Journal of Applied Engineering and Technological Science
Vol 7(1) 2025: 617-630

GENERATING ACCURATE TOPOGRAPHIC MAP BY INTEGRATING DRONE IMAGERY AND GNSS DATA

Aqeel A. Abdulhassan[1*], Noor A. Alwan[2], Marwaa K. Azeez[3], Doaa T. Yaseen[4]
Department of Civil Engineering, College of Engineering, Wasit University, Wasit, Iraq[134]
Department of Construction and Projects, Presidency of Wasit University, Wasit, Iraq[2]
aqeel@uowasit.edu.iq

Received: 09 April 2025, Revised: 08 October 2025, Accepted: 27 October 2025
**Corresponding Author*

ABSTRACT
When operating in big or hard-to-reach areas, traditional topographic survey methods can be costly, difficult to organize, and time-consuming. Some of these technologies use total stations and GPS on the ground and aerial photogrammetry done by planes or helicopters. We need a better and cheaper approach to collect geographic data fast. This article discusses employing unmanned aerial vehicles (UAVs) for topographic surveying, mapping, and updating data as one option. A DJI Mavic 2 Pro quadcopter drone with a 20-megapixel digital camera took photographs of the Wasit University campus from 125 meters above the ground. The pictures indicated a space of around 0.43 km², with 80% of the front and 70% of the sides overlapping. The research area was turned into an orthomosaic by Agisoft PhotoScan Professional. This was then loaded into ArcMap so that features may be taken out. By comparing the coordinates of fourteen Ground Control Points (GCPs) that we got using the Real Time Kinematic Global Navigation Satellite System (RTK-GNSS) mechanism, we were able to get a reference positional precision of 0.050 m RMSE. The results of this study demonstrate that geospatial data obtained from UAVs, when augmented by GCPs, can produce and update comprehensive maps with accuracy comparable to RTK GNSS and Total Station methodologies. Many individuals use these methods for surveys of land, buildings, and engineering.
Keywords*: High-Resolution Aerial Imagery, Large-Scale Topographic Maps, Orthomosaic Generation, RTK-GNSS, Ground Control Points, UAV Photogrammetry.*

1. Introduction

Topographic maps show several aspects of the Earth's surface. Rivers, lakes, and plants are depicted with both natural and man-made features, such as buildings, highways, and political borders (Dlamini & Ouma, 2025). Due to their attractive geometric designs and accurate geographic information, these maps are extremely helpful. A nation's infrastructure and development plans cannot be completed without geospatial data and location-based technology(Stock & Guesgen, 2016). A wide variety of industries make use of spatial data, such as transportation, real estate, utilities, city planning, and land management. By facilitating better infrastructure planning and more sustainable development, geospatial technology, when integrated into national systems, can assist economies (Silwal et al., 2022).

Traditional surveying methods have made topographical map making more difficult (Perera & Nalani, 2022). Thanks to developments in computer vision and the widespread use of small Unmanned Aerial Vehicles (UAVs), photogrammetry has become a popular method for collecting topographical data (Beretta et al., 2018). The quantity and quality of the data are same as with RTK-GNSS surveys, but the expense is much lower. Unmanned Aerial Vehicles (UAVs) can simultaneously take orthophotos and track their own position using photogrammetry (Pathak et al., 2024). Thanks to advancements in technology, topographic maps may now be made with greater precision and detail. Seo et al. (2024) noted that computerized maps have become extremely accurate and up-to-date as a result of GPS and satellite photography. These maps teach us a lot about land management, disaster assistance, and distributing resources. In order to identify possible roadblocks, this study examines the pros and cons of integrating drones with a GIS mapping system. According to Ahmad et al. (2018), less field surveys are needed to build very accurate topographic maps.

A completely automated system or humans on the ground can manage unmanned aerial vehicles (UAVs), sometimes known as drones (Aber et al., 2019). Unmanned Aerial Vehicles

(UAVs) are ideal for remote sensing due to their exceptional picture quality, ability to fly freely, and ability to fly through clouds. When compared to other methods, they can save money while still getting precise time and position data from hard-to-reach regions (Colomina & Molina, 2014). You may have these planes in two primary wing configurations: fixed and retractable. Small unmanned aircraft and UAVs with fixed wings look and operate similarly, according to Remondino et al. (2012). Alternatively, there are unmanned aerial vehicles (UAVs) that look like little helicopters and have adjustable wings; they fly similarly to drones. According to the American Society for Photogrammetry and Remote Sensing (Wolf et al., 2014), photogrammetry encompasses the practice, study, and technology involved in scanning, photographing, and analyzing physical features and their environments for information, some of which may contain patterns of electromagnetic radiation.

Find out how closely an image's geometry matches the shape of the actual thing it depicts; that's photogrammetry's principal purpose. According to Mikhail et al. (2001), if the association is obvious, visuals can teach you anything. Thanks to their superior sensors and ability to fly at low altitudes, UAVs are able to capture high-resolution images along with a wealth of other data. Nevertheless, these images may be a challenge due to the large amount of information they contain and the specific software that is required to alter them. Ruwaimana et al. (2018) conducted a study. Prior to data processing, flight planning, camera setup, picture acquisition, alignment, and UAV photogrammetry are the most critical phases. According to Nex & Remondino (2014), this method is commonly used to generate Digital Surface Models (DSMs), point clouds, and detailed ortho-mosaics. There are very many potential applications for the images captured by UAVs, as pointed out by Crommelinck et al. (2016). Some of these applications include developing smart cities, precision agriculture, archaeology research, traffic monitoring, safeguarding cultural heritage, and 3D model creation.

The application of UAVs to map and survey land has shown promising outcomes. Taiwanese scientists conducted an investigation into the potential of creating high-accuracy topographic maps by integrating information from UAV missions with GCP. In their research in 2016, Chi et al. Scholars have recently indicated that unmanned aerial vehicles (UAVs) can potentially be used as a substitute for man-power-consuming surveying instruments such as total stations and GPS in the future. Ghanaian researchers discovered that UAVs have the capacity to cover previously un-reachable areas (Quaye-Ballard et al., 2020). One such area can be mapped precisely and dependably with a blend of RTK systems, GIS, and UAV technologies, discovered the research. Running concurrently with the Wasit University ground control stations (GCPs), the study seeks to define the precision of unmanned aerial vehicles (UAVs).

The advantage of conventional field surveys is lost with the large-scale use of UAVs. The primary objective of the present study is to determine optimal best practices for the use of UAVs in order to create reliable topographic maps and high-resolution orthophotos. Besides, it seeks to ascertain whether UAV photogrammetry can outperform total station and RTK-GNSS techniques in speed, accuracy, cost-effectiveness, and coverage area.

2. Study Area

Wasit Governorate is one of Iraq's middle governorates. It is in Kut City, which is roughly 180 kilometers south of Baghdad. The Wasit University Campus, which is a research area, is there. The research area is shown in Figure 1. It is roughly 0.43 km^2 and goes from 32° 29' 42" N to 32° 30' 15" N and from 45° 50' 12" E to 45° 50' 37" E (Abdulhassan, 2025). This area was chosen as a research site due to its diverse buildings, streets, and land cover.

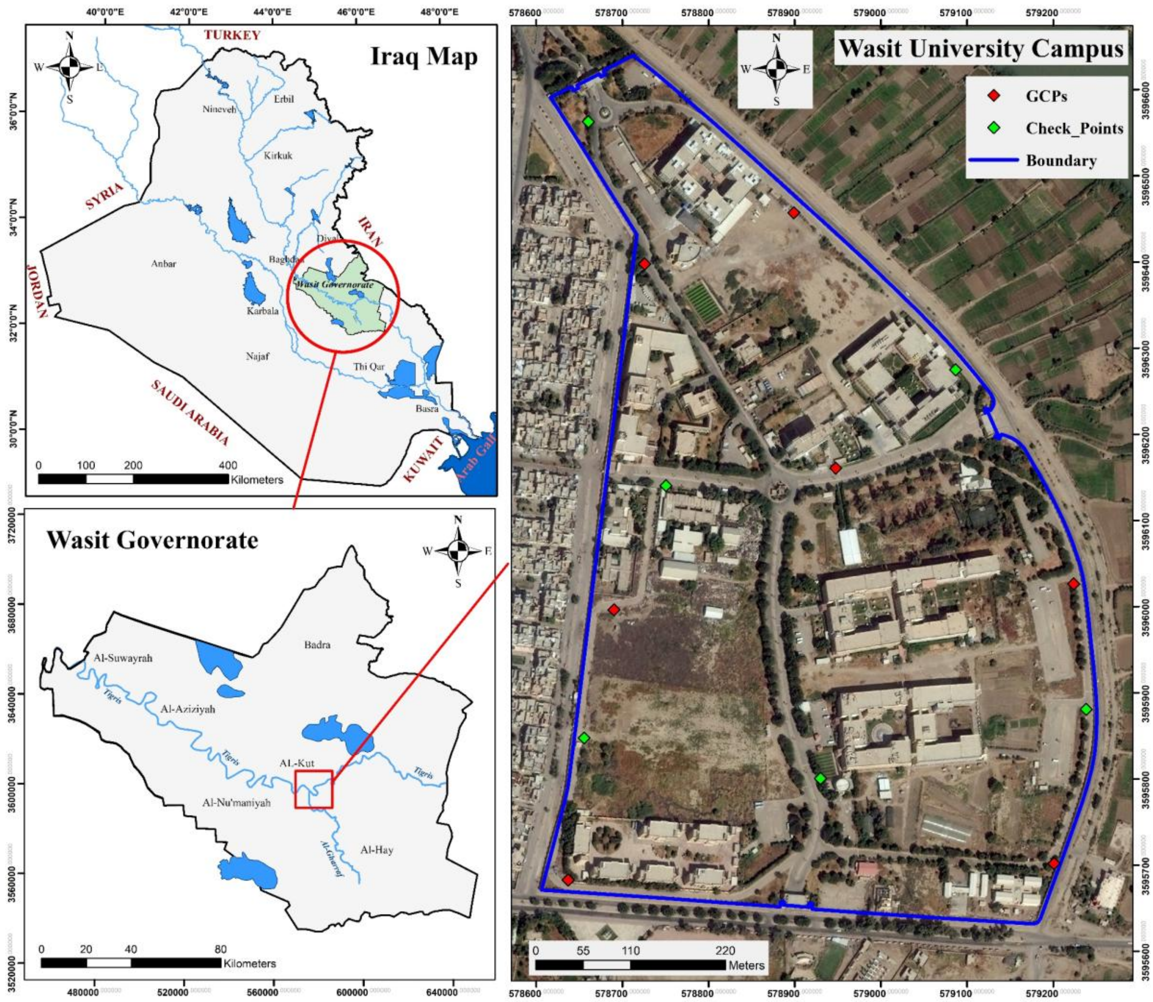

Fig. 1. Area of Study

3. Material and Software

This work uses both primary and secondary sources of information. Secondary data sources that have information on the university campus include geographic information system (GIS) data, field reconnaissance, satellite pictures, and land use maps (Zhang et al., 2023). On the contrary, the data collected by the multirotor drone are well thought-out as foremost data (Hung et al., 2019). Certain information is needed in order to generate the topographical map model. There are numerous issues to be taken into consideration when choosing a research drone model, such as price, coverage area, and compatibility with software (Chaudhry et al., 2020). The most suitable drone for the gathering of aerial data is clearly the DJI Mavic 2 Pro multirotor drone (Jiménez-Jiménez et al., 2021). The specifications of the UAV employed in the present study are given in Table (1). A variety of software programs are engaged in data filtering, processing, generating orthophoto maps, and result analysis (Guan et al., 2022). The Pix4Dcapture tool is employed to conduct the present study. In order to process the drone footage, the Agisoft PhotoScan program is employed. The completion of the urban form analysis is made easy through the implementation of the geographic information system (GIS) applications, including ArcGIS and MapInfo (Udin & Ahmad, 2014).

Table 1 - Specification of drone (DJI Mavic 2 Pro)

Specification	Detail
Model	DJI Mavic 2 Pro
Drone system	Multi rotor
Landing	Vertical

Flight speed	10.3 m/sec
Ground Sample Distance GSD	2.93 cm/pixel
Camera angle	-90°
Image dimension	5472 x 3648 (9.37 MP)

4. Methodology

This study's research methodology is shown in Figure 2 and has five separate phases (Lu, 2020). The first step is to get information, and the second step is to make plans. During Phase 3, RTK-GPS was used to make ground control points, and a UAV took pictures of the study site from above. We use these numbers to see how accurate UAV-made topographical maps are. In the fourth stage, Agisoft PhotoScan 1.8 and ArcGIS 10.8 are used. The abilities of Agisoft PhotoScan support mosaics, orthophoto, and indoor/outdoor object detections among many other features. Some possibilities for ArcGIS from its wide functionalities include georeferencing, image uploading, updating databases, and setting coordinates. In phase 5, 2D characteristics are extracted by analyzing mapping findings from the processed data (Syetiawan et al., 2020).

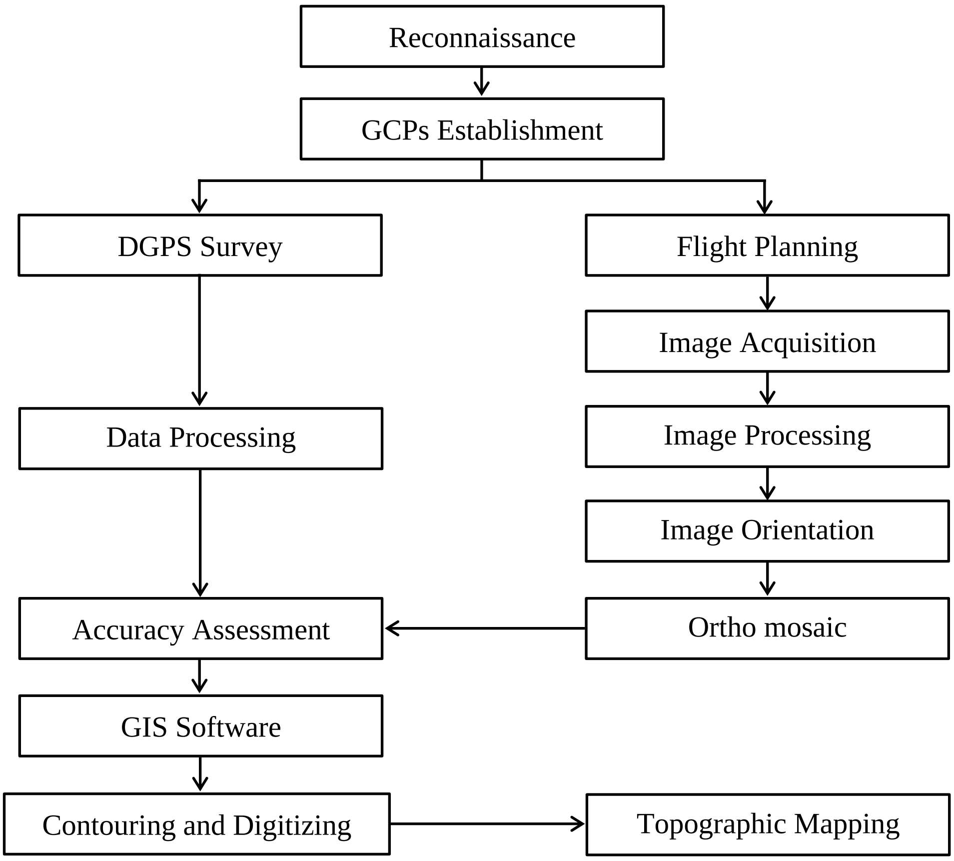

Fig. 2. The workflow of methodology

4.1. Reconnaissance

Before making use of unmanned aerial vehicles (UAVs) ready to map the area, it was secured. They settled on a research subject and gathered the necessary equipment - in this case, a UAV platform and a high-quality digital camera- too (Mousa et al., 2025). The site visits also enabled us to determine flying height optimal to the terrain concerning GSD. The possible control sites were determined through satellite images as narrated by Abdulhassan et al. (2021).

4.2. Ground control points establishment

Setting up GCPs made it possible to check the accuracy and georeferencing before the aerial photos were taken. The survey team put fourteen GCPs in different places around the study area to make sure the data was correct and could be seen (Taş et al., 2023). Figure 1 shows this.

Table 2 shows the coordinates for these places as part of a static DGPS survey. A Topcon GR3 receiver was used to do this. During the exterior orientation phase, seven of the fourteen locations were chosen as GCPs, and the other seven were used as check points to make sure the orthophoto was correct(Yu et al., 2020).

Table 2 - The Rectangular Coordinate of GCPs

	WGS84 / UTM zone 38N		
Points	E (m)	N (m)	Elv. (m)
GCP1	578929.823	3595800.514	20.740
GCP2	579223.891	3596026.478	20.291
GCP3	579238.333	3595880.851	21.235
GCP4	579200.965	3595701.785	21.334
GCP5	578636.902	3595682.730	20.989
GCP6	578655.568	3595847.612	21.020
GCP7	578690.07	3595996.419	20.618
GCP8	578750.466	3596140.461	20.496
GCP9	578861.426	3595946.338	19.868
GCP10	579086.754	3596274.769	19.368
GCP11	578898.881	3596457.116	19.113
GCP12	578660.349	3596562.661	19.106
GCP13	578725.617	3596397.635	18.988
GCP14	578947.571	3596160.651	18.885

4.3. Flight planning and image acquisition

This stage talks about how the drone will fly. We need to sync up a few crucial things in order to get the high-quality photos we need to meet our goals. Some of these things are the flight path, the overlap of images, the altitude, the settings for the sensors, and the georeferencing (Sohl & Mahmood, 2024). On March 7, 2024, the drone shot photographs from the sky. The photos from mapping missions are arranged so that each one overlaps with the next one sufficiently for processing software to simply put them together. To acquire the right amount of overlap, you have to modify a variety of things, like the drone's speed, height, trigger interval, distance between transects, and the camera's internal geometry (Mukhlisin et al., 2023). We used Pix4Dcapture to make the flight path into a rectangle. You may adjust your flight plans and mapping settings right away with this software, and you can see the trip in real time through map and camera views. The drone flew at a height of 125 meters to avoid losing signals from surrounding cell towers and getting in the way of big buildings. The settings made it so that the front and sides had at least 80% and 70% overlap, respectively. Figure 3 demonstrates a simplified way to think about utilizing a drone to survey.

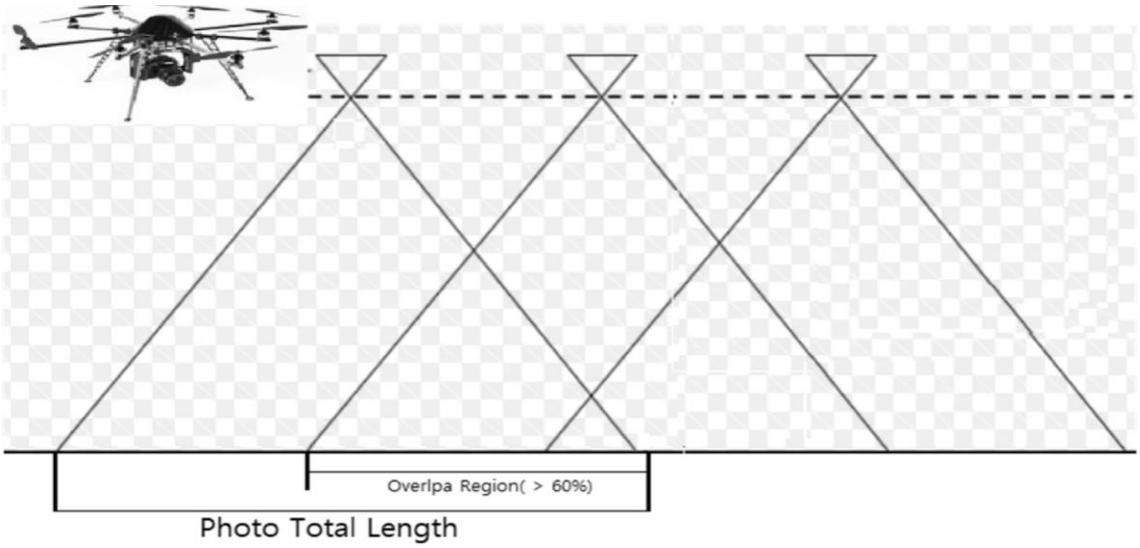

Fig. 3. Schematic diagram of the drone surveying concept (Lee, 2018)

We captured 652 images, which were used to generate the orthomosaic images of the university campus. Figure 4 shows a sample of drone images for the study area.

4.4. Image processing

The raw images are sent to a computer when the drone flight is over. We save the pictures as JPEG files and then check the quality of each one by looking at it and getting rid of any that are crooked or not needed. Changes in altitude during flight are a big reason for frequent quality problems like blurriness and color imbalance. All of the survey photos for this study were entered into Agisoft PhotoScan, which transformed the picture coordinate system to WGS84 automatically. To work, the app needs hundreds of still photos that overlap. We used Scale-Invariant Feature Transform (SIFT) and other ways to match images to deal with these geotagged, overlapping photos. This algorithm's first step is to find the tie points (Pepe et al., 2018). These tie points come from looking for things that are the same in pictures that are comparable to each other. The technology initially discovers and records thousands of important spots in each shot that match. To locate and make automatic tie places (ATPs), the patterns of these important sites in distinct photos are compared. Setting up the ATPs starts software-based aerial triangulation, which finds the camera calibration parameters to make picture location more accurate. This part makes the orthophoto more precise (Saleem et al., 2025). Seven GCPs were employed to make sure that all points were captured in at least six photographs without any distortion (Sharma & Garg, 2023).

Fig. 4. Sample of drone images

5. Results

5.1. Orthophoto

Using Agisoft PhotoScan, an orthorectified image of the research area was created. The georeferenced orthophoto that came out is seen in Figure 5. The orthophoto has a pixel size of 2.93 cm, which means that it depicts all the items clearly and properly. An orthophoto can be used to digitize things, identify features, produce different kinds of maps, and help with many other spatial planning tasks. An orthomosaic generated from drone footage shows the area from above in excellent detail; thus, it's quite unlikely that any data would be missing by mistake. It makes orthographic projections of things that are similar to the ones on traditional planimetric maps. These advantages make orthophotos invaluable tools in fields such as urban planning, environmental monitoring, and agriculture (Chio & Chiang, 2020). They help professionals make smart choices based on reliable visual data by giving them accurate and detailed pictures of the landscape. You can now directly measure distances, locations, angles, and areas with this orthomosaic because all the distortions have been fixed. The orthomosaic combines the exact features of aerial photography with the exact measurements of planimetric mapping.

Fig. 5. Orthophoto of Wasit University

5.2. Accuracy assessment

In order to conduct a qualitative assessment, we examined the orthophoto's attributes and looked for signs of distortion or haze. Since there were so many distinct components, we had anticipated that the task would be straightforward. However, GCPs were utilized in a quantitative accuracy test.

Azmi et al. (2014) stated that the quality of the fit between the measured and reference coordinates was determined by using the Root Mean Square Error (RMSE). Before valuing the orthophoto, it was ensured that (1) planimetrically, the control points were correct and, (2) geometrically, the components of the orthophoto were accurate.

We may apply the Relative Mean Squared Error (RMSE) to express how much, or by what degree, the UAV data varied from more accurate reference data; see Elkhrachy (2021). GCPs not used for image georeferencing are termed as “checkpoints” by Martínez-Carricondo et al. (2018). A comparison was made to determine whether the orthophoto and GNSS survey coordinates were equal. Since the coordinate systems varied, the RMSE could be calculated. The RTK-GNSS coordinates and those derived from the orthophoto of the check point, which were used for accuracy assessment, are summarized in Table 3.

Table 3 - RTK-GNSS and orthophoto-derived coordinates for the check point

check points	E m	N m	X m	Y m
GCP1	578929.823	3595800.514	578929.7856	3595800.481
GCP3	579238.333	3595880.851	579238.293	3595880.887
GCP6	578655.568	3595847.612	578655.6046	3595847.647
GCP8	578750.466	3596140.461	578750.4319	3596140.499
GCP9	578655.568	3595847.612	578655.6026	3595847.575
GCP10	579086.754	3596274.769	579086.7886	3596274.738
GCP12	578660.349	3596562.661	578660.3198	3596562.692

To get the RMSE, Nwilag et al. (2023) applied these equations in their calculation:

$$RMSE_x = \sqrt{\frac{\Sigma(X_{UAV} - E_{GNSS})^2}{n}} \quad (1)$$

$$RMSE_y = \sqrt{\frac{\Sigma(Y_{UAV} - N_{GNSS})^2}{n}} \quad (2)$$

$$RMSE = \sqrt{{RMSE_x}^2 + {RMSE_y}^2} \quad (3)$$

in which n refers to the number of checkpoints assessed for the study, X_{UAV} and Y_{UAV} refer to the coordinates measured in the orthophoto for a checkpoint, E_{GNSS} and N_{GNSS} are the coordinates measured with a GNSS for the same checkpoint above. The horizontal accuracy ($RMSE_x$), ($RMSE_y$), and ($RMSE$) calculated from seven checkpoints were 3.54 cm, 3.47 cm, and 4.96 cm, respectively. Based on the horizontal accuracy standards outlined in (Ludwig et al., 2020), the errors calculated using equations 1, 2, and 3 meet the requirements for horizontal accuracy. The orthophoto was produced with a resolution of 2.93 cm/pix.

We found the root-mean-squared error (RMSE) by comparing the coordinates of GCPs (used as checkpoints) made by the photogrammetric method with those found by the GNSS solution. This allowed for an assessment of the study's fit and accuracy (Abdulhassan, 2020). These findings illustrate that unmanned aerial vehicles (UAVs) can collect geographic data with precision akin to conventional terrestrial mapping methods such as GPS and Total Stations.

5.3. Feature extraction

It is a useful tool for making and changing maps because it lets you get features by hand or on a computer from the orthophoto (Shadhar et al., 2023). Figure 6 shows the final topographical map of the area where the study took place. It was made using this orthophoto and other parts of a GIS program. Features that were taken out were put into new feature classes and datasets. This led to the creation of a geodatabase. The UAV orthophoto's clarity and wealth of information make it easy to find more interesting things (Laporte-Fauret et al., 2019). This method makes it easier to make new vector datasets that have topological properties. This helps you plan better. A topographical map of the Wasit University site at a scale of 1:4000 was also made, as seen in Figure 6.

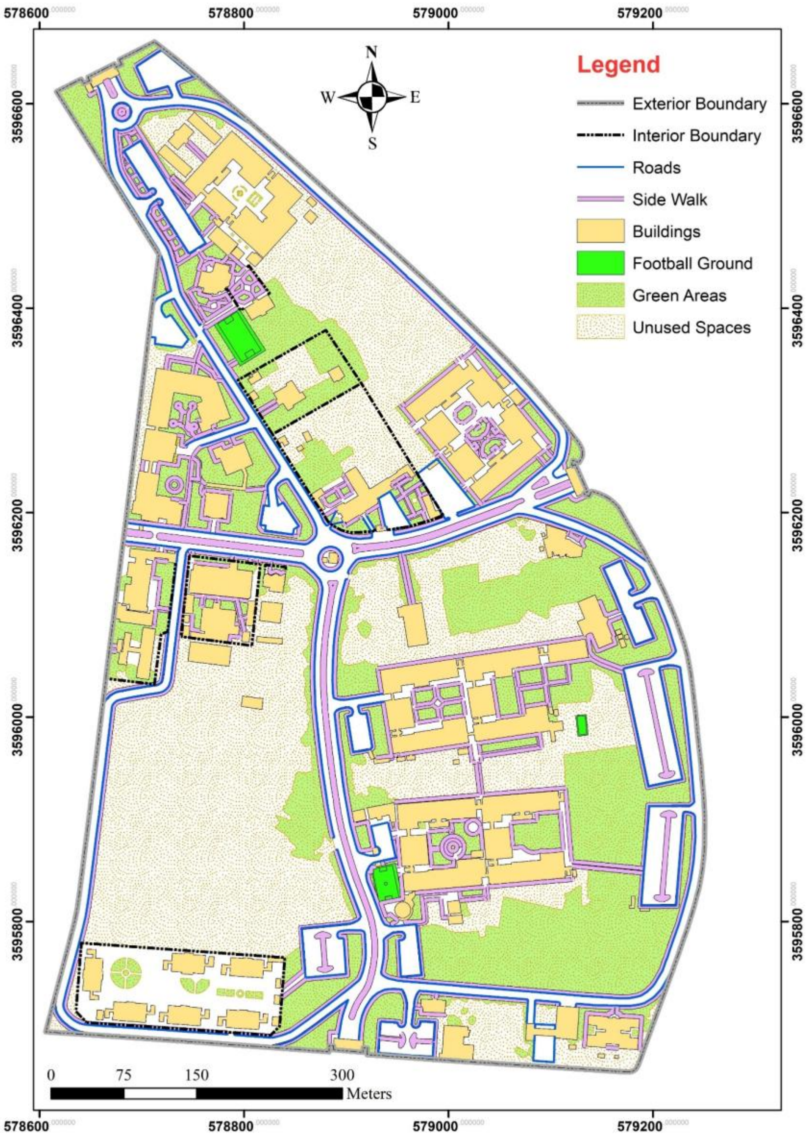

Fig. 6. Topographic map of Wasit University

6. Discussion

UAV mapping outperforms ground-based mapping in terms of data collection speed, cost-effectiveness, and comprehensive data visualization. UAV workflows that automatically acquire and analyze images reduce mistakes, speed things up, and ensure that the time it takes to collect field data, manage image parameters, and process the data are all the same. UAV maps usually have substantially better spatial coverage and data density than topographic surveys done on the ground. But drones made for the general public, like the DJI Mavic 2 Pro, don't always offer survey-grade precision. To solve this difficulty, GCPs are carefully placed and spread out over the study region. Some GCPs are used as checkpoints during image processing to verify that the UAV models are correct. Others are used to make georeferencing more accurate (Şenkal et al., 2021).

The research photos are excellent for making topographic maps because they have a very high spatial resolution. The tiny ground sample distance (GSD) in the original photos shows this. We generated an orthomosaic with a resolution of 2.93 cm by using a low flying altitude, a large image overlap, and a low GSD. These features offered us a great level of detail in space. The flying height and camera settings are used to figure out the GSD. This parameter has a direct impact on the spatial resolution of images taken by UAVs. A lower GSD makes the image clearer and more detailed, whereas a higher GSD makes it less clear and less detailed.

7. Conclusion

The position information from GNSS and total stations is the best there is. But current apps want more and more information and richness, which they don't supply. When used in conjunction with Real-Time Kinematic (RTK) positioning, UAVs revolutionize the collection of geospatial data. They have more data and coverage than anything else, and their spatial precision is nearly the same. When using unmanned aerial vehicle photogrammetry, you may quickly and precisely collect data in the field. UAVs cost a lot less than old-fashioned photogrammetry tools. They can also be programmed to do certain flight missions and can even work when it's cloudy. The study's quantitative and qualitative results show that UAV-based mapping can take the place of total station and GPS, which are two of the most common tools for surveying the land's topography. UAV mapping is the ideal way to do surveys in many cases since it speeds up and costs less to collect field data, and it also decreases the risks that survey professionals face on the job.

One of the many great things about UAV technology is that it can create high-resolution orthophotos that are quite accurate. This makes it much easier to make and update maps. Furthermore, quick data collection and low cost are other perks. But there are some restrictions to UAV technology. Some of these drawbacks include that it takes a long time to process data, the rules for airspace are too strict, flights are too short due to battery life, coverage areas are too narrow, and cargo capacity is too low. Poor weather can also make things harder. The dependability of the generated goods depends on how well other aspects are taken into account. These include the software that processes the photos, the number and placement of GCPs, and the camera's quality and calibration. The study objectives were successfully met by confirming the efficacy of UAV-based topographic mapping in conjunction with GCPs. This method seeks to resolve the issue of swift, economical, and accurate mapping of challenging-to-survey regions. The results also pave the way for more study, which might include using AI and ML to automate feature extraction and improve geographic data analysis, among other things.

References

Abdulhassan, A. (2025). Integration of UAV and GNSS Data for Accurate Land Use Mapping at Wasit University. *Wasit Journal of Engineering Sciences*, *13*(3), 74–85. https://doi.org/10.31185/wjes.Vol13.Iss3.742

Abdulhassan, A. A. (2020). Developing a three-dimensional city modeling with the absence of elevation data. *Periodicals of Engineering and Natural Sciences*, *8*(4), 2507–2515. https://doi.org/10.21533/pen.v8i4.1752

Abdulhassan, A. A., Naji, A. A., & Abbood, H. H. (2021). Vertical Accuracy of Digital Elevation Models Based on Differential Global Positioning System. *Iraqi Journal of Science*, *62*(SI 2), 91–99. https://doi.org/10.24996/ijs.2021.SI.2.10

Aber, J. S., Marzolff, I., Ries, J. B., & Aber, S. E. W. (2019). Unmanned Aerial Systems. In *Small-Format Aerial Photography and UAS Imagery* (pp. 119–139). Elsevier. https://doi.org/10.1016/B978-0-12-812942-5.00008-2

Ahmad, M. J., Ahmad, A., & Kanniah, K. D. (2018). Large scale topographic mapping based on unmanned aerial vehicle and aerial photogrammetric technique. *IOP Conference Series: Earth and Environmental Science*, *169*, 012077. https://doi.org/10.1088/1755-1315/169/1/012077

Azmi, S. M., Ahmad, B., & Ahmad, A. (2014). Accuracy assessment of topographic mapping using UAV image integrated with satellite images. *IOP Conference Series: Earth and Environmental Science*, *18*, 012015. https://doi.org/10.1088/1755-1315/18/1/012015

Beretta, F., Shibata, H., Cordova, R., Peroni, R. de L., Azambuja, J., & Costa, J. F. C. L. (2018). Topographic modelling using UAVs compared with traditional survey methods in mining. *REM - International Engineering Journal*, *71*(3), 463–470. https://doi.org/10.1590/0370-44672017710074

Chaudhry, M. H., Ahmad, A., & Gulzar, Q. (2020). A comparative study of modern UAV platform for topographic mapping. *IOP Conference Series: Earth and Environmental Science*, *540*(1), 012019. https://doi.org/10.1088/1755-1315/540/1/012019

Chi, Y.-Y., Lee, Y.-F., & Tsai, S.-E. (2016). Study on High Accuracy Topographic Mapping via UAV-based Images. *IOP Conference Series: Earth and Environmental Science*, *44*, 032006. https://doi.org/10.1088/1755-1315/44/3/032006

Chio, S.-H., & Chiang, C.-C. (2020). Feasibility Study Using UAV Aerial Photogrammetry for a Boundary Verification Survey of a Digitalized Cadastral Area in an Urban City of Taiwan. *Remote Sensing*, *12*(10), 1682. https://doi.org/10.3390/rs12101682

Colomina, I., & Molina, P. (2014). Unmanned aerial systems for photogrammetry and remote sensing: A review. *ISPRS Journal of Photogrammetry and Remote Sensing*, *92*, 79–97. https://doi.org/10.1016/j.isprsjprs.2014.02.013

Crommelinck, S., Bennett, R., Gerke, M., Nex, F., Yang, M., & Vosselman, G. (2016). Review of Automatic Feature Extraction from High-Resolution Optical Sensor Data for UAV-Based Cadastral Mapping. *Remote Sensing*, *8*(8), 689. https://doi.org/10.3390/rs8080689

Dlamini, S. M., & Ouma, Y. O. (2025). Large-Scale Topographic Mapping Using RTK-GNSS and Multispectral UAV Drone Photogrammetric Surveys: Comparative Evaluation of Experimental Results. *Geomatics*, *5*(2), 25. https://doi.org/10.3390/geomatics5020025

Elkhrachy, I. (2021). Accuracy Assessment of Low-Cost Unmanned Aerial Vehicle (UAV) Photogrammetry. *Alexandria Engineering Journal*, *60*(6), 5579–5590. https://doi.org/10.1016/j.aej.2021.04.011

Guan, S., Zhu, Z., & Wang, G. (2022). A Review on UAV-Based Remote Sensing Technologies for Construction and Civil Applications. *Drones*, *6*(5), 117. https://doi.org/10.3390/drones6050117

Hung, I.-K., Unger, D., Kulhavy, D., & Zhang, Y. (2019). Positional Precision Analysis of Orthomosaics Derived from Drone Captured Aerial Imagery. *Drones*, *3*(2), 46. https://doi.org/10.3390/drones3020046

Jiménez-Jiménez, S. I., Ojeda-Bustamante, W., Marcial-Pablo, M., & Enciso, J. (2021). Digital Terrain Models Generated with Low-Cost UAV Photogrammetry: Methodology and Accuracy. *ISPRS International Journal of Geo-Information*, *10*(5), 285. https://doi.org/10.3390/ijgi10050285

Laporte-Fauret, Q., Marieu, V., Castelle, B., Michalet, R., Bujan, S., & Rosebery, D. (2019). Low-Cost UAV for High-Resolution and Large-Scale Coastal Dune Change Monitoring Using Photogrammetry. *Journal of Marine Science and Engineering*, *7*(3), 63. https://doi.org/10.3390/jmse7030063

Lee, B.-G. (2018). A Study of Three Dimensional DSM Development using Self-Developed Drone. *Journal of the Korean Earth Science Society*, *39*(1), 46–52. https://doi.org/10.5467/JKESS.2018.39.1.46

Lu, R. S. (2020). Research on the Mapping of Large-Scale Topographic Maps Based on Low-Altitude Drone Aerial Photography System. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *XLII-3/W10*, 623–628. https://doi.org/10.5194/isprs-archives-XLII-3-W10-623-2020

Ludwig, M., M. Runge, C., Friess, N., Koch, T. L., Richter, S., Seyfried, S., Wraase, L., Lobo, A., Sebastià, M.-T., Reudenbach, C., & Nauss, T. (2020). Quality Assessment of Photogrammetric Methods—A Workflow for Reproducible UAS Orthomosaics. *Remote Sensing*, *12*(22), 3831. https://doi.org/10.3390/rs12223831

Martínez-Carricondo, P., Agüera-Vega, F., Carvajal-Ramírez, F., Mesas-Carrascosa, F.-J., García-Ferrer, A., & Pérez-Porras, F.-J. (2018). Assessment of UAV-photogrammetric mapping accuracy based on variation of ground control points. *International Journal of Applied Earth Observation and Geoinformation*, *72*, 1–10. https://doi.org/10.1016/j.jag.2018.05.015

Mikhail, E. M., Bethel, J. S., & McGlone, J. Chris. (2001). *Introduction to modern photogrammetry*. John Wiley & Sons Inc.

Mousa, Y. A., Sachit, M. S., & Hasan, A. F. (2025). A Hierarchical approach for efficient DTM and building footprint extraction from UAV images. *Al-Qadisiyah Journal for Engineering Sciences*, *18*(3), 265–271. https://doi.org/10.30772/qjes.2024.151126.1284

Mukhlisin, M., Astuti, H. W., Kusumawardani, R., Wardihani, E. D., & Supriyo, B. (2023). Rapid and low cost ground displacement mapping using UAV photogrammetry. *Physics and Chemistry of the Earth*, *130*, 103367. https://doi.org/10.1016/j.pce.2023.103367

Nex, F., & Remondino, F. (2014). UAV for 3D mapping applications: a review. *Applied Geomatics*, *6*(1), 1–15. https://doi.org/10.1007/s12518-013-0120-x

Nwilag, B. D., Eyoh, A. E., & Ndehedehe, C. E. (2023). Digital topographic mapping and modelling using low altitude unmanned aerial vehicle. *Modeling Earth Systems and Environment*, *9*(2), 1463–1476. https://doi.org/10.1007/s40808-022-01677-z

Pathak, S., Acharya, S., Bk, S., Karn, G., & Thapa, U. (2024). UAV-based topographical mapping and accuracy assessment of orthophoto using GCP. *Mersin Photogrammetry Journal*, *6*(1), 1–8. https://doi.org/10.53093/mephoj.1350426

Pepe, M., Fregonese, L., & Scaioni, M. (2018). Planning airborne photogrammetry and remote-sensing missions with modern platforms and sensors. *European Journal of Remote Sensing*, *51*(1), 412–436. https://doi.org/10.1080/22797254.2018.1444945

Perera, G. S. N., & Nalani, H. A. (2022). UAVS FOR A COMPLETE TOPOGRAPHIC SURVEY. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *XLIII-B2-2022*, 441–447. https://doi.org/10.5194/isprs-archives-XLIII-B2-2022-441-2022

Quaye-Ballard, N. L., Asenso-Gyambibi, D., & Quaye-Ballard, J. (2020). Unmanned Aerial Vehicle for Topographical Mapping of Inaccessible Land Areas in Ghana: A Cost-Effective Approach. *International Federation of Surveyors: Copenhagen, Denmark*.

Remondino, F., Barazzetti, L., Nex, F., Scaioni, M., & Sarazzi, D. (2012). UAV Photogrammetry for Mapping And 3d Modeling – Current Status and Future Perspectives. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *XXXVIII-1/C22*, 25–31. https://doi.org/10.5194/isprsarchives-XXXVIII-1-C22-25-2011

Ruwaimana, M., Satyanarayana, B., Otero, V., M. Muslim, A., Syafiq A., M., Ibrahim, S., Raymaekers, D., Koedam, N., & Dahdouh-Guebas, F. (2018). The advantages of using drones over space-borne imagery in the mapping of mangrove forests. *PLOS ONE*, *13*(7), e0200288. https://doi.org/10.1371/journal.pone.0200288

Saleem, H. D., Abdulhassan, A. A., Imariq, S. M., & Shamkhi, M. S. (2025). Innovative mapping for soil consolidation settlement for various loading cases using GIS tools for Wasit province. *Alexandria Engineering Journal*, *123*, 471–478. https://doi.org/10.1016/j.aej.2025.03.062

Şenkal, E., Kaplan, G., & Avdan, U. (2021). Accuracy assessment of digital surface models from unmanned aerial vehicles' imagery on archaeological sites. *International Journal of Engineering and Geosciences*, *6*(2), 81–89. https://doi.org/10.26833/ijeg.696001

Seo, D.-M., Woo, H.-J., Hong, W.-H., Seo, H., & Na, W.-J. (2024). Optimization of Number of GCPs and Placement Strategy for UAV-Based Orthophoto Production. *Applied Sciences*, *14*(8), 3163. https://doi.org/10.3390/app14083163

Shadhar, A. K., Mahmood, B. B., Abdulhassan, A. A., Mahjoob, A. M. R., & Shamkhi, M. S. (2023). Optimizing and coordinating the location of raw material suitable for cement manufacturing in Wasit Governorate, Iraq. *Open Engineering*, *13*(1). https://doi.org/10.1515/eng-2022-0486

Sharma, M., & Garg, R. D. (2023). Building footprint extraction from aerial photogrammetric point cloud data using its geometric features. *Journal of Building Engineering*, *76*, 107387. https://doi.org/10.1016/j.jobe.2023.107387

Silwal, A., Tamang, S., & Adhikari, R. (2022). Use of unmanned aerial vehicle (UAV) for mapping, and accuracy assessment of the orthophoto with and without using GCPs: A case study in Nepal. *Mersin Photogrammetry Journal*, *4*(2), 45–52. https://doi.org/10.53093/mephoj.1176847

Sohl, M. A., & Mahmood, S. A. (2024). Low-Cost UAV in Photogrammetric Engineering and Remote Sensing: Georeferencing, DEM Accuracy, and Geospatial Analysis. *Journal of Geovisualization and Spatial Analysis*, *8*(1), 14. https://doi.org/10.1007/s41651-024-00176-2

Stock, K., & Guesgen, H. (2016). Geospatial Reasoning With Open Data. In *Automating Open Source Intelligence* (pp. 171–204). Elsevier. https://doi.org/10.1016/B978-0-12-802916-9.00010-5

Syetiawan, A., Gularso, H., Kusnadi, G. I., & Pramudita, G. N. (2020). Precise topographic mapping using direct georeferencing in UAV. *IOP Conference Series: Earth and Environmental Science*, *500*(1), 012029. https://doi.org/10.1088/1755-1315/500/1/012029

Taş, İ., Kaska, M. S., & Akay, A. E. (2023). Assessment of Using UAV Photogrammetry Based DEM and Ground-Measurement Based DEM in Computer-Assisted Forest Road Design. *European Journal of Forest Engineering*, *9*(1), 1–9. https://doi.org/10.33904/ejfe.1312514

Udin, W. S., & Ahmad, A. (2014). Assessment of Photogrammetric Mapping Accuracy Based on Variation Flying Altitude Using Unmanned Aerial Vehicle. *IOP Conference Series: Earth and Environmental Science*, *18*, 012027. https://doi.org/10.1088/1755-1315/18/1/012027

Wolf, P. R., Dewitt, B. A., & Wilkinson, B. E. (2014). *Elements of Photogrammetry with Application in GIS* (4th Edition). McGraw-Hill.

Yu, J. J., Kim, D. W., Lee, E. J., & Son, S. W. (2020). Determining the Optimal Number of Ground Control Points for Varying Study Sites through Accuracy Evaluation of Unmanned Aerial System-Based 3D Point Clouds and Digital Surface Models. *Drones*, *4*(3), 49. https://doi.org/10.3390/drones4030049

Zhang, J., Xu, S., Zhao, Y., Sun, J., Xu, S., & Zhang, X. (2023). Aerial orthoimage generation for UAV remote sensing: Review. *Information Fusion*, *89*, 91–120. https://doi.org/10.1016/j.inffus.2022.08.007