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Research Article

Determination of Excavation Volume Using UAV-Based PPK Method in Open Mining Sites Tatlıdere Forests in Düzce

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ABSTRACT

Remote sensing technologies have the potential to provide cost-effective, fast, and easy solutions for the determination of surface changes (material volume) after quarrying (open-pit mine) activities. In areas where the topography is rugged and difficult to access, the use of ground measurement techniques causes difficulties. In such cases, the use of remote sensing techniques is indispensable. The Post Processing Kinematic (PPK) measurement technique provides an alternative solution to other photogrammetry methods in areas whose topography is not suitable for satellite-based positioning. This study investigates the applicability of the UAV-based PPK method for the calculation of cut volume in quarry operations. The study area was selected as a quarry located within the boundaries of Tatlıdere Forestry Operation Chief in Düzce province and operated by a legal entity. Using a DJI Phantom 4 RTK unmanned aerial vehicle (UAV) with a PPK application module, a total of two flights in PPK flight mode were performed at the quarry on 30 September 2021 and 19 May 2022 (covering a period of approximately 7 months). The material volume, which is important for quarry operation, was calculated and the excavation volume in the two flight time intervals was found to be 104.170 m³ and the cut area was found to be 44.348 m². According to the results obtained, UAV systems should be used in quarry management in terms of time and work safety in obtaining data.

Keywords: *Cut volume, UAV, PPK method, Quarry, Düzce*

Düzce Tatlıdere Ormanları Açık Maden Sahalarında İHA-Tabanlı PPK Yöntemi Kullanılarak Kazı Hacminin Belirlenmesi

ÖZ

Taş ocaklarında yapılan faaliyetler sonrası meydana gelen yüzey değişimlerinin (materyal hacmi) belirlenmesinde uzaktan algılama teknolojileri, maliyet-etkin, hızlı ve kolay çözümler sunma potansiyeli taşımaktadır. Topografyanın engebeli ve ulaşılması güç olduğu alanlarda yersel ölçüm tekniklerini kullanmak zorluklara neden olmaktadır. Bu gibi durumlarda uzaktan algılama tekniklerinin kullanımını olmazsa olmaz kılmaktadır. Coğrafi yapısı, uydu bazlı konumlamaya müsait olmayan alanlarda ölçü sonrası veri değerlendirme (Post Processing Kinematic-PPK) ölçüm tekniği diğer fotogrametri yöntemlerine alternatif çözüm sağlamaktadır. Bu çalışmada İHA-tabanlı PPK yönteminin taş ocağı işletmeciliğindeki kazı hacminin hesaplanmasında kullanılabilirliği incelenmiştir. Çalışma alanı olarak, işletmesi tüzel kişiliğe ait Tatlıdere (Düzce) Orman İşletme Şefliği'ndeki taş ocağı seçilmiştir. Çalışmada DJI Phantom 4 RTK marka ve PPK uygulama modülü sahip insansız hava aracı (İHA) kullanılarak, taş ocağında 30 Eylül 2021 ve 19 Mayıs 2022 tarihlerinde (yaklaşık 7 aylık süreci kapsayan) PPK uçuş modunda toplam iki uçuş gerçekleştirilmiştir. Taş ocağı işletmeciliği için önemli olan materyal hacmi hesaplanmış, iki uçuş zaman aralığındaki kazı miktarı 104,170 m³ ve kazı alanı ise 44,348 m² bulunmuştur. Elde

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edilen sonuçlar doğrultusunda taş ocağı işletmeciliğinde İHA sistemleri veri elde etmede zaman ve iş güvenliği açısından kullanmalıdır.

Anahtar Kelimeler: *Kazı hacmi, İHA, PPK metot, Taş ocağı, Düzce*

I. INTRODUCTION

With the increase in the world population, the use of natural resources has also increased. The management and utilisation of natural resources requires periodic observations and measurements. Geographic Information Systems (GIS) and remote sensing (RS) techniques are often favoured in all natural resource management science related research. In recent years, Unmanned Aerial Vehicles (UAVs) have been used to produce high resolution and accurate digital elevation models (DEMs) of spatial data. With UAV, workload is reduced, time is saved and more precise data is obtained.

The minerals that are offered and used for the benefit of humanity are generally obtained through surface mining activities in natural habitats considered as forests. Many geotechnical applications, including civil works, are carried out in mining areas for the purpose of operation, and the natural soil structure and soil cover are changed [1]. In mountainous areas with difficult terrain conditions, obtaining data with traditional surveying techniques is very labour intensive and tiring. Today, UA methods are more preferred instead of traditional ground surveying techniques which are costly. With the development of technology, ground, aerial and satellite-based data collection methods provide great advantages in terms of speed and cost. The data collected with modern methods and tools are quickly analysed and made available to applied disciplines [2].

Robotic systems developed in recent years provide researchers with different measurement techniques, saving time and economy. Among these techniques, which are gaining momentum rapidly, are UAV systems, which are evaluated within the scope of close-up photogrammetry and divided into various classes [3]. These systems are preferred for measurement and evaluation studies covering sciences such as forestry, agriculture, mining and construction due to their temporal flexibility and ability to produce precise data [4-7].

New generation image processing techniques have a significant impact on the widespread use of UAV systems. The increasing use of the Structure-from-motion (SfM) algorithm, which is described as the return of photogrammetry, in the digital environment has a large share in the development of UAVs and systems [8]. UAVs and their systems are equipped with global navigation satellite system (GNSS) receivers, Inertial Measurement Unit (IMU) and many other sensors. The knowledge of these systems and sensors is effective in converting the block images obtained from the 2D plane into 3D with the SfM technique. High resolution digital elevation models (DEMs) and orthophotos can be easily created with many commercial or open source software working with SfM logic [9, 10].

In models requiring high precision and accuracy, the position information obtained from the GNSS-GPS module on the UAV is insufficient. Different GNSS techniques are used to ensure that the position parameters of the UAV have centimetre accuracy [11]. This high precision includes direct georeferencing, real-time kinematics (RTK) and post-process kinematics (PPK) technologies [12]. PPK measurement technique provides an alternative solution to the RTK method in areas where the topographical structure and coverage limits of the stations providing data are not suitable for satellite-based positioning [13].

In the volume calculation of the material quarried in the quarry, the volume calculation was previously made by counting the loaded transport vehicles and entering them into the weighbridge. In addition, the material volume was also determined with devices such as takeometer, level etc. Nowadays, with the developing technology, material volume can be found by photogrammetric measurements. Cors-GPS is also used for monitoring open mine sites and determining the volume of material. The material volume is calculated with the boundaries of the permit area and the DEM created. However, since the open mine sites are generally located in mountainous areas, the topography is rugged and difficult to access, and the field measurement methods are more difficult and time-consuming in terms of occupational safety. In addition to UAV technology, automated data collection technologies include imaging of the land surface by photography, video or digitisation and the calculation of material volume using different remote sensors (non-contact) (laser, acoustic and infrared) [14]. The disadvantages of these methods are that remote sensing sensors are more expensive than existing UAV sensors. In addition, other methods are more difficult and time-consuming in terms of occupational safety since data will be obtained by walking around in the field. In addition to these, nowadays, local laser scanners, handheld and smart device compatible 3D devices (viDoc RTK, Handheld Lidar), GPS integrated cameras have the ability to be used in open mine sites. These methods are also disadvantageous compared to UAV systems since data is collected by walking in the field.

Open pit mining, or in other words surface mining, is a form of production applied in areas where the ore is located close to the surface of the ground in order to economically extract the cover layer on the mine when necessary [14] (Figure 1). The spread and size of the ore close to the surface has enabled open pit mining to diversify within itself. Today, three different methods for surface mining find their place in practice. These can be exemplified as lignite and coal quarries with horizontal ore deposits, metallic quarries with sloping or steeply dipping ore deposits, and industrial raw material and natural stone quarries with ore deposits formed on the slope close to the surface [15].

In this study, UAV-based PPK method was used to monitor the quarry performing surface mining activities with UAV and the volume of material extracted was calculated for the quarry operator. Therefore, this study aims to answer the question of whether the quarry material volume can be calculated without data loss with the UAV-based PPK method.

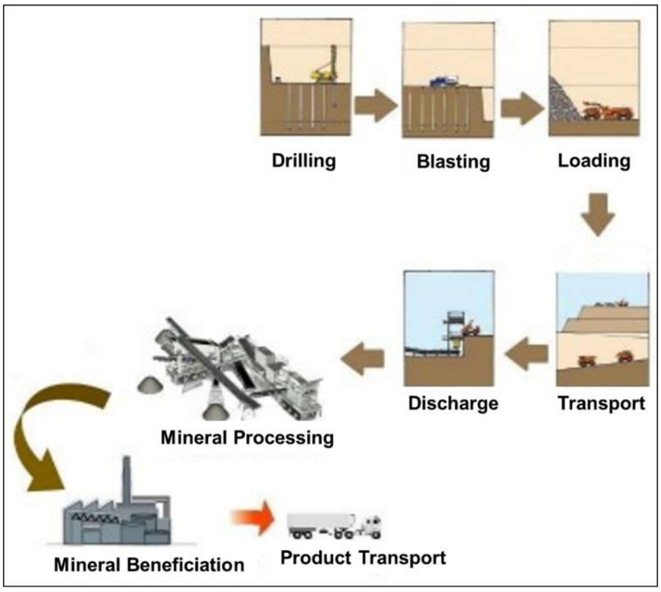

Figure 1. *Operation of open pit mining sites [14]*

II. MATERIAL AND METHOD

A. MATERIAL

A. 1. Study Area

The quarry, which is located within the boundaries of Tatlıdere Forest Management Chiefdom (FMC) within Düzce Forest Management Directorate, located in the southwest of the Western Black Sea Region, was selected as the study area (Figure 2). The quarry, which is 16 km away from the centre of Düzce, has an average elevation of 430 m above the sea and is a II-A Limestone site. The quarry permit area is approximately 112237 m² and the works were started in 2012 and production is still continuing. In the study area, UAV flights were carried out in two different time periods and the quarry was monitored for approximately 7 months. Bolu Regional Directorate of Forestry Permit Easement Branch Directorate, to which the study area is affiliated, has a total of 45 open pit mining permits operating in Düzce province as of 2024 [16].

The total area of Tatlıdere FMC is 4428 ha, of which 4090 ha is forested and 338 ha is non-forested. The study area is under the influence of both the Black Sea Climate Zone and the Central Anatolian Climate Zone. The differences in the climatic characteristics of the region have led to the formation of a rich range of plant diversity. The forests of the plan unit are generally leafy forests. The main tree species of Tatlıdere Forest Management Directorate are Oriental Beech (*Fagus orientalis*), European Hornbeam (*Carpinus betulus*), Sessile Oak (*Quercus petraea*), Scotch Pine (*Pinus sylvestris*), Austrian Pine (*Pinus nigra*) [17].

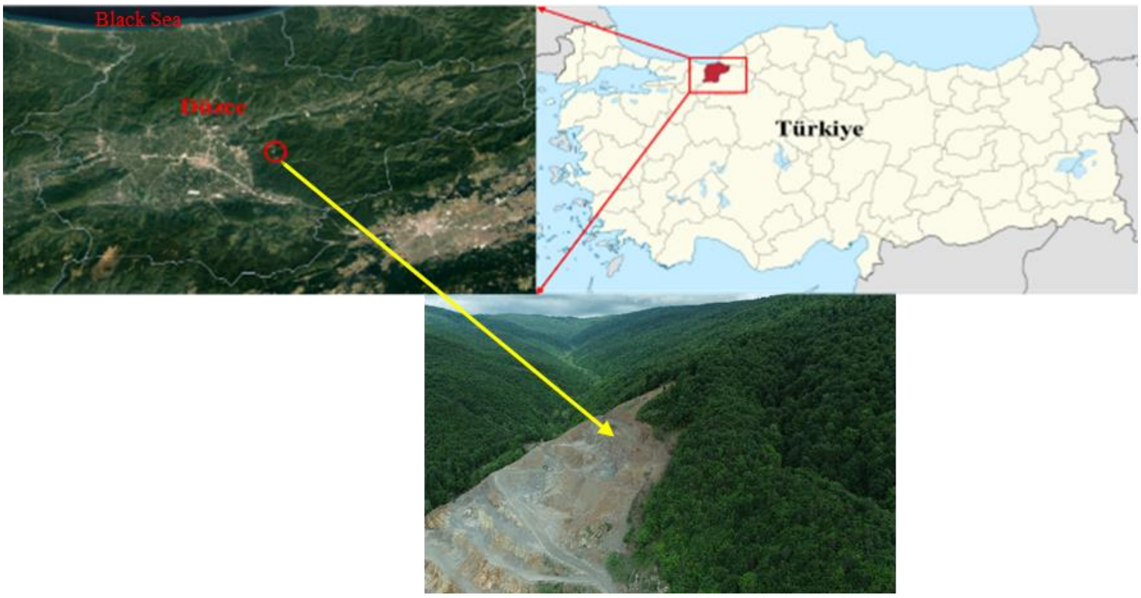

Figure 2. *Study area and its surroundings*

A. 2. Tools and Equipment Used

In the study, the first flight was performed on 30 September 2021 and the second flight was performed on 19 May 2022 with the DJI Phantom 4 RTK UAV platform. CHCN X91 GNSS receiver was used for coordinate acquisition (Figure 3). The UAV system used has a 20-megapixel camera capable of taking photos in the visible range (RGB) defined by the manufacturer. The UAV system is equipped with a multi-frequency RTK/PPK GNSS module that provides high position accuracy [18]. Intel ® Xeon ® CPU E5-1650 v3 @ 3.50GHz 48 GB processor model and 4 GB AMD FirePro W5100 graphics card workstation were used for data processing, visualisation and analysis. PPK method was used in the study. PPK method offers higher accuracy than RTK method. However, the PPK method has limitations such as extra time, equipment (GNSS receiver) and software. Although rare, a potential source of error in this method is the inability to collect static data with the GNSS receiver.

Figure 3. a) *UAV DJI Phantom 4 RTK System,* ***b)*** *CHCN X91 GNSS receiver*

B. METHOD

B. 1. Acquisition of Digital Images with UAV System

The basic steps of image acquisition by UAV are pre-field preparation (preparation of flight plans and field work), flight realisation and post-flight operations. In the pre-field preparation phase, some necessary preliminary information such as weather conditions and topography of the relevant area should be obtained before travelling to the field. The optimum weather conditions for UAV flight are stated as a cloudy sky without wind and precipitation [19, 20].

The flight planning process was created with the DJI GS RTK application from the control of the DJI Phantom 4 RTK system. In this context, firstly, DEM data was obtained in Global Mapper software for the study area. The DEM data of the site and a vector data (in KML format) covering the boundaries of the flight area were transferred to the controller via SD card and a flight plan was prepared (Figure 4). Then, using these data, the time was taken into account depending on the size of the area and the battery capacity of the UAV, and finally, planning was carried out to perform adaptive flight.

Figure 4. *Creation of DEM data and preparation of flight plan*

Using the DJI Phantom 4 RTK UAV system with PPK application module, two flights were carried out in PPK mode in the quarry, which is an open mining area, on 30 September 2021 and 19 May 2022. The photographs taken within this scope have 60% front and 70% side overlap ratios and the flight height is planned as 150 m. The flights were carried out in weather conditions without wind and precipitation. CHCN X91 GNSS receiver was used as a solution for PPK static measurement positioning. In PPK mode, when the UAV is in the air, the rover observation file "Rinex.obs" (RINEX observation data) is saved directly to the SD memory card. The GNSS receiver is installed on a tripod at a location with known coordinates and the measurement was started in static mode at an antenna height of 200 cm. Since RINEX observation data should cover the entire flight, static data acquisition was carried out before and after the UAV flight for 15 minutes each. The static data is stored in the internal memory of the GNSS receiver in a special file format ".HCN".

B. 2. Processing of Digital Images Taken by UAV

After the flights were completed, Agisoft Metashape Professional Version 1.5.2 software was used to process the images taken by the UAV and produce point cloud, DEM and orthophoto images with high resolution and accuracy [21] (Figure 5). Agisoft Metashape is a stand-alone software product that performs photogrammetric processing of digital images and generates 3D spatial data to be used in GIS applications, cultural heritage documentation, and visual effects production as well as for indirect measurements of objects of various scales [21]. The software ran on Windows 10 64-bit operating system. The accuracy level of the image registration process was set as medium, and the quality settings were selected as high for the other depth maps and dense cloud generation stages. The outputs produced as a result of photogrammetric analysis of the images are DEM and orthomosaics in "tiff" format.

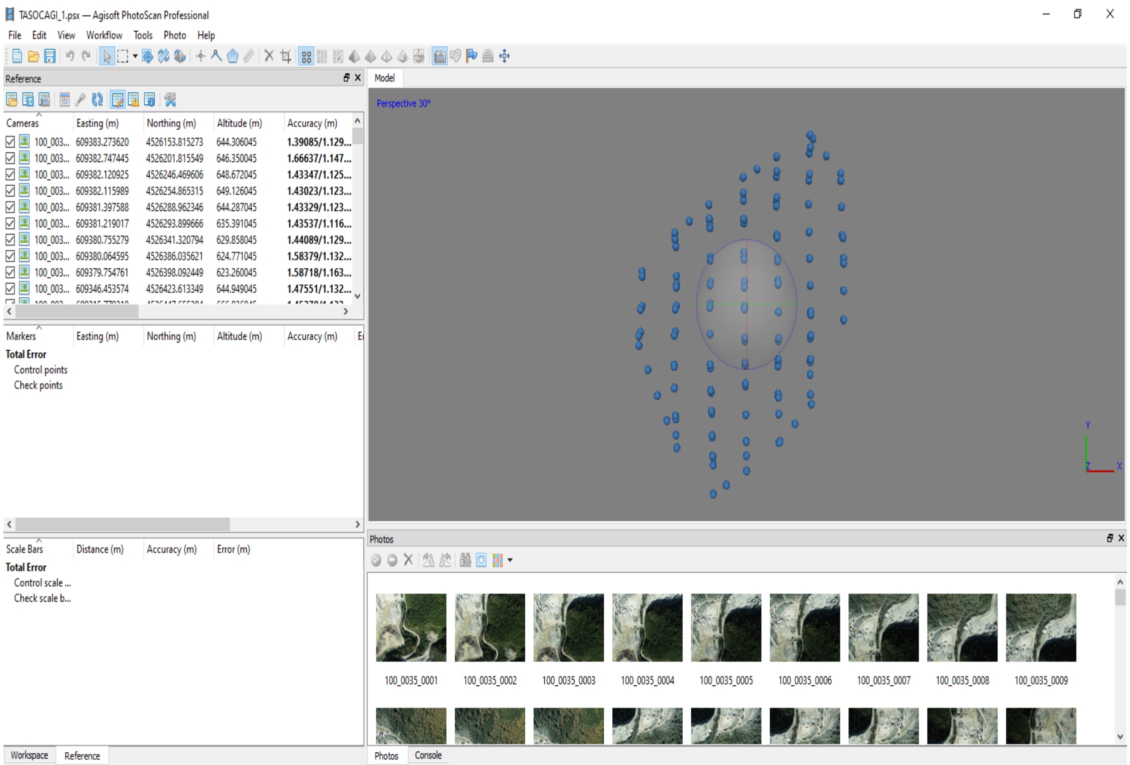

Figure 5. *Data processing in Agisoft Photscan Professional version 1.5.2*

Correction of camera positions for images taken in PPK mode was made using CHC Geomatics Office 2 software (Figure 6). The software is a powerful office software solution, designed for engineers as an integrated platform to make a link between field and office workflow from multiple sensors and generating rich deliverables. It supports 4 modules: GNSS, RTK, road and UAV, which allows for processing massive fieldwork data in one software. "PPKRAW" files for the rover and base observation files, "HCN" files for the GNSS base station were transferred to the software, and the corrected camera positions after the process were saved as a CSV file.

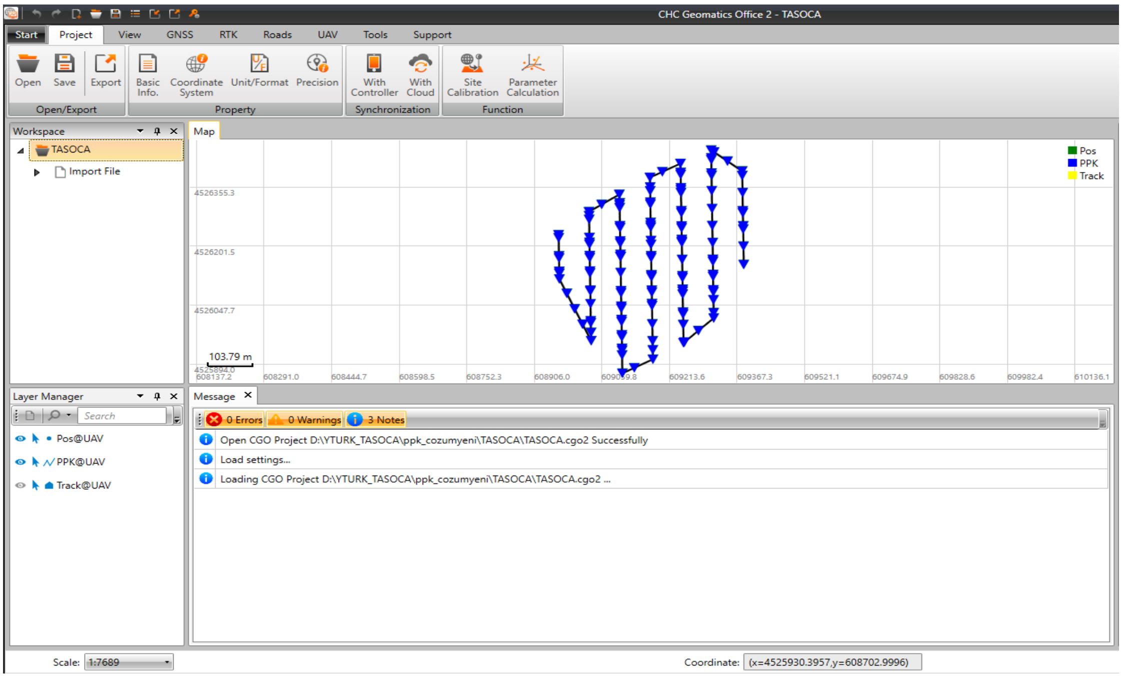

Figure 6. *Correcting photo positions in CHC Geomatics Office 2 PPK balancing software*

The corrected camera positions recorded as CSV were replaced with uncorrected camera positions in the Agisoft Metashape software, and the PPK data was analyzed and balanced and orthomosaic and DEM were produced (Figure 7).

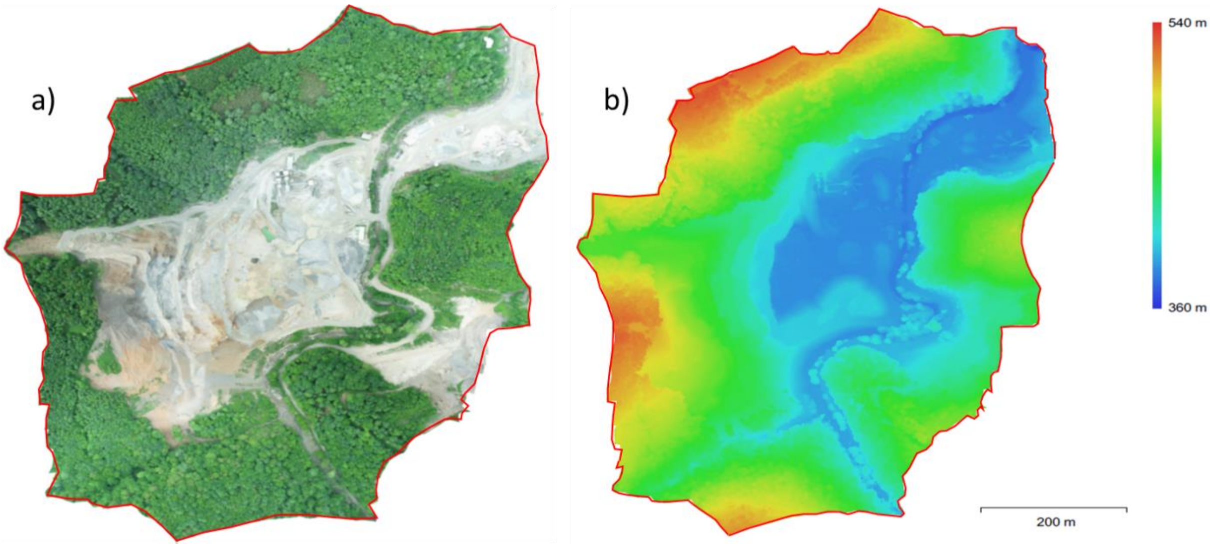

Figure 7. *Reconstructed:* ***a)*** *orthophoto image,* ***b)*** *digital elevation model*

During the photo alignment and optimization process, the root average square error rates for X, Y, Z, XY and total error of the calculated camera positions of the PPK data were calculated [21].

The average error was found by the following formula;

$$\text{Total Error} = \frac{\sqrt{\sum_{i=1}^{n}[(X_{i,t}-X_{i,g})^2+(Y_{i,t}-Y_{i,g})^2+(Z_{i,t}-Z_{i,g})^2]}}{n} \qquad (1)$$

In the formula, "g" is the input value for camera position i and "t" is the estimated value for camera position i.

B. 3. Determination of Cut Volume

In the study, the DEM difference method was used to determine the quarry excavation volume. In this process, DEM is applied by subtracting the value of each pixel that constitutes the DEM data produced in raster format (in DEM, this value is the height above sea level) from the value of the overlapping pixel in the other DEM in the time series (Figure 8-a). DEM differences were removed from the second flight based on the first flight data (Figure 8-b). The study area boundaries were cut out from the difference DEM data produced. Then, the material cut volume and area were determined. To determine the volume and area, an add-on in the form of a toolbox is designed into the ArcGIS software ArcMap module using the Python programming language [22] (Figure 8-c). As shown in Figure 8-d from the Algorithm difference data produced, all pixels with positive difference values give the filling volume and area, and negative difference values give the cut volume and area. The algorithm records the volume and area information as a text file (with .txt extension) in the location defined as the workspace. In the text file, the lower (0 m) and upper limit (30 m) values were determined according to the field measurement results (Figure 8-e).

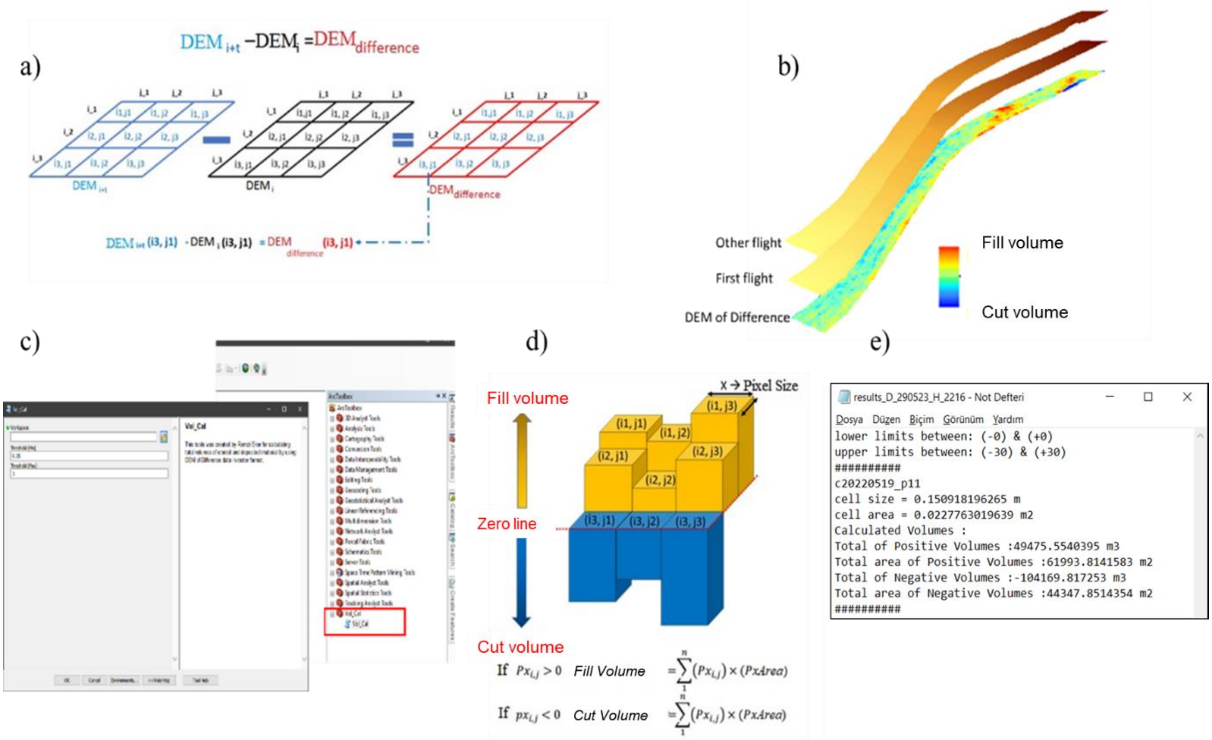

Figure 8. *Analyses for the determination of cut and fill volume*

III. RESULTS AND DISCUSSIONS

Photogrammetric products (orthophoto and DEM) that evaluate both horizontal (X and Y) and vertical (Z) position accuracy were created with the images obtained from PPK flights. When the location error estimates of all cameras in the orthophoto images created as a result of the PPK method were examined, the total average camera position error was found to be 47.41 cm before the balancing solution in the PPK method (GNSS), while it was calculated as 0.68 cm after the balancing solution.

According to the results calculated from the difference between the first flight and second flight data with the UAV; the excavation amount in the quarry is calculated as 104.170 m^3 and the cut area is 44.348 m^2. Volumetric cut map is given in Figure 9 and areal cut classes map is given in Figure 10. There are a limited number of studies on determining the amount of material with UAV [6, 23, 24]. [25] They evaluated the soil pile volume measurements with UAV and found a volume of 38.56 m^3 as a result of the study, and stated that the difference with the Total Station was 1.94 m^3 (98.95% compatible). In his study [26], he compared UAV and Total Station volume data and found that the values found as a result of both methods were 99.33% compatible with each other in terms of precision. In addition, other studies [6, 21, 27, 28, 29] have examined the usability of UAV in determining cut and fill volumes in the construction of forest roads. In these studies, they stated that UAV technology is effective in forest road volume calculations and can be used to accurately calculate the cut and fill volume.

In another study [30], UAV and close range photogrammetry were used to determine soil losses on forest road excavation slopes in semi-arid mountainous areas, and the results of the two methods were found to be close to each other. [31, 32], in their studies, concluded that laser scanning and terrestrial photogrammetry methods can be used for volume calculations. When these studies are analysed; it is revealed that UAV systems can also be used in volume calculations. The use of UAV systems for open pit quarry operations will contribute in terms of fast access to data, accuracy and occupational safety. In UAV applications, it is very difficult or impossible to obtain positional information with RTK-CORS network in hard-to-reach areas such as quarries and mostly close to mountainous areas (forestry, national parks, etc.) [13]. Therefore, more precise and reliable results can be obtained with the UAV-PPK method without data loss.

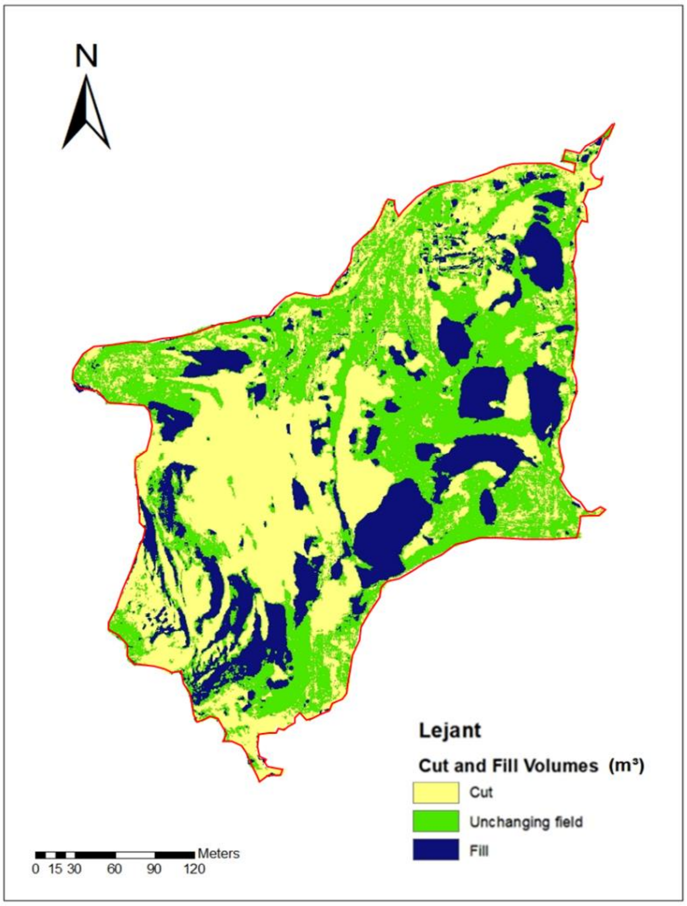

Figure 9. *Volumetric cut and fill map*

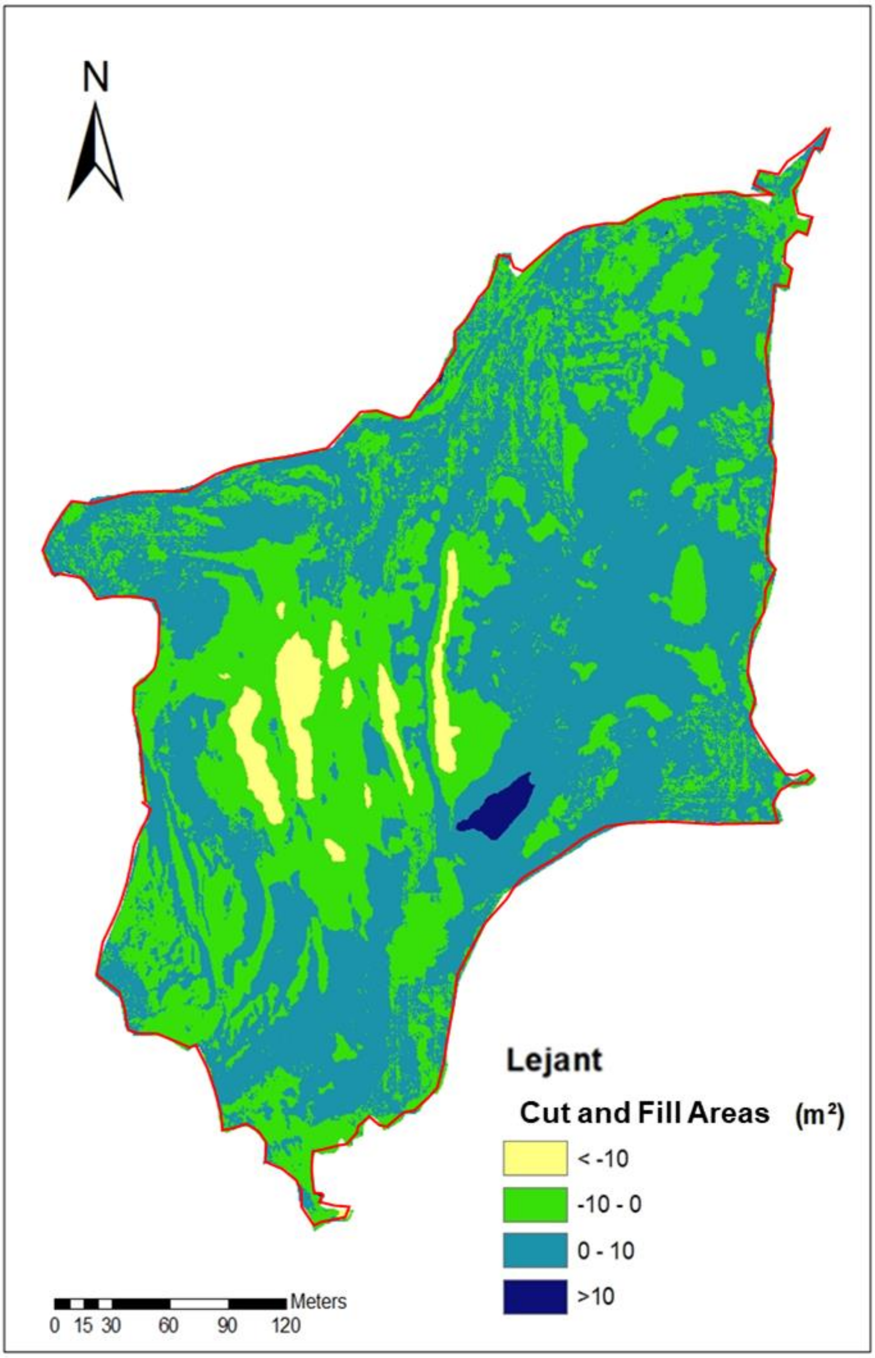

Figure 10. *Areal cut and fill classes map*

IV. CONCLUSION

In this study, the use of the UAV-based PPK method in monitoring ground change after cut in open-pit mining sites (quarries) was examined. The volume of material important for quarry operation was calculated, the cut amount was found to be 104.170 m^3 and the cut area was 44.348 m^2. The quarry operator's use of UAV also provides advantages in terms of workforce, occupational safety, time and controls. In addition, thanks to the flights made in shorter periods, how much material is produced between each flight and the total production will be calculated and border violations will be possible easily. Absolutely direct positioning method in UAV applications; The PPK method is more useful in terms of positional accuracy in areas that are difficult to reach and mostly close to forested areas, such as quarries, and therefore it is appropriate to use it in such areas. The General Directorate of Forestry can also use UAVs to control permit-easement areas, thus providing significant advantages in terms of workforce, occupational safety, time and control. Since the calculations and controls to be made with UAV are easier and faster than traditional methods, permit areas can be checked more frequently in shorter periods and make it easier to determine the amount of material produced. In addition, the use of the PPK method in studies carried out with UAV allows more precise results to be obtained.

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Data Availability The entire dataset was presented in the manuscript.

Declarations

Ethical approval This article does not contain any studies with human participants or animals.

Conflict of interest The authors declare no competing interests.

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