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USAGE OF UNMANNED AERIAL VEHICLES (UAVs) IN DETERMINING DRAINAGE NETWORKS

ABSTRACT

As a result of the rapid growth of the world's population and the consequences of climate change, water resources need to be used correctly and sustainably. Achieving drainage network, one of the most important aspects of watershed management, is crucial to avoid floods that are among the most important natural disasters. DEM (Digital Elevation Model) data can be used to obtain drainage networks with high accuracy. DEM can be produced fast, reliable and accurate thanks to Unmanned Aerial Vehicles (UAVs). In this study, direction, length and drainage area were calculated in order to prevent possible flood disaster and to investigate the risk of landslide in the residential area at the Hisarcık/Kayseri. Using the camera integrated UAV, images related to the landscape were captured and 3D spatial coordinates were obtained using the Structure from Motion (SfM) method. Generated point cloud is converted to DEM data format. The high-resolution DEM(~5cm) was resampled to different resolutions (5m, 10m, 15m and 30m). In addition to the effect of DEM resolution on terrain attributes, stream characterization and watershed delineation effected by flow accumulation threshold values were investigated. It has been shown that high-resolution DEM and low flow accumulation threshold value should be used for quality of drainage networks.

Keywords: Digital Elevation Model (DEM), Unmanned Aerial Vehicles (UAVs), Drainage Network

1. INTRODUCTION

The world population is growing day by day and water usage is rapidly increasing in industry, agriculture and housing. Decrease in available water resources due to global warming, urbanization, industrialization and climate change require further work on watershed management. To manage existing water resources and perform sustainability, topographic elements such as vegetation, soil and water must be obtained in the basin [1]. There are various methods for watershed management and these are studied by various researchers for many years. Until recently, the operations performed with the contours created by digitizing topographic maps produced rather crude results. It is often time-consuming and impossible for researchers to produce results with the desired accuracy. This method is often used as prior knowledge in present-day technology. With the use of UAVs in the field of Geographic Information System (GIS), DEM can be produced with

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fairly high accuracy [2]. DEM is a topographical product containing important information about the Earth Surface and used for watershed management, flood risk analysis, determining water flow direction, dam site, landslide risk areas and land visualization. In hydrological modelling and watershed management problems, spatial data such as Triangulated Irregular Network (TIN), Digital Line Graph (DLG) and DEM are frequently used. DEM resolution affects accuracy of the application to be performed and obtained by different techniques such as SfM, Light Detection and Ranging (LIDAR), Radar Interferometer or field survey methods. The main advantages of DEM, which numerically represents Earth terrain height information, can be shown to have low storage requirement and high computability. Therefore, raster DEM data is used in the production of surface hydrology information [3 and 8].

In this study, drainage basin area, drainage network length and water flow direction were determined using different resolution DEM data. Images captured with camera integrated UAV were processed using SfM technique for obtain point cloud. The point cloud represents the Digital Surface Model (DSM) and contains 3D details related to the land. The noisy points were removed by applying Moving-Least Square Filtering (MLS). Then, the point cloud was formed Bare-Earth or DEM using TIN filtering technique. The DEM data with a Ground Sample Distance (GSD) of about 5 cm was resampled at different threshold values by using Nearest Neighbor method. When low threshold values (dm or cm) are used to produce low resolution DEM, results are not meaningful and close to each other. So that, resampling was performed experimentally using threshold values of 5m, 10m, 15m and 30m. Finally, the length of the drainage network and drainage area were calculated with different resolution DEMs. As the resolution decreases, the land begins to flatten and the point cloud cannot represent the character of the land. So, the length and density of the drainage network, the hill slope and the hydrological response are reduced.

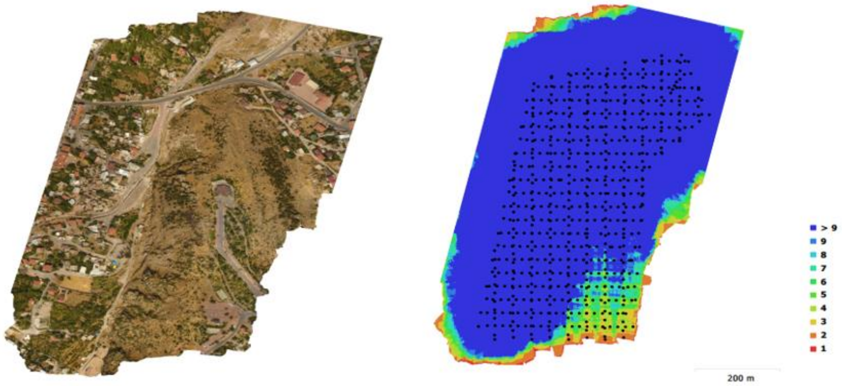
2. RESEARCH SIGNIFICANCE

The rapid development of photogrammetric studies and the increasing availability of unmanned aerial systems in Earth science and applications provided the opportunity for geoscientists to collect fast, low-cost and reliable data. DEM data generated from the point cloud produced by SfM method contains all the details of the topography. DEM can be prerequisite to extract drainage networks. Also, various analyzes can be made about the topography by using DEM. In this study, the effects of different resolution DEM produced by UAV on the extraction of drainage networks were investigated. Application was performed in Kayseri-Turkey.

3. METHOD

3.1. Study Area

The study area is Hisarcık neighborhood, located on the south-west of the city center of Kayseri-Turkey. The area used as settlement and promenade area has steep and excessive slope. The area that hosts the old settlements is also rich in chrome mines and there are many galleries even though they are not used today. The analysis showed that if the open water channel was made to block the flood disaster in the region, this structure was not enough for the region. This channel, located in the hillside area, is not constructed with sufficient accuracy, so the water goes out of the channel. Due to the fact that the topographic structure is extremely rough, the rainfall in winter and melting of snow in the Erciyes Mountain may be the risk of flooding especially in spring .High resolution orthophoto produced by SfM method and camera location produced by UAV of the region are shown in Figure 1.



a) b)

Figure 1. a) Orthophoto of study area b) Camera location and image overlap

Referring to Figure 1.b, image overlaps appear to be sufficient for data production and provide the flight plan given in Table 1. It is seen that a minimum of 5 and a maximum of 9 images are obtained at many points in the field. Location map of the study area and satellite image is given in Figure 2.

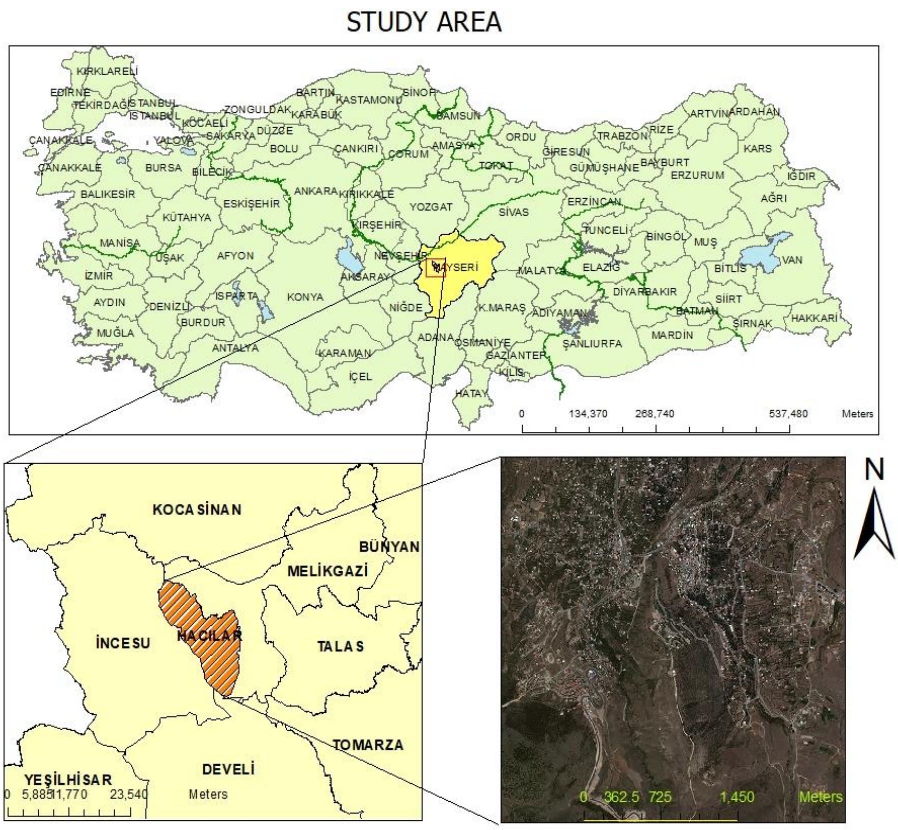


Figure 2. a) The location map of study area over Turkey

3.2. UAV System and DEM Creation

Thanks to the developing technology, point cloud production from photogrammetric products is produced fast, cheap and high accuracy results with various methods. Especially usage of the SfM method, 3D spatial coordinates produced through photographs. SfM method which enables reconstruction of 3D scene geometry from 2D images has started to be used more frequently after UAVs have been used in scientific researches and practical applications [9]. The depth value of each pixel that produces the image is calculated by the semi-global matching (SGM) method to form the point cloud that represents the object. Because of the fact that the dense point cloud created by this method contains every detail of the field, this model is called as DSM [10]. Flight planning should be prepared in accordance with the land topography to obtain the point cloud. The flight planning to be prepared is very dependent on the UAV, camera and terrain surface. Flight planning and camera features are also given in the Table 1.

Table 1. Flight plan and camera properties

Number of Images	707
Flight Altitude	120m
Side-lap/Front-lap	%70-80
Ground Resolution	4.59cm
Camera Resolution	CMOS 20Mp (4096×2160)
Coverage Area	0.457 km2
Mean Absolute Control Points Error	[X Y Z]=[3.1 3.8 5.2]cm

Through DSM, objects (buildings, trees, roads etc.) representing the land cover can be extracted using filtering techniques and Bare-Earth can be obtained. There are various filtering techniques such as Progressive Morphology, Maximum Local Slope, Polynomial Two Surface Filter and TIN to obtain Bare-Earth. Such filters are very important for more accurate interpretation of DEM data and for eliminating false-noisy points. TIN filter was preferred because it was observed to produce more successful results than other methods. In the TIN filtering method, a square grid including the entire data set is created, and the points of the land with minimum altitude in each grid are determined as seed point. Using this seed points, triangulated network model is created by using Delaunay triangles covering the entire data set. Using each triangle within the triangular network model, other points are classified according to the determined angle-distance threshold value. For filtering, an open source software that is called ALDPAD was used [11]. After applying TIN filtering, noisy points were removed using Moving Least Square Filter. In addition, in the experimental studies, it was observed that applying the TIN filter to the DSM data was worse after applying the MLS filter in the irregular areas. Besides the MLS method being robust, the sharp edges are defined more clearly and the noisy regions are transformed into very smooth surfaces. Figure 3 shows the change in terrain resulting from the TIN filter applied to the area where the settlements are located.

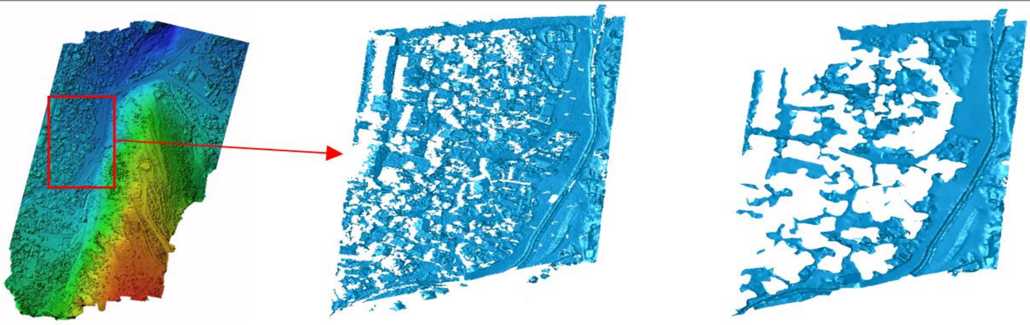


Figure 3. High-resolution DSM of study area, settlements area; pre-TIN and post-TIN, respectively

After that, the DEM data was generated from the filtered point cloud data. Then the generated DEM data was resampled to different spatial resolution levels using the Nearest Neighbor method. The nearest neighbor resampling techniques have been preferred because they produce attractive, easy applicability and effective results in local slope [12 and 14]. In this method, the new pixel value in the corrected image is assigned the brightness value of the pixel closest to this pixel in the original image. So this method determines the nearest pixel in the first step and assigns the value of this pixel to the input pixel. After resampling, the values of the pixels in the output image need to be recalculated. In other words, after the geometric transformation of the resampled input image, the process of defining new values for output pixels is based on the original output image. As can be seen in Figure 4, DEMs (5m, 10m, 15m and 30m) are resampled according to the Nearest Neighbor Method.

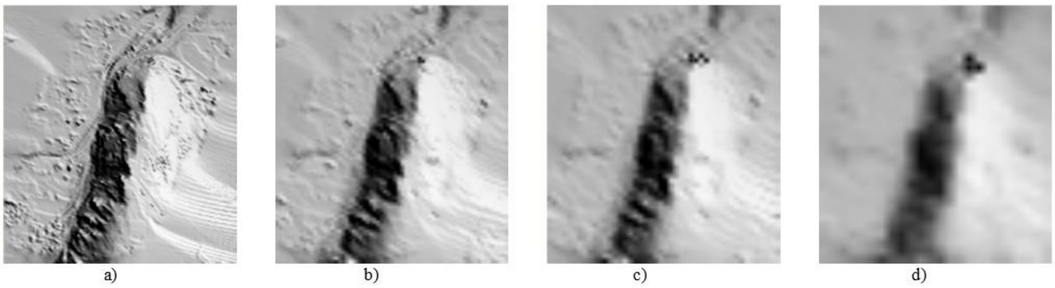


Figure 4. Different resolutions of DEM a)5m b)10m c)15m d)30m

The resample fields shown in Figure 4 are available for illustration only. When determining the drainage network, the external boundaries of the DSM are taken as region of interest (ROI). Outside the ROI, no calculation has been made to avoid misleading the calculation. Therefore, as can be seen in Figure 4, the areas outside the ROI have been damaged by extrapolation.

3.3. Watershed Analysis-Drainage Network

Topography is the most important factor in the formation of water flow direction and water collection zones. Water can change its path on topography depending on various reasons (earthquake, erosion, human factors etc.). Changing the direction of water flow, causes the damage of settlements, farmland, infrastructure facilities and living things. In this case, socio-economic activities will be interrupted and the region will lose its functionality. Many hydrological analysis data such as drainage networks, drainage basins, drainage basin water flow direction, water flow length, land slope and water areas can be calculated via DEM data. It was investigated whether the above-mentioned calculations could be made with the use of UAV in less cost, faster and local areas. This study was carried out because the use of UAV for the production of DEM for Watershed Analysis is not common and its effectiveness has not been adequately investigated. These calculations, which should be determined especially in the preparation of city plans, will be carried out via DEM, which is created using UAV in small areas. Also, such numerical data are directly used relationally in the database of the GIS. Thus, city growth and risk maps can be created to prevent possible disasters. DEM data produced in small regions can be combined in GIS database and analyzed for larger areas.

First stage of determination of drainage networks is the identification of basin boundaries along the basin boundary. Along this border, water flows on both sides to the water collection basin. There are various methods for water flow direction such as Deterministic Eight-Node (D8), Random Eight-Node (Rho8), Multiple Flow Direction (MFD), D-Infinity (D-inf) and Digital Elevation Model Networks (DEMON) [15]. The D8 algorithm is a method in which flow is determined in only one direction among 8 neighbors in a 3x3 window. The flow is one-way in the window and low to high value. By determining the flow direction of the cells, it is possible to determine how much the total number of cells travels to any cell. Among the reasons why the D8 algorithm is preferred, the calculation burden, the algorithmic ease and the understandable structure, there is no difference between the determined flow patterns [7].

Cumulative flow model is obtained by creating a water flow direction model. By using the flow model, flow grids are obtained by calculating the total amount of water entering a cell. Using the water flow direction model, the cell flow collection values are calculated starting from the upper right corner. If there is no flow from any cell, the flow value is assigned as zero (0). After the cumulative flow model is established, drainage networks are calculated. In the cumulative flow model, the lower limit value is determined according to the largest cell value. Each cell larger than this limit value is considered to be part of the drainage network. The size of the working area and the working precision while creating the model also affect the size of the drainage network to be constructed. The drainage network has a vector feature and consists of cells on the boundary value. Drainage networks formed by using combined water flow direction and cumulative flow model are main and side distributary. The water flow direction is from the small cell value to the large cell direction [16 and 17].

4. RESULTS

A drainage network can be created from a selected point within the basin boundary, as well as the entire area forming the basin. It is preferred to construct drainage network for the entire area instead of point-based for the study area. The cell threshold value is very important to create a drainage network with the whole area. The selection of a high cell threshold value in the production of drainage network produces rough results. However, the minimization of threshold value is not guarantees expected results. Table 2 shows the total Drainage Network Length of different spatial resolution DEMs with different threshold values.

Table 2. Drainage network length (m) analysis for Hisarcık

DEM Resolution(m)	Cell Size(m)			
	25	50	75	100
5 (m)	13213	9636	7771	6635
10 (m)	6346	3859	3035	2314
15 (m)	3787	2181	1545	1364
30 (m)	1756	884.77	788.71	741.58

Drainage area defines the area of the land where water flows from the surface of the land and falls into rivers, streams or water flow path. Drainage area is an important concept for determining stream length and water collection limits which are varies with the threshold value. Flow accumulation threshold value depending on the resolution of the DEM, it can take different values the test area and according to the application purpose. In this study, 25 m, 50 m, 75 m and 100 m cell sizes were chosen to show the effect of different cell threshold values on drainage network length. In Table 3, DEM data generated at different resolutions are given drainage area values generated using different cell threshold values.

Table 3. Drainage area (m^2) analysis for Hisarcık

DEM Resolution(m)	Cell Size(m)			
	25	50	75	100
5 (m)	402.779	397.731	393.457	391.258
10 (m)	397.886	389.427	389.427	379.558
15 (m)	399.712	388.993	388.993	388.993
30 (m)	407.268	344.78	285.83	285.83

Morphological features such as basin boundary, drainage network, stream length and area of sub-basin can be extracted with data such as DEM. In addition, land profile, geomorphic indices, slope and aspect maps and special catchment regions can be produced with DEM. Such morphological analyzes provide useful information to compare basin characteristics. Drainage network analysis was performed with DEM data generated at different resolutions and drainage networks produced in vector format. The vector format was superimposed on DSM to improve visual quality and better understand the difference of result. Results are given in Figure 5-8.

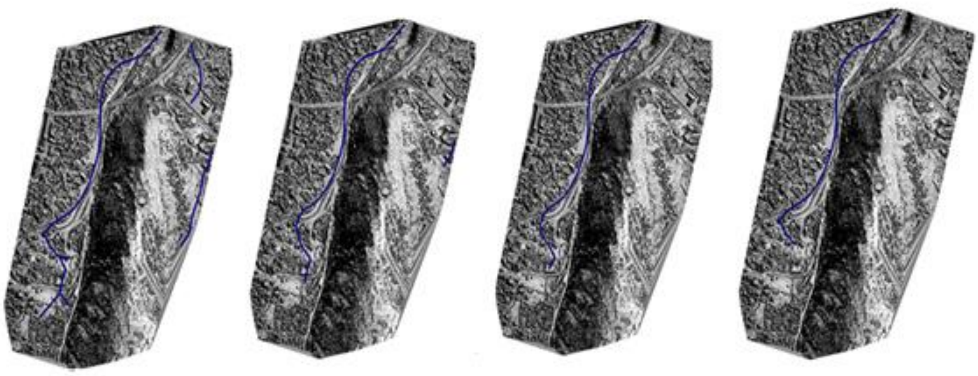

a) b) c) d)

Figure 5. Demonstration of drainage networks with different threshold values on DEM (30m). Threshold; a)25 b)50 c)75 d)100 (m)cell

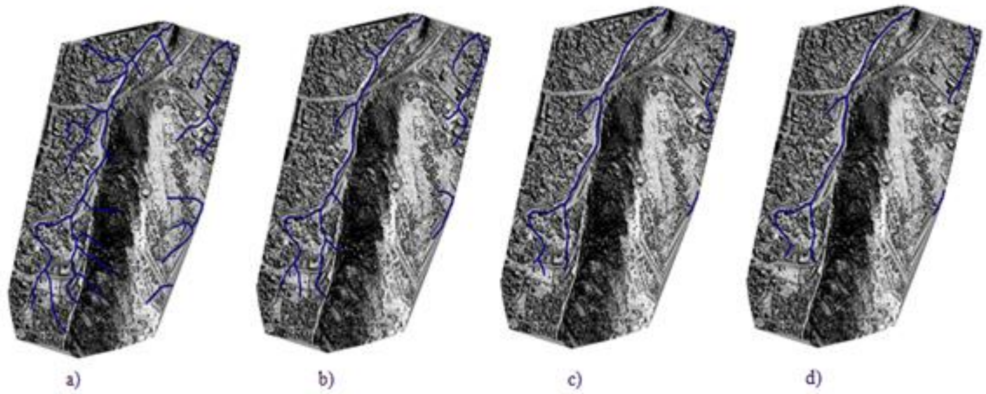


Figure 6. Demonstration of drainage networks with different threshold values on DEM (15m). Threshold; a)25 b)50 c)75 d)100 (m)cell

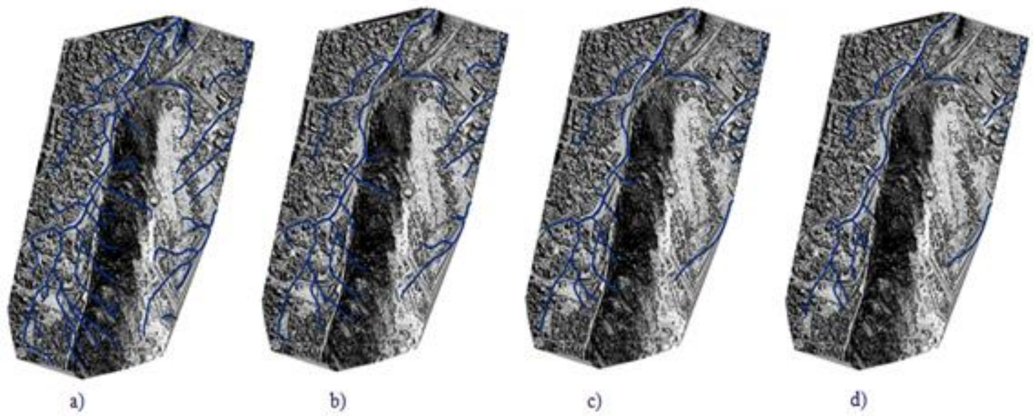


Figure 7. Demonstration of drainage networks with different threshold values on DEM (10m. Threshold; a)25 b)50 c)75 d)100 (m)cell

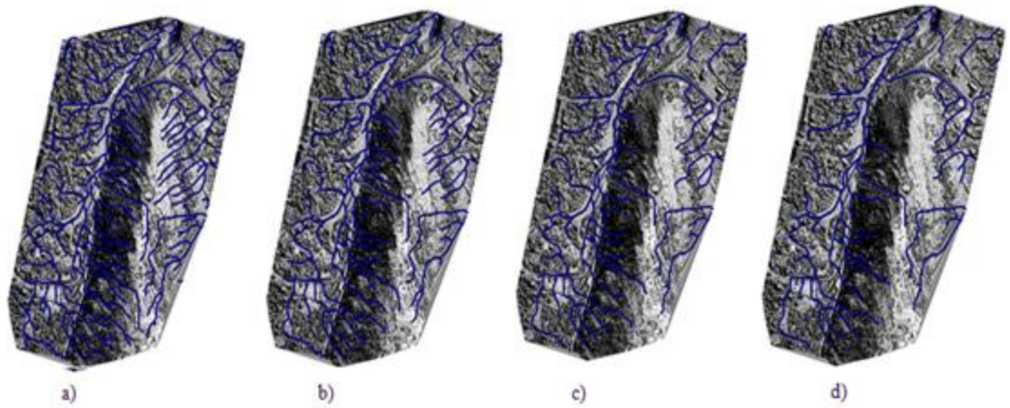


Figure 8. Demonstration of drainage networks with different threshold values on DEM (5m). Threshold; a)25 b)50 c)75 d)100 (m)cell

As a result, the feasibility of watershed analysis is demonstrated by generating DEMs at fast, inexpensive and different resolution using UAVs. The DEM obtained in this way provides faster, more objective and more reproducible measurements than conventional methods. While city plans are being prepared to prevent natural disasters and build livable cities, it is necessary that the residential/workplaces should not be prepared in the direction of water flow and drainage networks used as an input in determining landslide areas. The data generated by this approach has the advantage of being easily identified and analyzed by GIS. Thus, while smart cities are being established and existing cities are revised, watershed areas with an input for analysis for risk of natural disaster such as floods, landslides and erosions are identified. As a result of the study, the effect of the flow accumulation threshold values applied to the DEMs produced at different resolutions was observed. There are too many methods to change the resolution of DEM data. It is possible to determine the most appropriate method for the application with personal observations and analytical solutions. Due to the fact that economic and highly accurate data can be generated in a short time with UAVs, drainage network deformations and shearing effects can be observed. Especially in small areas such as in this application, different levels of DEM data obtained from different levels of flow accumulation threshold value are applied to the effect of drainage areas and the effect of the formation of drainage networks was investigated. Especially in small areas such as this application, the effect on drainage areas and drainage networks were examined when different flow accumulation threshold value is applied on different resolution DEM data. Finally, the higher the DEM resolution, the higher the spatial resolution, the greater the power to discriminate. In this way, the water flow direction can be better determined and longer drainage networks are obtained.

NOTICE

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