Research Article
https://doi.org/ 10.51489/tuzal.1385412

2023; 5(2); 89-96

Turkish Journal of Remote Sensing

Türkiye Uzaktan Algılama Dergisi

https://dergipark.org.tr/tr/pub/tuzal

e-ISSN 2687-4997

Investigation of Position Accuracy in UAVs

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Keywords
Accuracy
DTM
GCP
GNSS
UAV

ABSTRACT

Digital Terrain Models (DTMs) are used as primary data in many engineering projects. In addition to classical terrestrial techniques, space and satellite techniques and Unmanned Aerial Vehicles (UAVs) are commonly used in the production of the DTMs. In the production of the DTM with the help of the UAVs, measurements can be made easily where people can access hardly, and large areas can be mapped quickly. However, one of the most fundamental problems in the UAVs is to obtain the most accurate DTM by choosing the homogeneously spread ground control points (GCPs) number. In this study, the effect of flight altitude and the density of GCPs on position accuracy were investigated in production of the DTM. For this purpose, 56 points were established at approximately 40 m intervals and images from 80, 100, 120 m flight altitude were taken in the test area. The rapid static Global Navigation Satellite Systems (GNSS) method was used to obtain the coordinates of the points with high accuracy. Then, the homogeneously spread 5, 10, and 15 points were chosen as GCPs, respectively. The images were evaluated in Pix4d Mapper software with 9 different combinations and DTMs were produced. Outliers of the coordinates obtained from the models were detected by Bland-Altman Plot. To determine the geometric accuracy of the produced models, the coordinates of the test points obtained from the models and the results of rapid static GNSS measurements were compared with the statistical methods and the obtained results were interpreted.

İHA'lardan Elde Edilen Konum Doğruluğunun İncelenmesi

Anahtar Kelimeler:
Doğruluk
GNSS
İHA
SAM
YKN

ÖZ

Sayısal Arazi Modelleri (SAM) birçok mühendislik projesinde temel veri olarak kullanılmaktadır. SAM'ların üretiminde klasik yersel tekniklerin yanı sıra yaygın olarak uzay ve uydu teknikleri ile İnsansız Hava Araçları (İHA'lar) kullanılmaktadır. SAM'ın İHA'lar yardımıyla üretilmesinde insanların ulaşmasının zor olduğu yerlerde kolaylıkla ölçümler yapılabilmekte ve geniş alanların haritaları kısa sürede üretilebilmektedir. Ancak İHA'larda en temel sorunlardan biri homojen yayılmış yer kontrol noktaları (YKN) sayısını seçerek en doğru SAM'ı elde etmektir. Bu çalışmada, SAM üretiminde uçuş yüksekliği ve YKN yoğunluğunun konum doğruluğuna etkisi araştırılmıştır. Bu amaçla test alanında yaklaşık 40 m aralıklarla 56 nokta tesis edilmiş ve 80, 100, 120 m uçuş yüksekliğinden görüntüler alınmıştır. Noktaların koordinatlarının yüksek doğrulukla elde edilmesi için hızlı statik Küresel Navigasyon Uydu Sistemleri (GNSS) yöntemi kullanılmıştır. Daha sonra homojen olarak yayılan 5, 10 ve 15 nokta sırasıyla YKN olarak seçilmiştir. Görüntüler Pix4d Mapper programında 9 farklı kombinasyonla değerlendirilerek SAM'lar üretilmiştir. Modellerden elde edilen koordinatlardan uyuşumsuz ölçüler Bland-Altman yöntemi ile belirlenerek ölçü grubundan çıkartılmıştır. Üretilen modellerin geometrik doğruluğunun belirlenmesi amacıyla modellerden elde edilen test noktalarının koordinatları ve hızlı statik GNSS ölçüm sonuçları istatistiksel yöntemlerle karşılaştırılmış ve elde edilen sonuçlar yorumlanmıştır.

Article Info

Received: 02/11/2023
Accepted: 05/12/2023
Published: 30/12/2022

Citation:

Yıldırım, O., İnal, C., Bülbül S. & Bilgen, B. (2023). Investigation of Position Accuracy in UAVs . Turkish Journal of Remote Sensing, 5 (2) , 89-96.

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1. INTRODUCTION

Digital Terrain Model (DTM) is required to realize many engineering projects. DTM can be defined as a digital representation of all the artificial and natural details of the physical earth and in a broad sense it contains the position and elevation information of all the details in the field. Global Navigation Satellite Systems (GNSS), Total Station (TS) and Terrestrial Laser Scanning (TLS) techniques are used in the production of the DTM required for many applications in the field of engineering (Liu, 2008; Lague et al., 2013; Martínez-Carricondo et al., 2018; Akgul et al., 2018, Makineci, 2023). Along with the developing technology over the years, the measuring instruments used in the surveying sector have come to a different point and Unmanned Aerial Vehicles (UAV) have been commonly used in the production of the 3D model of the earth.

The UAV was primarily used for military applications. Nowadays, it can be used in geological and meteorological research, natural disaster management, international border patrols, detection of forest fires, determination of deformations, production of a topographic map and modeling of 3D city or land (Ottichilo and Khamala, 2002; Koeva et al., 2018; Otto et al., 2018, Makineci, 2022). The use of such aircraft also brings many advantages in the field of surveying. Thanks to digital cameras installed on the UAVs, measurements can be made easily where people can access hardly. The accuracy of the measurements performed with the help of the obtained images can almost compete with the classical terrestrial techniques.

The UAV is a vehicle that can be moved automatically or semi-automatically depending on a flight plan or is remotely controlled by a pilot on the ground or in another vehicle (Otto et al., 2018; Dalamagkidis, 2015). The UAV systems can be used as an alternative to low-resolution and high-cost constraints arising from the high flight altitude of manned mapping systems (Westoby et al., 2012; Hugenholtz et al., 2013; Tonkin et al., 2014; Smith et al., 2016; Ewertowski et al., 2019).

The UAV platform can be equipped with LiDAR sensors or several of these technologies, thermal or infrared camera systems, video camera, multispectral cameras, depending on their capacity and characteristics. In addition, the UAV GNSS/Inertial Navigation System (INS) may include compass systems and barometric altimeter. Such an integrated system is often called as Unmanned Aerial Vehicle System (UAS) (Nex and Remondino, 2014).

There are several studies on achievable accuracies of UAV imagery. Lucieer et al. (2014) generated landslide displacements map using UAV imagery. They obtained horizontal Root Mean Square (RMS) of 7.0 cm and vertical RMS of 6.2 cm from 1 cm resolution Digital Surface Models (DSMs). Tonkin et al. (2014) compared total station data and the coordinates obtained from UAV based DTMs. They noted that the total station data and the coordinates obtained from UAV based DTMs were in a good agreement. Mesas-Carrascosa et al. (2015) investigated the effect of flight altitude, flight mode and configuration of GCPs. Ruzgiene et al. (2015) investigated the accuracy of DSMs produced with UAV imagery and the effect of the Ground Control Points (GCPs) number. Uysal et al. (2015) analyzed the accuracy of DSMs produced using UAV and they concluded that DSMs produced with UAV have advantages such as low-cost, minimum field work, time conservation comparing with classical methodologies. Agüera-Vega et al. (2016), investigated the effects of GCP number, different land structures and flight altitudes on accuracies of DSM and orthophoto. In all these studies, GCP coordinates were determined by Real Time Kinematic-GNSS (RTK-GNSS) method and when determination of the accuracy of the UAV, only the RMS of produced models taken into account. Here, the rapid static GNSS technique was used to obtain the coordinates of test points and the GCPs with high accuracy. Then, the effect of flight altitude and the density of GCPs on position accuracy were investigated in the production of DTM. For this purpose, images from 80, 100, 120 m flight altitude were taken in the test area and 5, 10, 15 GCPs were selected and evaluated in Pix4d Mapper software with 9 different combinations and DTMs were produced. The coordinates of the test points were obtained from produced DTMs. Bland-Altman Plot was used to detect outliers of the coordinates obtained from the models. In order to determine the geometric accuracy of the produced models, the coordinates of the test points obtained from the models and the results of rapid static GNSS measurements were compared statistically and the obtained results were interpreted.

2. THE RELATIVE POSITIONING WITH GNSS

The GNSS has been a commonly used positioning method since 1990s. The GNSS consists of global systems such as Global Positioning System (GPS), Russian Global Navigation Satellite System (GLONASS), European Navigation Satellite System (Galileo), BeiDou Navigation Satellite System (BeiDou) as well as regional navigation systems such as Quasi Zenith Satellite System (QZSS) and Indian Regional Navigation Satellite System (IRNSS). GNSS that used all weather conditions is a highly precise microwave (L-band) technique (Jin et al., 2014). The GNSS can be used wider applications such as positioning, intelligent transport systems, navigation and timing, terrestrial reference frame, precise orbit determination, monitoring of plate movements, real-time active control networks (RTK-CORS), crustal deformation, location-based services, cadastral measurements, deformation measurements (dam, bridge, viaduct, etc.), hydrographic and photogrammetric measurements.

With the GNSS, point positions can be determined by relative and absolute techniques. The relative techniques are used more commonly than the absolute techniques due to their high accuracy. The relative techniques are kinematic and static positionings. Static positioning is preferred due to its high accuracy, in applications such as deformation monitoring, tectonic plate movements, monitoring of large engineering structures (Table 1).

Table 1. Accuracies of relative techniques (Hoffman-Wellenhof et al., 2008)

Technique	Horizontal accuracy
Kinematic	5 cm + 5 ppm
Static	5 mm + 0.5 ppm

Static positioning is sub divided into three different techniques; rapid static, stop and go and pseudo kinematic. The rapid static solves the ambiguities fast and, in the technique, code and carrier phase observations are usually used. Up to 20 km baselines, millimeter level accuracy can be achieved (Hoffman-Wellenhof et al., 2008). Session durations for static positioning are listed in Table 2. The more session duration enhances the accuracy.

Table 2. Session durations for static observations (up to 20 km baselines)

Receiver	Rapid Static	Conventional Static
Dual-frequency	10 min + 1 min/km	20 min + 2 min/km
Single-frequency	20 min + 2 min/km	20 min + 3 min/km

3. UNMANNED AERIAL VEHICLES

UAVs are described as pilotless aerial vehicles which can be controlled remotely or automatically move along a flight plan. UAVs were originally produced for military purposes and are now widely used in civil / scientific purposes (Otto et al., 2018). UAVs are produced with both fixed fin and rotary vanes. These different designs have superior and weak sides compared to each other. As fixed-fin-UAVs use a special platform for taking off or they are thrown by hand, rotary vanes -UAVs are just like aircrafts with the ability to move vertically as helicopters (Canis, 2015). A calibrated, digital, and integrated camera can be placed in the UAV and images of the earth can be obtained. The images obtained during UAV flights can be processed by photogrammetric methods at considerably lower costs compared to the cost of receiving from an aircraft with complex and expensive equipment, devices, and facilities (Suziedelyte Visockiene et al., 2016). UAVs can be integrated with various imaging devices with sensors such as thermal, infrared, hyperspectral, radar, chemical and biological, and provide day and night images. The UAVs can send the data to ground control stations in real time and thus important information such as fire, flood, forecast can be obtained instantaneously (Rawat and Lawrence, 2014).

Thanks to real time-GNSS system integrated on the UAVs, routing of the UAVs can be performed automatically. In addition, the images obtained with this system are both coordinated instantaneously and oriented with Inertial Measurement Unit (IMU) systems. Also, the images can be processed instantaneously at the control station, or they can be processed in the office after taking the images (Samad et al., 2013).

Although the UAVs have many advantages, they have also disadvantages such as incapability of use on very large areas, low flight time, limited applications for windy weather, difficulties in landing, take-off and flight stages. The 3D position information obtained from the digital elevation model produced using the UAVs can sometimes produce erroneous results due to the disadvantages of the UAVs. Incorrect position information obtained in this case can be eliminated using appropriate statistical methods.

4. APPLICATION

In order to investigate the use of UAVs in producing a digital terrain model, a test area of ~5.5 hectares (ha) was selected in an area belonging to the private sector in province of Konya, Çumra (Figure 1). In the selected test area, 56 points were established at approximately 40 m intervals. In order to investigate the density of GCP and the effect of flight altitude on the accuracy, the flight altitude 80, 100, 120 m and the homogeneously spread GCPs number were chosen as 5, 10, 15 respectively, while the remaining points were considered as the test point (Figure 2).

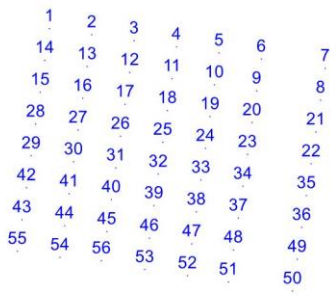

Figure 1. The points in the test area

Figure 2. One of GCPs

In the study, The Geo V3 Multicopter produced by Geomatics Inc. Co. was used (Figure 3). Detailed information can be obtained from (http://www.geomaticsgroup.com/contents/urunler/77/327/481) .

Figure 3. Geo V3 Multicopter

The Sony A6000 16 mm – 6000 × 4000 camera was used to take images in RAW format. During the flight with the UAV, one picture was taken in about two seconds on average. For this purpose, the main control card of the UAV was programmed to take regular pictures. The camera shutter was pressed at constant time intervals. Vibration damping equipment has been installed in the connection point between the UAV platform and the camera, so that the camera was not affected by the vibration generated during flight (Table 3-4). More information about the platform can be found at (Yildirim et al., 2016).

Table 3. Platform technical specifications (Yildirim et al., 2016)

Specification	Technical Detail
Weight	3.6 kg
Wingspan	103 cm
Payload	4 kg
Height	34 cm with GPS Antenna
Range	4 km
Endurance	30 min
GPS	5 Hz – 72 channels
Speed	7 m/sec
Telemetry Radio	433 MHz
Radio Control	24 GHz
Maximum Speed	110 km - 30 mm /sec
Frame Transponder (FPV)	5.8 GHz

Table 4. Sony A6000 digital camera specifications (https://www.sony.com/electronics/interchangeable-lens-cameras/ilce-6000-body-kit/specifications)

Specification	Technical Detail
Megapixels	24.7 MP
Size of Sensor	23.5 x 15.6 mm
Dimensions	2.63 x 4.72 x 1.78 inches
Sensor Type	APS-C
Weight	10.05 oz
Media Format	Secure Digital (SD), SD Extended Capacity, SD High Capacity
Maximum ISO	51200
Battery Type	Lithium Ion
Size of LCD	3 inches
Aspect Ratio of LCD	4:3
LCD Dots	921600
Type of Viewfinder	0.39” type electronic viewfinder (colour)
35 mm-Equivalent (Wide)	25 mm
35 mm-Equivalent (Telephoto)	500 mm

Images obtained by the UAVs can be evaluated using different software. In this study, UAV data were evaluated with Pix4D software. Detailed information can be obtained from (http://www.geomaticsgroup.com/contents/urunler/77/328/486).

As a result of the software evaluation; GeoTIFF format, orthomosaic with real coordinate, Google fields in KML and HTML formats, DSM with real coordinate, point cloud in LAS, LAZ, XYZ and PLY formats, vector data in dxf, shp and kml formats, adjustment result report can be obtained (http://www.geomaticsgroup.com/contents/urunler/77/328/486).

4.1. Evaluation of the measurements

The point coordinates were determined by rapid static method using Javad TRIUMPH1 GNSS receiver that exists in Konya Technical University Geomatics Engineering Laboratory. Data were collected as 10 minutes for recording intervals of 5 seconds at all the points in the test area. Until the measurement was completed at all points with 4 GNSS receivers, 2 GNSS receivers also collected data simultaneously at the benchmark points at the immediate surroundings of the study area. The collected data were evaluated based on two benchmark points at the immediate surroundings of the study area using LGO v7.0 GNSS software and the Transversal Mercator (TM) projection coordinates and ellipsoidal heights of the points were calculated at International Terrestrial Reference Frame-1996 (ITRF96) in 2005.00 epoch. The RMS of obtained coordinates were between ±0.4 mm and ±1.2 mm, ±0.4 mm and ±1.0 mm, ±1.2 mm and ±2.4 mm, in the direction of x, y and h axes, respectively. These RMS values are more accurate than the RTK-GNSS technique. This would increase the accuracy of the produced models. Then, the Geo V3 Multicopter was flown at 80, 100, and 120 meters altitude. Overlap ratios were taken as 80%, 70% for forward, side, respectively. Data obtained by the UAV was evaluated in Pix4D software and coordinates of the test points were obtained from DTM produced using 5, 10, 15 GCPs spread homogeneously from the test points whose coordinates were determined by rapid static method.

The coordinates obtained from DTMs and the coordinates calculated by rapid static method were compared. For this purpose, considering the selected flight altitude and the number of GCPs used, the coordinate differences were calculated (Eq. 1);

$$d_{x_i} = x_{si} - x_i, \quad d_{y_i} = y_{si} - y_i, \quad d_{h_i} = h_{si} - h_i, \qquad (1)$$

n_x, n_y, n_h are to show the number of coordinate differences, RMS errors were (Eq. 2);

$$m_x = \pm\sqrt{\frac{\sum d_{x_i} d_{x_i}}{n_x}}$$
$$m_y = \pm\sqrt{\frac{\sum d_{y_i} d_{y_i}}{n_y}} \qquad (2)$$
$$m_h = \pm\sqrt{\frac{\sum d_{h_i} d_{h_i}}{n_h}}$$

In the equations above, x_{si}, y_{si}, h_{si} are the coordinates of point i, calculated by rapid static method, x_i, y_i, h_i are the coordinates obtained with the UAV. Outliers of the coordinates obtained from the models were detected by Bland-Altman Plot (Bland and Altman, 1986;1999; Stöckl et al., 2004; https://www.medcalc.org/manual/blandaltman.php). After outlier detections, test statistics were calculated (Table 5). The RMS errors in the directions of y, x and h axes are shown in Figure 4.

Table 5. The descriptive statistics (cm)

Number of GCPs	Flight Altitude (m)	Descriptive Statistics											
		y (cm)				x (cm)				h (cm)			
		max	min	mean	RMS	max	min	mean	RMS	max	min	mean	RMS
5	80	9.6	-11.3	-1.0	±4.65*	7.0	-8.9	-0.5	±3.79*	25.6	-19.6	-0.6	±10.10
	100	11.5	-9.2	1.6	±5.53	10.6	-6.4	2.2	±4.70	12.1	-9.9	2.5	±6.19*
	120	8.0	-11.2	-2.5	±5.39	10.0	-15.9	-1.6	±6.30	68.0	-39.1	3.0	±16.77
10	80	10.6	-8.3	0.1	±4.18*	9.1	-8.1	-0.2	±4.41*	15.4	-10.0	1.4	±7.00
	100	9.1	-8.2	-1.1	±4.65	8.6	-9.5	-0.2	±5.26	11.2	-9.3	2.2	±5.65*
	120	10.6	-12.1	-2.1	±5.90	10.1	-11.4	-2.3	±6.28	12.8	-10.8	4.2	±7.73
15	80	9.6	-11.3	-1.0	±4.65*	7.0	-8.9	-0.5	±3.79*	68.2	-36.6	5.7	±24.74
	100	8.2	-12.1	-1.9	±5.23	12.9	-13.7	-1.1	±6.08	12.2	-10.9	2.3	±6.41*
	120	10.1	-10.9	-1.1	±5.33	9.0	-9.8	-0.6	±4.44	13.1	-11.9	2.1	±6.94

* The least RMS error in different scenarios

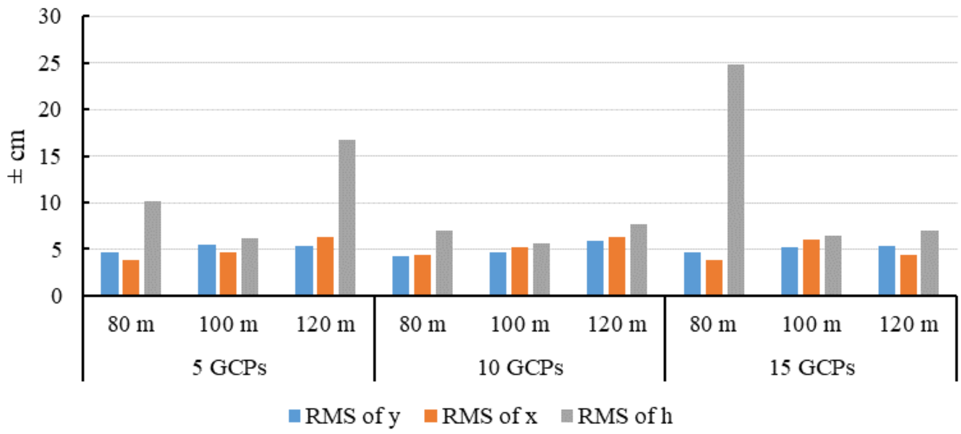

Figure 4. The RMS of y, x, and h (cm)

When Table 5 is examined, it is seen that there is no significant difference between the coordinate accuracies of the different flight altitudes. The number of GCPs when producing the DTM does not affect the results. This situation is due to the small and disinclined test area. When the RMS errors are examined, it is seen that the accuracies of x and y directions are nearby 5 cm and the height accuracy is nearby 15 cm. The least RMS error at a flight altitude of 80 meters is achieved by using 10 GCPs in the direction of the y axis. For the direction of x axis, the least RMS error of 80 meters flight altitude is achieved by using both 5 and 15 GCPs. The least RMS error in the height component at a flight altitude of 80 meters is obtained by using 10 GCPs. For the flight altitude of 100 meters, minimum RMS errors in the y, x, and h directions are obtained with 10, 5, and 10 GCPs, respectively. At the flight altitude of 120 meters, these values are 5, 15, and 15 GCPs. Figure 4 clearly shows these findings.

Table 6. 2D and 3D position accuracies

Number of GCPs	Flight Altitude (m)	Position Accuracy (cm)	
		2D	3D
5	80	±6.00 *	±11.74
	100	±7.26	±9.54 *
	120	±8.30	±18.71
10	80	±6.07 *	±9.26
	100	±7.02	±9.01 *
	120	±8.61	±11.58
15	80	±6.00 *	±25.46
	100	±8.02	±10.26
	120	±6.94	±9.82 *

* The least RMS error

The RMS errors, obtained from models, are shown in Table 6. It is seen that 2D and 3D position accuracies vary between ± 6.00- ± 8.61 cm and ± 9.01- ± 25.46 cm, respectively. For the 2D position accuracy in the test area, the least RMS are at 80 m, while the 3D position accuracy is generally obtained at a flight altitude of 100 m. While the best horizontal accuracy (2D) at 80 m flight altitude is achieved by using 5 and 15 GCPs, the best 3D accuracy is achieved with 10 GCPs. The best 2D position accuracy at flight altitudes of 100 and 120 meters is achieved with 10 and 15 GCPs, respectively. The GCP numbers, which the best 3D accuracy is achieved, are the same as 2D for 100 and 120 m flight altitudes.

5. RESULTS

In recent years, the UAVs have been widely used in the production of DTMs. It is possible to produce a DTM of larger areas with lower costs in a shorter time than classical terrestrial techniques with the UAVs. However, as with every method, the UAVs also have some disadvantages. The need for trained pilots and the high cost of purchasing them are seen as their most significant disadvantages.

The main problem encountered when producing DTM with UAVs is to determine the appropriate conditions for more accurate modeling of the selected area. It is necessary to determine the optimal flight altitude and ideal GCPs number. In this study, different flight altitude and a different number of GCPs were set in a selected region and the accuracy of the produced DTM was investigated. The images taken with the UAV on the flights at 80, 100 and 120 meters were evaluated with 5, 10 and 15 GCPs and 9 DTMs were generated. The coordinates of the test points were determined by the rapid static method as it provided more accurate results than RTK-GNSS technique. The coordinates obtained from the models were compared with the rapid static coordinates using the Bland-Altman plot and the outliers were detected in the direction of the coordinate axes.

In each model, statistical differences in the direction of coordinate axes, 2D and 3D position accuracies were calculated (Table 5-6). When a comparison is made to the number of GCPs, the best result regarding 2D position accuracy was obtained using 5-15 GCPs, while in 3D position accuracy was obtained using 10 GCPs. When compared to the flight altitude, it was determined that the highest geometric accuracy of the model was 80 m for 2D position accuracy and 100 m for 3D position accuracy. It was found that the accuracy obtained here provides the expected accuracy from the DTMs to be used as a base in maps. It should not be overlooked that these accuracies may vary depending on the structure and size of land, weather conditions and position accuracies of GCPs.

Author contributions

O. Yildirim : Designed the research, analyzed the data, Methodology, Validation.

C. Inal : Designed the research, Investigation, Validation, Conceptualization, writing the manuscript–review and editing.

S. Bulbul : Collected the datasets , Analyzed the data, Methodology, Validation, Writing. Writing the manuscript–review and editing.

B. Bilgen : Collected the datasets , Analyzed the data, Methodology, Validation, Writing. Writing the manuscript–review and editing.

Conflicts of Interest

The authors declare no conflict of interest.

Research and publication ethics statement

In the study, the authors declare that there is no violation of research and publication ethics and that the study does not require ethics committee approval.

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