and east. Figures (16-17).



Figure 16: Image of a Cadastral Map Spatially Corrected According to the GCS_Clarke_1880 System [2]



Figure 17: Image of a Cadastral Map Spatially Corrected According to the GCS_WGS_1984 System [2]

5.2 Spatial Correction According to the UTM Coordinate System

The geographic coordinates were converted to UTM coordinates using the UTM Calculator program. The coordinates were transformed from the Clarke_1880_UTM_Zone_38N system to the WGS_1984_UTM_Zone_38N system. The difference between the two systems was calculated, representing the shift of the

points from the Clarke_1880 system to the north and east. See Figures (18-19).

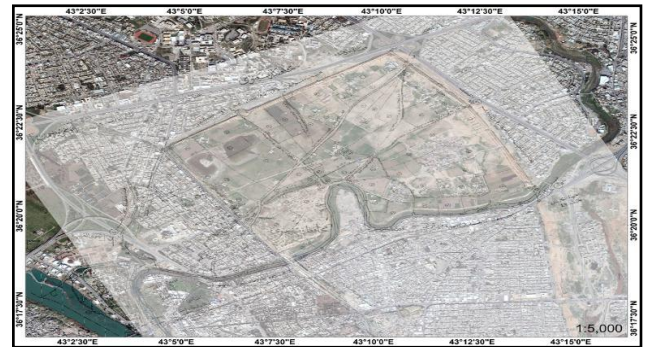


Figure 18: Image of a Cadastral Map Spatially Corrected According to the Clarke_1880_UTM_Zone_38N System [2]

Based on the above, there are discrepancies in UTM coordinates for the cadastral map between the Clarke_1880_UTM_Zone_38N and WGS_1984_UTM_Zone_38N systems. These discrepancies arise due to differences in longitude and latitude positions between the two systems. Minimal differences only represent deviations from the prime meridian and equator. The UTM Calculator program cannot accurately compute full deviations, as it provides differences for a single map image, not for both. Matching based on random points is unsatisfactory due to visual observation inaccuracies and the small size of image units (pixels), especially with low-resolution satellite images.

5.3 Spatial Correction Using the Hybrid System

In this system, both coordinate systems (coordinate points) are utilized for spatial matching with their locations on satellite imagery. Fundamental elements are involved in performing map alignment, as the issue of spatial matching with different spatial data leads to the use of coordinate systems and projection systems to complete the alignment process. In this phase, the spatial features of the cadastral map are matched with satellite images with a 60 cm resolution. Cadastral maps have their own problems, including projection issues and the primitive techniques and sources used to draw cadastral maps during that period, resulting in meter-level shifts and differences in the distribution of geographical features from reality. This means that the ground features on the cadastral maps do not match the satellite imagery, necessitating the use of hybrid spatial correction by overlaying points of selected geographical features on the cadastral map with the satellite imagery. The following steps were taken for alignment using the (ArcGIS 10.8.1) program:

1. Transforming Coordinate Systems: Random points on the map of the study area were converted using the ARCGIS program according to the

WGS_1984_UTM_Zone_38N system, as it matches the satellite imagery.

2. Entering Maps into ARCGIS: Maps of the study area districts were entered into the ARCGIS program after performing coordinate corrections for the points and features according to the WGS_1984_UTM_Zone_38N system using (Exestuation Georeferencing) options.
3. Identifying Errors: Errors were identified by matching the corrected maps based on the map coordinates and comparing them with the corrected satellite imagery. For matching operations, the (Exestuation Overlay) command was used, revealing the differences between the overlay points of selected features. These differences are evident for geographical features as shown in Figure (19), where selected points on the map are matched with their counterparts on the satellite imagery: (Georeferencing = Transformation = Spline = Rectify).

For many navigation applications, a straightforward method exists to convert latitude and longitude to WGS84, as well as converting UTM coordinates to Clarke1880, by determining the shift to be applied to the geographic and UTM coordinates. One method of calculating the shift is by using (OPS) techniques and the ArcGIS program together. Users must be familiar with applying the appropriate parameters for various ellipsoids according to the applicable region.

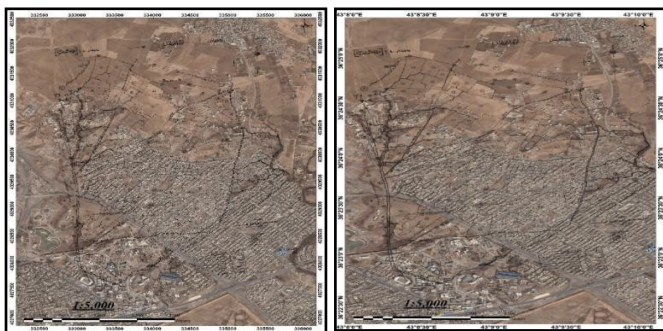


Figure 19: Transformations between Clarke 1880 for the Cadastral Map and WGS_1984_UTM_Zone_38N, and their Cartographic Matching Based on the Geographical Features of the Satellite Imagery [2]

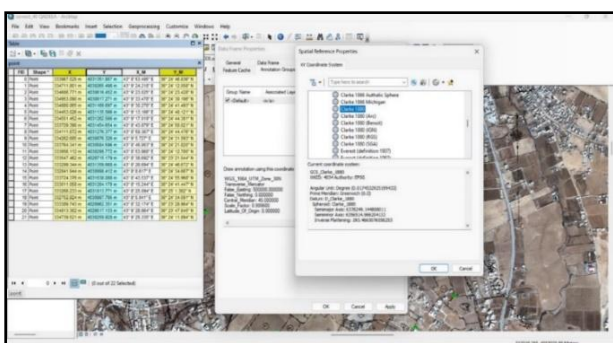


Figure 20: of Selected Points in Meters According to the Overlay Points and WGS_1984_UTM_Zone_38N Systems [2]

From this, we find that the matching process was conducted through transformation operations on the cadastral map based on satellite imagery. Variations and deviations vary in intensity from one point to another. To complete the matching process for the purpose of addressing distortions in the deviations, transformation and corrective operations were carried out. These included:

1. Projection adjustments.
2. Spheroidal Earth approximation issues.
3. WGS and Clark 1880 systems.
4. Distortions occurring in cadastral map drawing.

VI. CONCLUSION

1. Through studying cadastral maps and the challenges of updating and matching them with satellite imagery, it became evident that there is inconsistency between cadastral maps prepared under the Clarke 1880 system and maps or satellite imagery based on the WGS 1984 system. This discrepancy arises from differences in scales, spheroidal Earth approximations, and variations in Earth ellipsoids (Datum).
2. Cadastral maps prepared under the Clarke 1880 system from aerial visuals and field surveys are typically in vertical projection, whereas maps and images derived from satellite imagery are in central (planar) projection before correction.
3. Distortions occur in edges, discrepancies, and offsets in data and coordinates of locations. Several preparatory steps must be undertaken to facilitate matching operations between differently sourced maps, including standardizing scale and coordinate systems. These steps are essential as auxiliary factors in the final output alignment process.
4. High-resolution satellite imagery available through accredited providers or from survey drones such as DJI's survey drones currently facilitate correction processes for paper maps.
5. Extensive capabilities in using software for digital technologies enable the construction of spatial and descriptive databases and the correction of paper maps.
6. Old paper maps have been converted into modern digital maps using the WGS 1984 global coordinate system instead of the old Clarke 1880 system.

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