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Investigation of the effect of height difference and geometry of GCP on position accuracy of point cloud in UAV photogrammetry

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In this study, the effect of the height difference, geometry, and number of GCPs on the positional accuracy of point cloud was investigated in UAV photogrammetry. It has been determined that the topographic change of the study area, the geometric structure of GCPs, and the distance between GCPs are the most important factors in GCP network design. It was observed that the GCP network design is more important than the number of GCPs in the UAV Photogrammetry method to increase the positional accuracy.

Keywords: UAV, GCP, Photogrammetry, Positional accuracy, Height Difference of GCP

1. Introduction

The use of Uncrewed Aerial Vehicle (UAV) in civilian life has gained momentum since the early 2000s. It has gained a place in multiple application areas, including photogrammetry, urban studies, Earth Science, and other areas with a wider scope. With the developing technology, UAVs have started to be used effectively and efficiently in areas such as military applications, archaeological site investigation, meteorological and geological research, natural disaster management, national or international border patrol, forest fire detection, earth mapping, etc. (Okuyama et al. 2005, Ollero and Merino 2006, Xiang and Tian 2011, Mozas-Calvache et al. 2012, Niethammer et al. 2012).

The use of UAV systems in photogrammetry has provided many advantages. These advantages are less affected by seasonal conditions, access to unreachable and risky regions, operational convenience, low investment and operating cost, high location accuracy, and fast data processing. However, besides its advantages, there are also some usage limitations. These limitations, which reduce the airborne time, accuracy, and picture quality, can be listed as follows; Increased wind speed, dust cloud, misty and rainy weather, battery technology, trade-off coverage/ ground sample distance, and limited loading capacity (Gençerk 2016).

The combined use of UAVs and aerial photogrammetry technique is called UAV photogrammetry. The use of UAVs with GCP or RTK/PPK GNSS in this area provides advantages such as operational convenience, low investment and operating cost, high positional accuracy, and greatly increases the overall accuracy of the obtained map. The geometric distortions are present in the sensors that are used as a payload for UAVs. Therefore these images are not suitable for use with direct map-based products.

Ground Control Points (GCP) are essential tools used in aerial photogrammetry. Geodetic methods obtain GCP coordinates, and they help the coordinates of any point on the map correspond to the real ground-centered geodetic coordinates. The number and geometric distribution of GCPs' directly affect the positional accuracy of photogrammetric and remote sensing products. Previous studies have shown that the number of GCP, its accuracy, and spatial pattern affect the accuracy and reliability of the corrected image (Orti 1981, Labovitz and Marvin 1986, Mather 1995, Zhou and Li 2000, Wang et al. 2005, Sertel et al. 2007). For this reason, the number and location of GCPs should be determined accurately before the study, especially in UAV photogrammetry studies. Since the number of GCPs directly affects labor, time, and cost values, the appropriate GCP design provides a significant advantage in surveys.

With the introduction of RTK (Real Time Kinematic)-based systems in recent years, studies have been conducted to compare systems using GCP with systems that do not use GCP. (Forlani et al. 2018), observed three different methods in a test area without changing the flight plan. These methods were GCP only, RTK only, and RTK with one GCP. As a result, it has been observed that the first and third configurations provide the best Digital Elevation Model (DEM) internal consistency (Forlani et al. 2018). Precision was observed to worsen almost twice when using only RTK data. Stöcker et al. (2017) stated that position errors could be reduced by adding an additional four GCPs to RTK systems.

Rabah et al. (2018) showed that the classical GCP method is more accurate than direct geo-georeferencing (DG). The obtained accuracies RMSE (Root Mean

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Square Error) for the Virtual Reference station Direct Geo-referencing (VRS-DG) and RTK-DG are 0.029 and 0.034 m for the vertical position, 0.026 and 0.029 m for the horizontal position. On the other hand, in the classical GCP method, the RMS for horizontal and vertical RMS was determined as 0.014 and 0.013 m.

As can be understood from the above studies, using GCPs gives more accurate results than the Direct Georeferencing method. It is important to understand the levels of accuracy provided by UAS in relation to the requirement of the survey. RTK UAS provides a good level of accuracy that can be improved by the use of GCP if needed. In some cases, it may not be possible to place GCP due to inaccessible or hazardous ground.

In Wang et al. (2012), both a simulation experiment and real image analysis were conducted to investigate the relationship between GCP selection and sampling design in the geometric correction of remotely sensed images. This study compared simple random sampling, spatial coverage sampling, and universal kriging model-based sampling. The results show that the sampling design strongly affects the accuracy of the geometric correction in GCPs. In addition, according to the study, universal kriging model-based sampling GCP optimization showed the best results in both simulation and real image experiments. In addition to these results, it was stated in the study that the more scattered GCPs increase the geometric correction accuracy.

Ruzgiene et al. (2015) investigated how the number of GCPs used for UAV image transformation affects the mapping results. According to the study, it has been determined that when the UAV image correction is performed using only the projection center coordinates without using GCPs, it has significant distortions up to 3 m. However, with well-distributed 5 GCP points, these distortions are negligible. As a result, it was stated in the study that using the appropriate number of GCP increased the quality of the UAV photogrammetry product.

Aguera-Vega et al. (2017) examined the effect of the number of GCP on the orthophoto and DEM accuracies obtained by UAV photogrammetry. In the study, which was carried out on an area of approximately 17 hectares at an altitude of 120 m above ground level, 160 photographs of the region's surface were taken, and photogrammetric projects were made, taking into account different GCP points. The results showed that both horizontal and vertical accuracy increased as the number of GCP used increased.

Tonkin and Midgley (2016) found that the vertical error increased with distance from the GCP cluster, and vertical error and distance to the nearest GCP followed a strong polynomial trend in the UAV-SfM survey.

Sanz-Ablanedo et al. (2018) showed that optimum accuracies are achieved when GCPs are evenly distributed over the entire area in SfM photogrammetry. This study has determined that concentrating GCPs in certain areas, leaving gaps without GCPs, and focusing on points in the periphery or the center are strategies that will not achieve reasonable accuracy. Also, this study has shown that large projects can only achieve high accuracy with a medium to high number of GCPs (i.e.> 3 GCPs per 100 photos).

Villanueva and Blanco (2019) examined the impact of Ground Control Point (GCP) distribution, quantity, and inter GCP distances on the DEM. The results showed that the best configuration is the evenly distributed GCP. It was also observed that as the number of GCPs used increases, RMSE consistently decreases for all configurations. However, in this study, the topographic change in the field was ignored while designing GCPs.

Oniga et al. (2020), using a low-cost Uncrewed Aircraft System (UAS), investigated the effect of the GCP number on accuracy when flying 28 m above the ground in 1 ha. As a result of this study, they determined that when the GCP number was increased from 4 to 20, the RMSE values decreased by 50%.

In Martínez-Carricondo et al. (2018), five GCP combinations were created to investigate the effect of GCP combinations on UAV photogrammetry position accuracy. These combinations were edge distribution, central distribution, corner distribution (equivalent for all four corners), stratified distribution, and random distribution. As a result of this study, they stated that GCPs should be placed at the edge of the work area to achieve optimum planimetry results. However, they stated that this configuration did not optimize results in altimetry. So, they stated that GCPs placed inside the study area with a stratified distribution order to achieve optimum results in altimetry. On the other hand, they stated that as the density of GCPs increases, the results improve, but this improvement stops after a certain GCP number.

Ferrer-González et al. (2020) investigated how the number and distribution of GCPS affected the accuracy of UAV photogrammetry projects in a corridor-shaped study area. For different GCP distributions, it has been observed that both horizontal and vertical accuracy improve as the number of GCPS used increases, and planimetric accuracy is always better than vertical accuracy.

Although aircraft with RTK positioning features are used, if results with higher accuracy are needed, GCP should be used. As can be understood from the above studies, the use of GCPs gives more accurate results than the Direct Geo-referencing method. However, while designing GCPs in these studies, the general topographic change of the study area has not been taken into consideration. Moreover, the effect of height difference between GCPs on accuracy has not been studied in detail. This study investigated how the number of GCP points and their geometric distribution and height difference affect the location accuracy of the point cloud produced by the UAV photogrammetry method. The study was carried out in two regions by applying ten GCP network designs and different GCP numbers. The effect of GCP geometric distribution and number on position accuracy was determined.

GCPs installed in the study areas were homogeneously distributed over the entire study area with a maximum interval of 400 m, taking into account the height differences, and Real-Time National Fixed Global Positioning Satellite Systems (GNSS CORS) and Real-Time Kinematic (RTK) observations were made at these points. First of all, the base station coordinates were determined by measuring ten epochs with two repetitions at two-hour intervals using the GNSS CORS method. Then, rover stations (GCPs and CPs) were measured by the RTK method. The position accuracy of the GNSS receiver set used in RTK measurements is 8 mm + 1 ppm on the horizontal and 15 mm + 1 ppm on the vertical. Checkpoints (CP) were established for all three study areas, and these CPs were measured with the GNSS RTK method. Since it is not possible to reach all points in the study areas, CP points do not reflect the whole area. However, to systematically reflect the general character of the study area, the position of CPs in the form of a cross was preferred. In addition, attention has been paid to obtaining control points from different topographies. Evaluations were carried out in PIX4D (Url-1 2020) software using GCP networks with different geometries and numbers for each study area. As a result of each evaluation, the CP point position has been analyzed. As a result, by comparing the CP position accuracies, the most suitable GCP design was determined for each region.

2. Materials and methodology

2.1. Study area

This study was carried out by applying ten different GCP network designs and different GCP numbers in two different regions. The effect of GCP distribution and number on position accuracy was determined. While determining the study areas, attention was paid to the fact that the topographic characteristics of the two selected regions were different from each other. One of the selected regions is in the Kangal district of Sivas province in Turkey, and the other is in the Nizip district of Gaziantep province in Turkey. These study areas are named the first and second study areas.

The first study area is approximately 160 hectares in size, and although it has a generally smooth topography, it is inclined in a linear line, especially in the interior (Figure 1). Considering the variation of the topography in this study area, 46 GCPs have been established at regular intervals to obtain minimum position errors. In addition, 122 CPs were installed in the study area to investigate the effect of GCPs on position accuracy. The position information of these points was established using RTK GNSS. As a result, the position accuracy 3D RMS values of these points were found by comparing the position information obtained by the Pix4D photogrammetric evaluation software (Pix4D Support 2020) with the location information obtained by the GNSS.

The second study area in Nizip is about 231 hectares in size and is inclined, especially in the middle and outer frame parts of the region in terms of topographic structure. It has a less sloping structure in the intermediate parts. Considering the change of topography in this study area as in the first study area, 52 GCPs with the most appropriate distribution have been established at regular intervals to obtain minimum position errors. In order to investigate the effect of GCPs on position accuracy, 126 CPs were installed in the study area and the coordinates of these points were measured with the GNSS RTK method Figures 2 and 3.

2.2. UAV and GNSS measurements

The aircraft, camera, flight altitude, overlap ratio, and the number of photographs used in UAV photogrammetry are very important. Considering the change of the topography in the study area, regularly spaced GCPs and CPs were established and measured using RTK GNSS to investigate the effect of these GCPs on position accuracy. A DJI Matrice 600 Pro hexacopter was used as aircraft in all study areas. A DJI Zenmuse X5 camera was used for both study areas. In the first study area, 912 photographs were taken with a flight height of 170 m, 842 photographs at a flight height of 200 m in the second study area, 80% forward overlap 60% side overlap were applied for all study areas (Table 1). While the GSD for the first study area is 5.23 cm, it is 7.26 cm for the second study zone. RTK/PPK was not used in this study because only the effect of GCP on position accuracy was examined.

3. Photogrammetric evaluations and analysis

In the study, different GCP network designs were applied to examine the effect of the distribution geometry and number of GCPs on the generated point cloud and position accuracy in UAV photogrammetry. Considering the change of topography in the study areas, ground control points with the most appropriate distribution at regular intervals were established to obtain minimum position errors. GCP network designs with different GCP geometries and numbers were made using these ground control points (Figures 4 and 5). For networks that are not dependent on height changes (eg. sparse networks), sudden topography changes are ignored while determining the locations of the GCPs, and only the geometric distribution is considered. Of course, in these networks, some of the GCPs may have fallen into regions with height variation, but the geometric distribution is the only criterion here. On the other hand, the GCPs selected for the Height Difference Network, especially the GCPs falling into the regions with sudden elevation changes in the topography were preferred. For the Non-Height Difference Network, GCPs that fall in areas where the height variation in the topography is low was preferred as much as possible. These network designs are as follows:

- All Network: It is a network design consisting of GCPs covering the whole region and made the most appropriate distribution to obtain minimum position errors at regular intervals, considering the change of topography in the study area.
- Internal Network: It is a network design consisting of GCPs only near the center of the study area and not near the boundaries of the study area.
- Height Difference and External Network: It is the network design from which GCPs are taken, located on the sloping surface where the topography changes in the study area and surrounding the outer line of the study area.
- Height Difference Network: The network design from which GCPs located on the sloping surface where the topography varies in the study area.
- Sparse Network: The network design where the GCPs in the study area are diluted without any specific criteria and the distance between GCPs is generally over 400 m.
- Breadthwise Dense Network: It is a network design consisting of two GCPs located at the beginning and end of the study area in the North–South direction and GCPs located breadthwise (East–West direction) in the interior.
- Non-Height Difference Network: It is a network design with points other than GCPs located on the

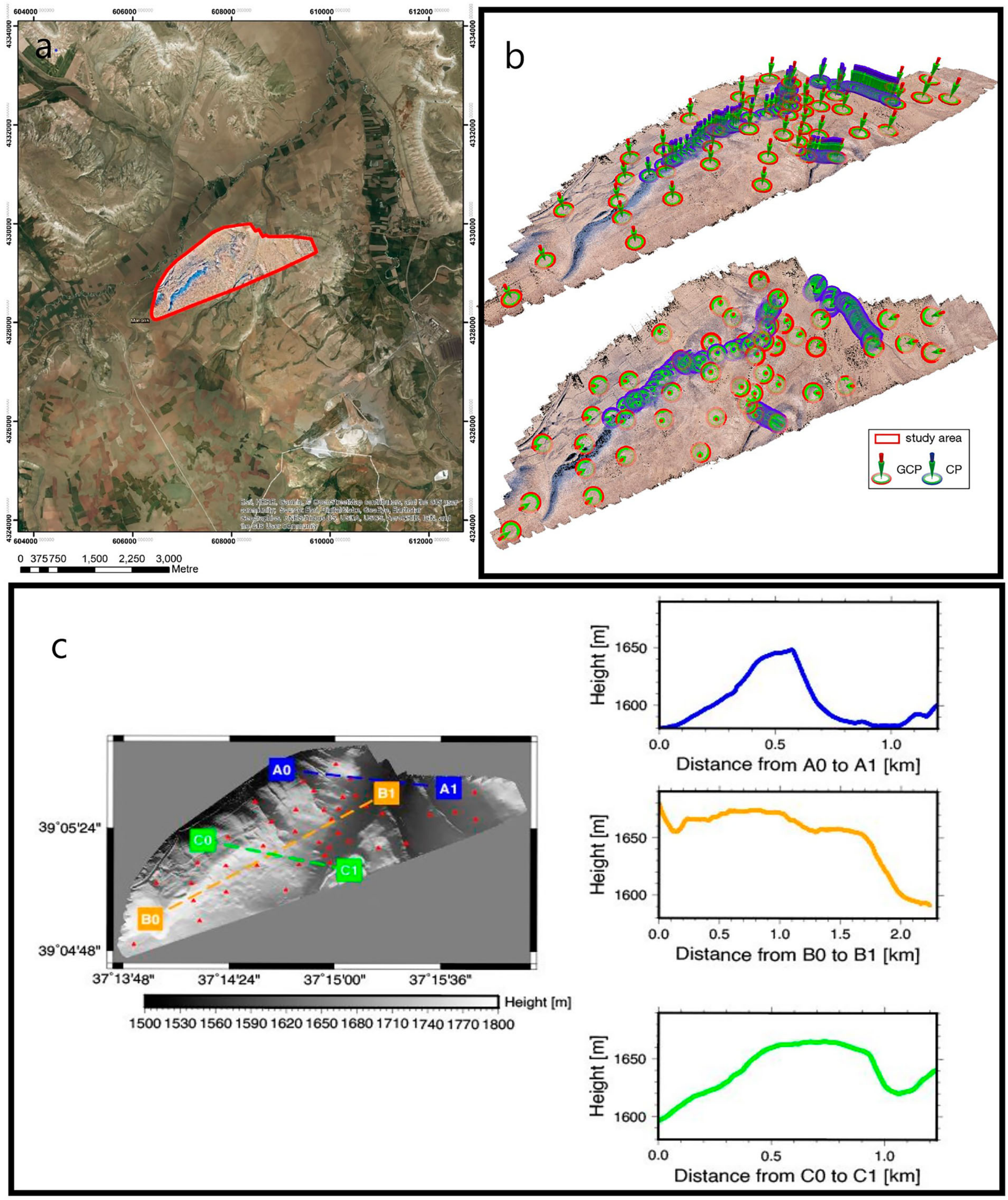

Figure 1. a) First study area b) All network design GCP and CP points of the first study area.

sloping surface where the topography changes in the study area.

- Lengthwise Dense Network: It is a network design consisting of two GCPs located at the beginning and end of the study area in the East–West direction and GCPs located lengthwise (North–South direction) in the interior.
- External Network: It is the network design with GCPs surrounding the outer line of the study area.
- Line Network: It is the network design with GCPs located in the direction of the specified line by determining a line that will pass through the middle of the working area.

Evaluations were carried out using PIX4D software according to ten different network designs for two study regions. As a result of these evaluations, the root means square values obtained for the CP and the GCP numbers and rates used are presented in Tables 3 and 4. In addition, CP RMS values obtained from 10 different network designs for two different study areas are presented in Figures 4 and 5.

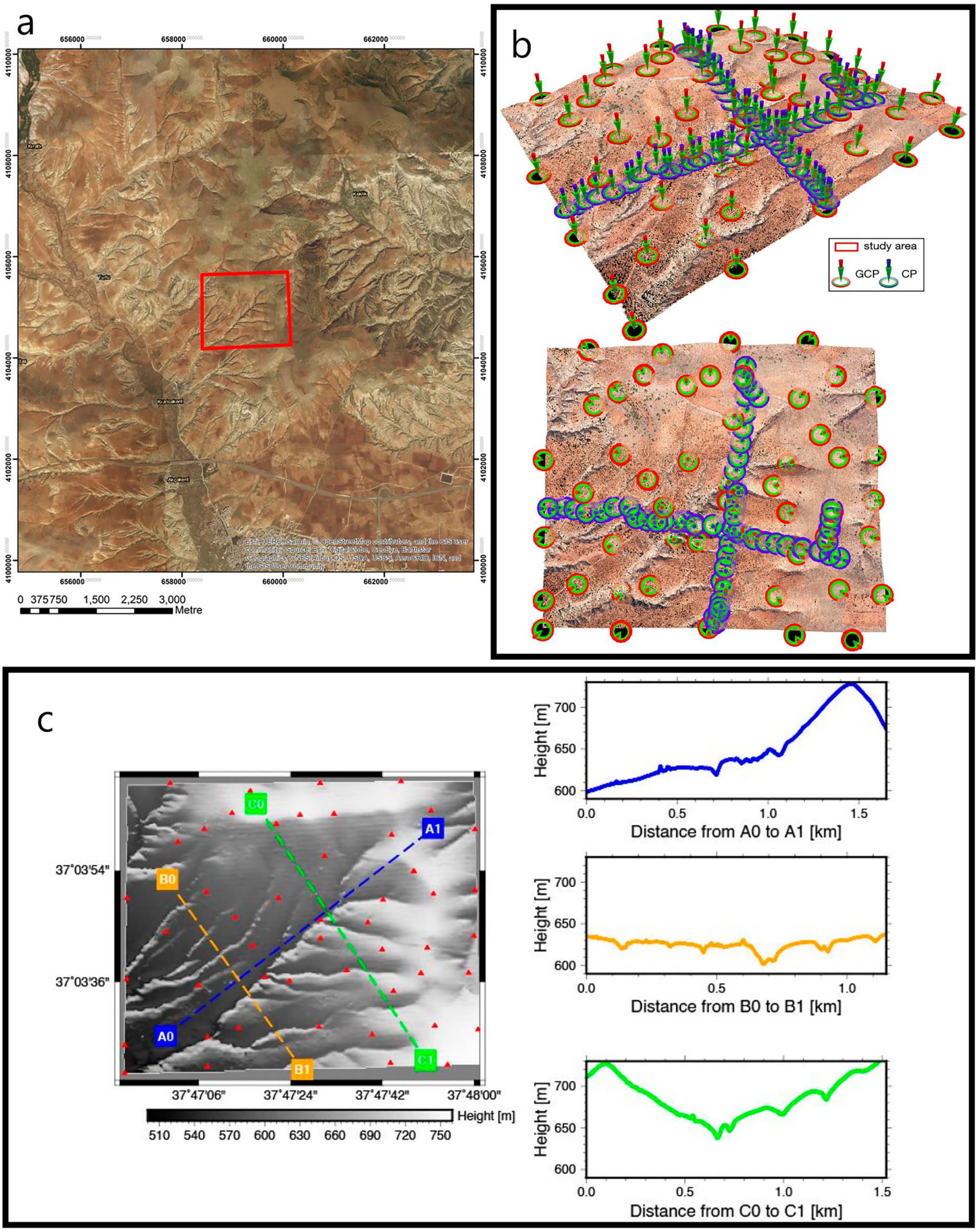

Figure 2. a) Second study area b) All network design GCP and CP points of the second study area.

4. Analysis results

The horizontal, vertical, and position RMS values obtained from the evaluations are presented in Figures 6 and 7. In addition, the rate of GCP per 1-hectare area is shown in Figures 6 and 7. In Figure 6, the horizontal, vertical, and position RMS values for both study areas are presented in separate graphics. When Figure 6 is examined, it is observed that the RMS values in both study areas are in the same trend. In Figure 7, RMS values are presented in separate graphs for the two study areas. When Figure 7 is examined, it is observed that the RMS values in the horizontal component are lower in both areas compared to the vertical component.

Bartlett's Test for Homogeneity of Variances is a statistical test used to determine whether or not the variances between several groups are equal. Bartlett's Test for Homogeneity of Variances was used to decide whether

Figure 3. DJI Matrice 600 Pro hexacopter with DJI Zenmuse X5 camera.

the RMS values obtained from this study can be considered equal. Bartlett's Test results are presented in Table 2.

When Table 2 is examined, it is seen that the differences between the RMS values obtained for all methods are statistically significant this means the variances are considered not equal. In sections 4.1 and 4.2, the differences in RMS values are examined in detail, and the main reasons for the differences are discussed.

Bartlett's Test is aimed to group the results that give the smallest RMS values. For this process, the method that offers the closest RMS value to the results of all network designs was determined in both study areas. Accordingly, the method that provides the closest result to all network RMS values for the I. study area is the sparse (6.1 cm) network design, while the internal (4.58 cm) network design for the II. study area. F test was performed to determine whether the RMS values of the methods that offer the best RMS value after all designs in both study areas and the RMS values obtained from other methods are considered equal.

When Table 3 is examined, it is seen that the RMS values obtained from the Sparse method, which offers the best RMS value for the I. study area, and the RMS

Table 1. Flight information.

Flight Configuration	Zone 1	Zone 2
Average flight altitude (m)	170	200
Autopilot	Yes	Yes
Camera features	DJI Zenmuse X5	DJI Zenmuse
Image format (pixels)	4608 × 3456	4608 × 3456
Pixel size (in)	2.06	2.86
Focal length (mm)	12	12
Flight Speed (m / s)	8.7	9.3
GSD (cm)	5.23	7.26
Forward/Side Overlap (%)	80/60	80/60
Number of images	912	843
Stıdy Area (ha)	160	231

values of the Height Difference method can be considered equal. In addition, it is observed that values close to the limit value are obtained for the Height Difference and External method. In summary, it can be said that Sparse, Height Difference, Height Difference, and External methods are the methods that give the best results of all methods for the I. study area. While the number of GCPs in the Sparse network is 32, this number is 25 in the Height Difference network, as it can be understood from here, that the Height Difference network gave the same RMS values with less GCP. Increasing the GCP number to 35 in the Height Difference and External network did not provide a noticeable improvement in RMS value. In addition, in other networks (External, Breadthwise Dense, Non-Slope, Lengthwise Dense, Line) with a GCP number between 24-25, RMS values gave worse results between 2 and 7 times. As it can be understood from here, the main reason for obtaining good RMS values with a small number of GCPs is the design of GCPs by considering the height difference.

Again, when Table 3 is examined, it is seen that the RMS values obtained from the Internal method offer the best RMS value for the II. study area and the RMS values of the Height Difference External and Height Difference methods can be considered equal. In addition, for the Sparse method, a value close to the limit value is obtained in the horizontal component, while high test values are obtained for the other components. In summary, it can be said that Internal, Height Difference, and Height Difference External methods are the methods that give the best results after all methods for the II. study area. While the number of GCPs in the Internal network is 35, this number is 30 in the Height Difference network, as it can be understood from here, that the Height Difference network gave the same RMS values with less GCP.

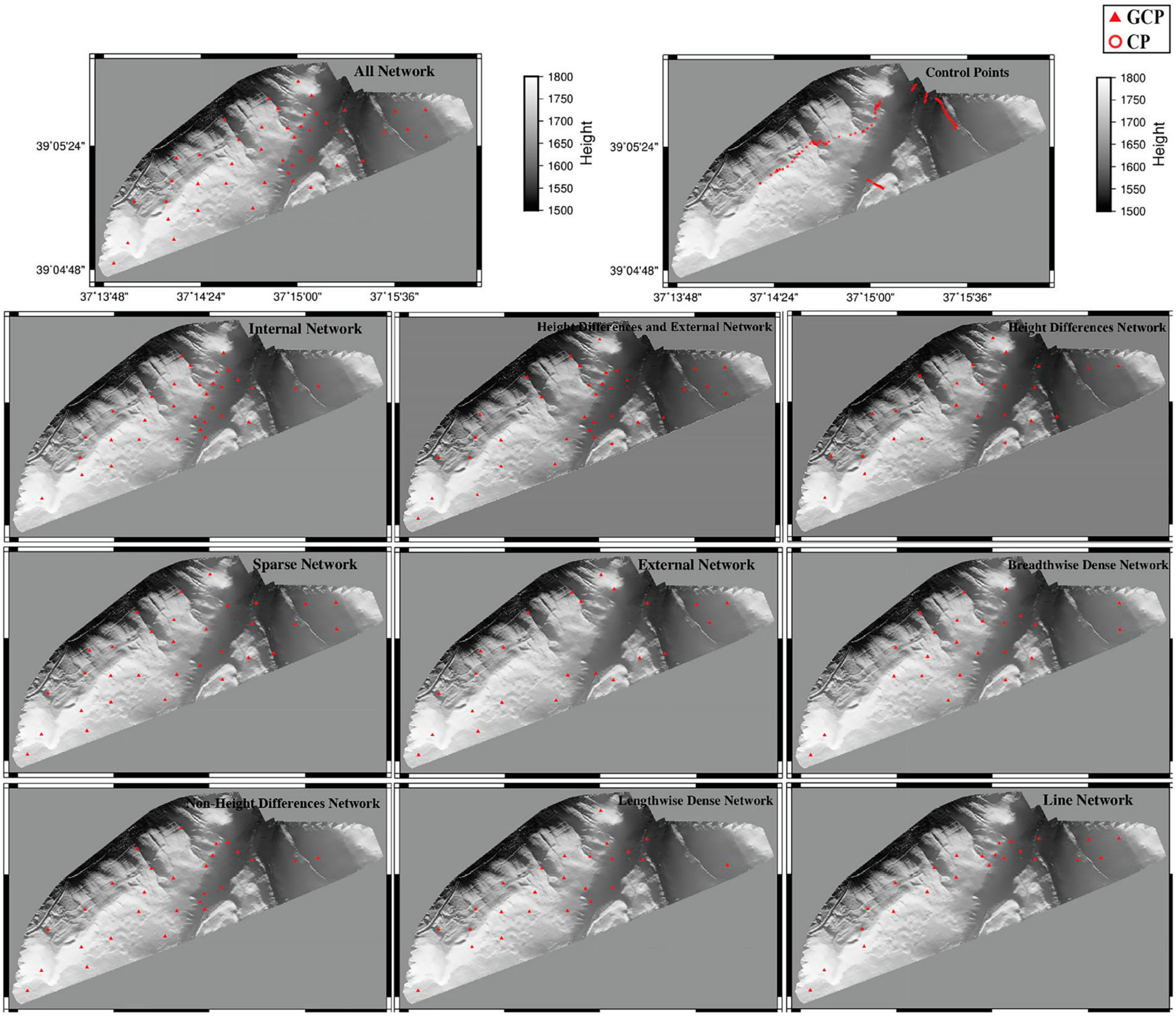

Figure 4. I. Study Area GCP Network designs.

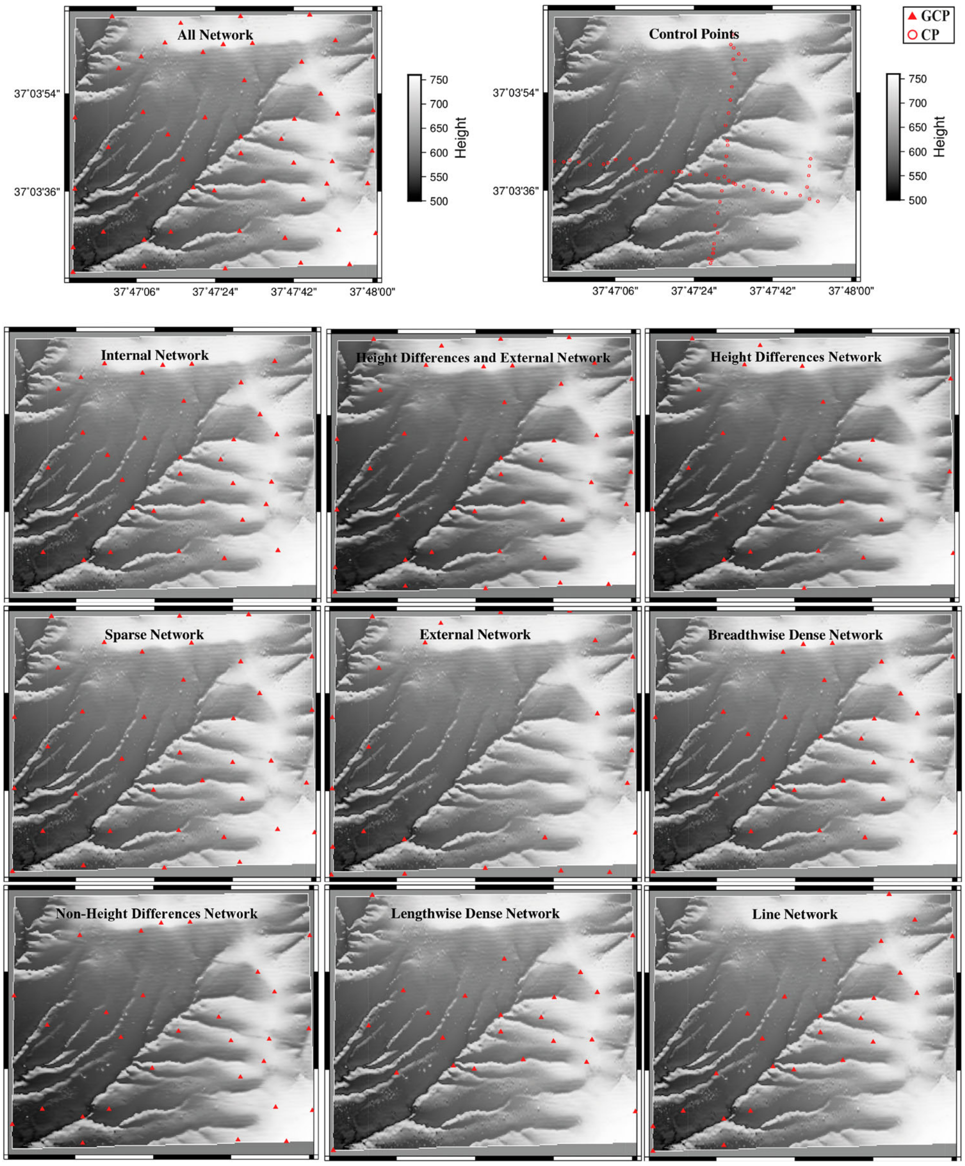

Figure 5. II. Study Area GCP Network designs.

Increasing the GCP number to 42 in the Height Difference and External network did not provide a noticeable improvement in RMS value. In addition, in other networks (External, Breadthwise Dense, Non-Slope, Lengthwise Dense) with a GCP number between 28-30, RMS values gave worse results about 2 times. As it can be understood from here, the main reason for obtaining good RMS values with a small number of GCPs is the design of GCPs by considering the height difference.

The method that offers the best RMS value due to the study's different geometric and topographic features is the Sparse method in one and the Internal method in the other. However, in both study areas, Height Difference and Height Difference External are in the group that gives the best RMS value. As it can be understood from here, considering the height difference changes in the GCP design affects the results positively.

4.1. First study area results

For the first study area, 46 GCP was used, with an average of 1 GCP per 3.5 ha area in the all-network design. As a result, vertical, horizontal, and position RMS values of CP were obtained as 1.4, 2.1, and 2.6 cm, respectively.

In the sparse network design, the GCP number was reduced to 32 (1 GCP per 5 ha area) without deteriorating the general geometric distribution, and vertical, horizontal, and position RMS values were obtained as 3.8, 4.8, and 6.1 cm, respectively. Here, while the number of GCP was reduced by approximately 30%, RMS values increased approximately 2.5 times.

There are two most suitable distribution types when considering the structure of the study area. The position RMS value is 7.4 cm when the Height Difference network design, considers the 25 GCP (1 GCP per 6.4 ha area) on the sloping surface where the topography varies in the study area, is applied. This result is almost similar to the sparse network design, the difference between these two network designs is 0.5 cm. Although there is a decrease of approximately 22% in the number of GCPs, the fact that approximately the same RMS values are obtained in these two methods clearly reveals the effect of the height difference on the accuracy.

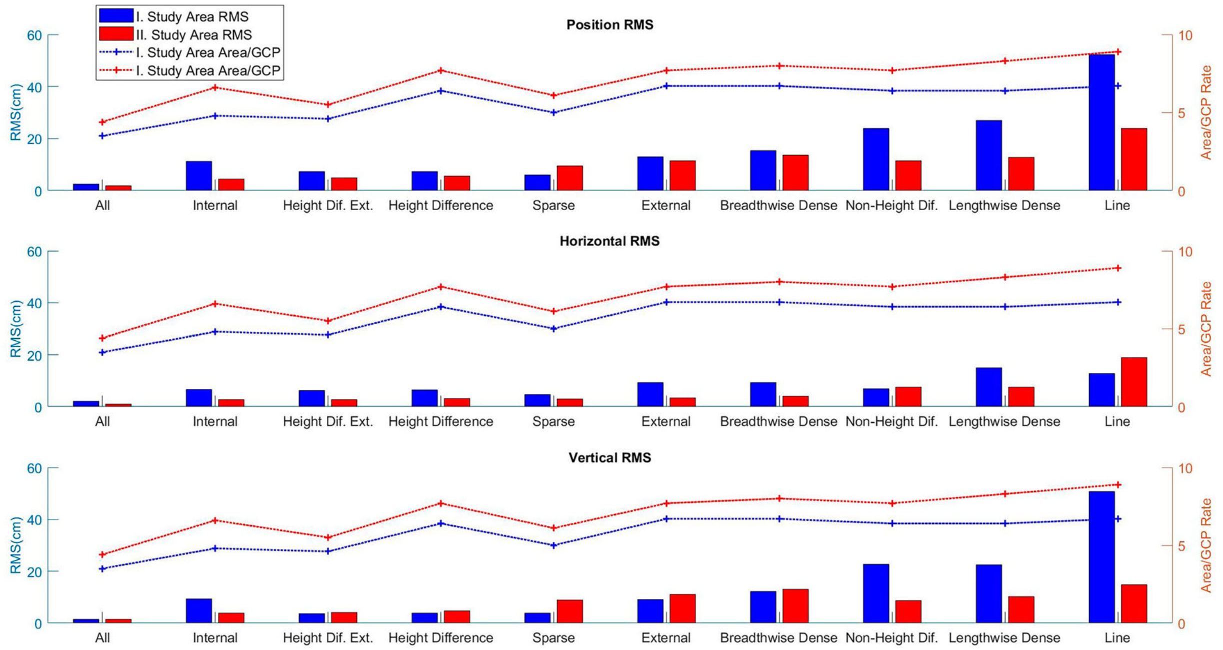

Figure 6. CP horizontal, vertical, and position RMS values are obtained from two study areas according to different network designs.

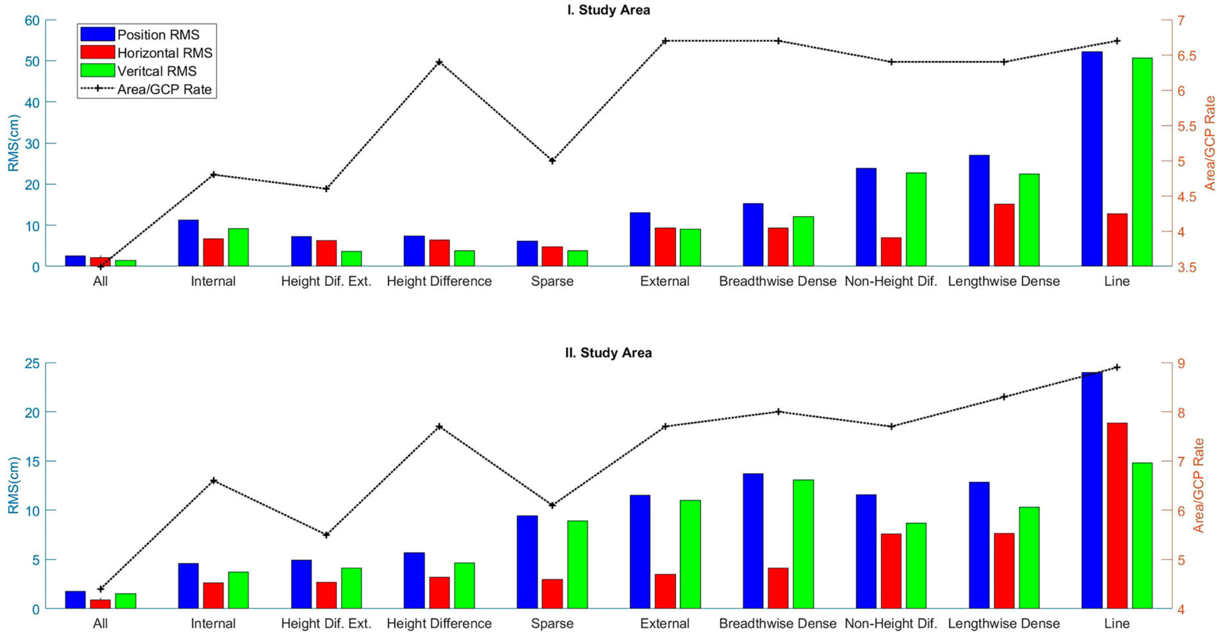

Figure 7. CP RMS values according to different network designs obtained from two study areas.

Table 2. Barlett's Test for Homogeneity of Variances.

	I.Study Area			II.Study Area		
Bartlett's Test	Position	Horizontal	Vertical	Position	Horizontal	Vertical
$\hat{\chi}^2$	1479.35	533.458	2138.69	926.17	1545.61	762.34
Decision	Significant	Significant	Significant	Significant	Significant	Significant

Table 3. F test Results.

		F critical value										
Study Area	Component	All	Int.	Slope Ext.	Slope	Sparse	Ext.	Bre. Den.	Non-Slope	Len. Den.	Line	f test value
I	Position	5.50	3.43	1.43	1.47	–	4.54	6.29	15.22	19.59	73.22	1.35
	Vertical	7.36	5.86	1.05	1.00	–	5.60	10.13	35.68	34.74	177.3	
	Horizontal	5.22	1.94	1.72	1.77	–	3.75	3.75	2.12	9.89	7.11	
II	Position	6.77	–	1.15	1.52	4.23	6.34	8.94	6.37	7.83	27.41	1.34
	Vertical	5.97	–	1.21	1.55	5.71	8.65	12.19	5.41	7.56	15.63	
	Horizontal	9.06	–	1.03	1.45	1.26	1.74	2.44	8.26	8.35	50.70	

Not: Red-colored values show F > f and blue-colored values show F≅f

Table 4. RMS table for I. study area.

	RMS of CPs (cm)					
Network Design (GSD 5.23 cm)	Position	Horizontal	Vertical	Area/GCP Rate (ha / piece)	GCP (piece)	GCP per 100 photos
All	2,6	2,1	1,4	3,5	46	5,0
Internal	11,3	6,7	9,2	4,8	33	3,6
Height Difference and External	7,3	6,3	3,7	4,6	35	3,8
Height Difference	7,4	6,4	3,8	6,4	25	2,7
Sparse	6,1	4,8	3,8	5,0	32	3,5
External	13,0	9,3	9,0	6,7	24	2,6
Breadthwise Dense	15,3	9,3	12,1	6,7	24	2,6
Non- Height Difference	23,8	7,0	22,7	6,4	25	2,7
Lengthwise Dense	27,0	15,1	22,4	6,4	25	2,7
Line	52,2	12,8	50,6	6,7	24	2,6

Table 5. RMS table for second study area.

	RMS of CPs (cm)					
Network Design (GSD 7.26 cm)	Position	Horizontal	Vertical	Area/GCP Rate (ha / piece)	GCP (piece)	GCP per 100 photos
All	1,76	0,88	1,53	4,4	52	6,2
Internal	4,58	2,65	3,74	6,6	35	4,2
Height Difference and External	4,92	2,70	4,12	5,5	42	5,0
Height Difference	5,66	3,20	4,67	7,7	30	3,6
Sparse	9,42	2,98	8,94	6,1	38	4,5
External	11,54	3,50	11,00	7,7	30	3,6
Breadthwise Dense	13,70	4,14	13,06	8,0	29	3,4
Non- Height Difference	11,56	7,62	8,70	7,7	30	3,6
Lengthwise Dense	12,82	7,66	10,29	8,3	28	3,3
Line	23,98	18,87	14,79	8,9	26	3,1

The position RMS value in the height difference and external network design was 7.3 cm, considering the GCPs located on the sloping surface where the topography varies in the study area and surrounding the outer line of the study area, 35 GCPs (1 GCP per 4.6 ha area). The height difference and external network design give the best result after the sparse and height difference network design. However, when the results were compared with the height difference network, no change was observed in the RMS values, although there was an increase of approximately 40% in the number of GCPs. As it can be understood from here, the factor that affects the RMS results is the consideration of the height difference.

Except for the GCPs surrounding the outer line of the study area, the position RMS obtained with 33 GCP (1 GCP per 4.8 ha area) in the internal network design, in which the GCPs remaining in the inner part of the study area are taken into account, is 11.3 cm. Although this network design has approximately the same GCP number as the sparse network design, it yielded twice the error rate of the sparse network design. This RMS is generally thought to be caused by the fact that the dots are not homogeneous but dense inside. On the other hand, ignoring the height changes while designing the points increases the RMS value, especially in the vertical component.

The position RMS of the external network design, in which 24 GCP (1 GCP per 6.7 ha area) is considered, surrounding the outer line of the working area is 13.0 cm. 6 fewer GCPs were used than in the internal network. As with the internal network, it is thought that the RMS value has increased because the GCPs do not reflect the geometric structure well, and the height differences are ignored.

The breadthwise dense network design, in which two GCPs located at the start and end of the North–South direction of the study area and 24 GCPs (1 GCP per 6.7 ha area) located in the East–West direction are taken into account, is position RMS 15.3 cm. It is seen that RMS increased by 2.3 cm with the same number of GCP compared to the external network design with the highest RMS value among the network designs made so far. Here, too, it is thought that there is an increase in RMS values due to the GCP geometric structure and height difference factors.

The position RMS of the non-height difference network design in which points other than GCPs located on the sloping surface where the topography changes in the study area and 25 GCPs (1 GCP per 6.4 ha area) are located is 23.8 cm. In this network, where height changes were ignored, especially the vertical RMS value showed a rapid increase. In this network, although the same number of GCPs are used with External and breadthwise dense networks, especially the vertical RMS value has doubled. Despite using the same number of GCPs in the Non-Height Difference network and the Height Difference network, the RMS values deteriorated approximately 3 times. Here, the effect of the height difference on the RMS values is clearly seen.

The position RMS is 27.0 cm in the lengthwise dense network design. Two GCPs located at the beginning and end of the study area E-W direction, and 25 GCPs (1 GCP per 6.4 ha area) are located N-S direction in the inner part are taken into account. This network design resulted in an about 2-fold increase in positions RMS value. However, according to the number of GCP used, it has the same number of points as breadthwise dense and external network analysis. It is observed that the height changes in the lengthwise structure are not too much in the study area. In this case, it causes the results of lengthwise and non-height differences to appear close to each other.

The position RMS is 52.2 cm in the line network design, which is formed as a line that will pass through the middle of the study area and uses 24 GCP (1 GCP per 6.7 ha area). Considering the number of GCP used, it has the same GCP number with breadthwise and lengthwise dense network designs. However, there is an increase of 3.5 times the RMS value according to the breadthwise dense width network design and two times the lengthwise density network design. This network design gives terrible results due to ignoring the height changes along the line and not reflecting the geometric structure. Line network design provides the worst RMS values for the workplace.

As a result, Height Difference and sparse network designs in which the GCP number is reduced by approximately 30%–35% give the closest result to the results using all GCPs. RMS and GCP values for all network designs in the first region are given in Table 3.

4.2. Second study area results

For the second region, there are 52 GCPs (1 GCP per 4.4 ha area), with the most appropriate distribution covering the entire study area in the all network design. Considering all GCPs, the position RMS for CPs is 1.76 cm.

Except for the GCPs surrounding the outer line of the study area, the position RMS obtained with 35 GCP (1 GCP per 6.6 ha area) in the internal network design, in which the GCPs remaining in the inner part of the study area are taken into account, is 4.58 cm. This result revealed a 2.6-fold increase in error with a 32% decrease in GCP count. It is observed that the height changes in the study area are generally in the inner parts. The good RMS value is thought to be due to the excellent reflection of the height changes of the GCPs.

The position of RMS in the height difference network design considering 30 GCP (1 GCP per 7.7 ha area).on the sloping surface where the topography changes in the study area are 5.66 cm. Although it is 5 GCP more than the internal network design, an error increase of 0.9 cm is observed in the height difference network design. Considering that the general height changes in the study area are more in the inner parts of the region, the internal and height difference networks for this region are very similar. As a result, it is natural to give approximately the same results. Although there is a decrease of approximately 15% in the number of GCPs, the fact that approximately the same RMS values are obtained in these two methods clearly reveals the effect of the height difference on the accuracy.

The amount of error in the height difference and external network design was determined as 4.92 cm, considering the GCPs (1 GCP per 5.5 ha area) and located on the sloping surface where the topography changes in the study area and 42 GCPs surrounding the outer line of the study area. There is an error difference of 0.34 cm between these results and the internal network design. However, considering the number of points, the increase of 8 GCP in the height difference and external network design is significant in approaching this value. Likewise, when compared to the height difference network design, it is seen that it shows better results than the height difference network analysis with a 0.74 cm difference, but when the number of points is considered, 12 GCP is more than the height difference network design has been effective in this result. As a result, the 12 GCP added from the study area outer frame did not affect the position accuracy much.

The position RMS was 9.42 cm when the sparse network design considering 38 GCPs (1 GCP per 6.1 ha area) created by diluting without any specific criteria was applied to the study area. Although the number of points has approximately the same GCP (+1 GCP) number as the height difference network design, there is an error increase of about two times. This increase in RMS value manifests itself, particularly in the vertical RMS component. This is thought to be that the points falling into the sparse network design do not reflect the general height changes in the study area.

The position RMS of the external network design, in which 30 GCP (1 GCP per 7.7 ha area) is considered, surrounding the outer line of the working area is 11.54 cm. It is thought that there is an increase in the RMS value because the general geometry is not well reflected, and the GCP number is reduced to 30. In addition, since the height changes are concentrated in the inner regions of this study area, the external network design could not reflect these changes.

The position RMS of the non-height difference network design in which points other than GCPs located on the sloping surface where the topography changes in the study area and 30 GCP (1 GCP per 7.7 ha area), are located is 11.56 cm. Despite using the same number of GCPs in the Non-Height Difference network and the Height Difference network, the RMS values deteriorated approximately 2 times. Here, the effect of the height difference on the RMS values is clearly seen. RMS values also increase in this network structure where geometry and height change are not well-reflected.

Similar results were obtained for the same GCP number for both breadthwise dense network design and lengthwise dense network design. The breadthwise dense network design, in which two GCPs located at the start and end of the North–South direction of the study area and 29 GCPs (1 GCP per 8.0 ha area) located in the East–West direction are taken into account, is position RMS 13.70 cm. The RMS is 12.82 cm in the lengthwise dense network design. Two GCPs located at the beginning and end of the study area E-W direction and 28 GCP (1 GCP per 8.3 ha area) located N-S direction in the inner part are taken into account. The main reason for the high RMS values is that these network structures do not reflect the general geometry well.

The position RMS of the line network design in which 26 GCP (1 GCP per 8.9 ha area) is considered by determining a line that will pass through the middle of the working area is 23.98 cm. According to the results, this design revealed approximately two times more errors than the dense lengthwise design with the nearest point number.

In summary, the most relevant results in the study area are given by reducing the GCP number to 35 GCP and the internal network design where a 4.58 cm error is obtained. In addition, the height difference and external network design give an error amount of 4.92 cm by reducing the GCP number to 42 GCP. RMS and GCP values for all network designs in the second region are given in Table 5.

The RMS value of the CPs in Tables 4 and 5 is obtained by comparing the measured coordinate values with the calculated coordinate values. As it is known, CPs are marked in a pixel while marking on the photo. The CPs were marked as sensitive in the processes carried out to give the min error values. Obtaining RMS values smaller than the GSD values indicates that the CPs are marked as inaccurate pixels with high precision. If the CPs are marked in the suitable pixels, the maximum error will equal the pixel resolution in an evaluation performed with the appropriate distribution of the GCPs. Also, when the CPs are marked in the optimal position within the pixel, the RMS values are likely to be smaller than the GSD. Therefore, it was considered reasonable that some of the RMS values obtained due to the evaluations were smaller than the GSD value.

5. Conclusion and discussion

As a result of the analysis, it is clear that detailed studies should be carried out on the positions of GCPs in order to maximize the accuracy achieved in UAV photogrammetry projects. As a result of the analysis, it was seen that the geometric distribution of GCPs in the study area is more important than the number of GCPs, and it was observed that the results did not improve as the density of GCPs increased, but the accuracy increased as a result of the appropriate distribution.

It was clearly observed that GCP designs, which do not reflect the general geometric structure of the land, especially inline form, negatively affect the results. In addition, it has been observed that sufficient GCP points are not established in the inner parts of the study area, and only the network design consisting of GCPs close to the field borders negatively affects the accuracy.

In addition to all these, it has been determined that it is very important that the points reflect the general geometric structure of the study area while planning the GCP design to increase the positional accuracy obtained with UAV Photogrammetry. Especially when the distance between GCPs is over 400 m (Sparse network), it has been observed that the location accuracy decreases. In addition, it has been clearly observed that the topography is the other and most important factor to increase the location accuracy. While designing GCP points, the general topography of the study area should be taken into consideration, and GCP should definitely be established in regions with significant slope changes.

To achieve the best location accuracy in the UAV Photogrammetry method, a network design that reflects the topographic changes, general geometric structure, and boundaries of the study area should be created in the GCP design.

Our study observed that the UAV photogrammetry position accuracy could not be increased by simply increasing the GCP number by ignoring the above-mentioned criteria.

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Authorship statement

Kemal Ozgur Hastaoglu led the research design, UAV mesurment and writing.

Hacer Sura Kapicioglu assisted in process and writing.

Yavuz Gul assisted in writing and UAV mesurment.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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