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Reaserch Article

New Approach in Integrated Basin Modelling: Melen Airborne LIDAR

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Abstract

Airborne LIDAR technology which has an increasing importance in recent years, has entered into the field of application of many disciplines by obtaining fast and highly accurate 3D data. It provides precise topography information with dense point cloud data as well as all details on the surface. Thus, it has become useful in all disciplines associated with space such as cartography, construction, city planning, forest, energy, hydrology, geology, transportation, telecommunications, security, disaster, aviation, and infrastructure. By mounting LIDAR measurement units on aircraft large areas can be measured relatively quickly and cost-effectively. In this study, Riegl Q680i scanner and CCNS5 flight management system were mounted to the aircraft. The digital elevation models; DEM (Digital Elevation Model) and DSM (Digital Surface Model) of the Melen basin, which is located within the boundaries of Düzce and Sakarya was generated using LIDAR point cloud data (.las format) with a point density of 16 points/m2 and also 1/1000 base maps of the basin were produced. In addition, many details such as road, slope, culvert, electricity poles were drawn in accordance with the principles of large-scale map construction regulations and transferred to GIS environment. The Melen basin with an important water storage area, boundaries, basin model, water collection lines, determination of flow directions and connections, the topographic surface of the basin sub-areas, morphology were created using 3D laser point cloud data. So, the digital terrain model of the basin in GIS environment is visualized with linear maps. LIDAR data provides 3D geometric and morphological information that cannot be obtained according to classical methods in this kind of engineering studies. Results suggest that the higher spatial resolution LIDAR-derived data are preferable and can introduce more detailed information about basin hydro geomorphic behaviours.

Keywords: Airborne LIDAR, Basin Modelling, Melen Basin

Introduction

The precise representation of Earth surface is fundamental for many aspects of modelling in the natural sciences, in which the detailed reconstruction of a territory is required to simulate different physical processes (Petroselli, 2012) and allow examining both natural and manmade environments with accuracy, precision, and flexibility. Light Detection And Ranging - LIDAR is a technology that is able to generate high density and geometric features of digital elevation data at approximately the same accuracy as the local measurements, but faster than air photogrammetry (Ekercin & Üstün, 2004). Airborne LIDAR technology cost effective measurements of topography (Baş et al., 2018), has rapidly evolved into a state-of-the-art technique for topographic data acquisition, providing Earth-science modellers with the possibility of utilizing high-resolution digital surface/digital elevation models (DSMs and DEMs). In addition to the fact that LIDAR technologies are an alternative to terrestrial measurement methods, they provide basic data sets for many applications (Wehr & Lohr, 1999). Examples of LIDAR technologies utilization could be found in several disciplines such as wetlands dynamics (Jenkins & Frazier, 2010), landslides, erosion and depressions areas (Perroy et al., 2010; Zandbergen, 2010; Kaya & Gazioğlu, 2015), the mapping of buildings and roads (Büyüksalih, 2012; Zhang et al., 2005), among other interested parties is the telecommunication industry that uses information in 3D city models for the planning of locations of antennas (Brenner, 1999; Kirtner, 2000), vegetation monitoring or biomass estimation in forestry sciences (Solberg et al., 2010; Nakajima et al., 2011), coupled fluid dynamics-sediment transport modelling (Nelson, 2019), and water-surface mapping (Yan et al., 2018; Gazioğlu, 2018; Höfle et al., 2009). Many automotive manufacturers perform one of the different applications of LIDAR technology using smaller and lower-range scanners to assist in the navigation of autonomous vehicles.

LIDAR systems typically return a three-dimensional cloud of point measurements from reflective objects scanned by the laser beneath the flight path. In order to generate a DTM, measurements from nonground features such as buildings, vehicles, and vegetation have to be classified and removed (Zhang et al., 2003). LIDAR data is widely used to construct 3D terrain models to provide realistic impressions of the urban environment and models of the buildings. LIDAR provides a promising resource for three-dimensional building detection. Due to the difficulty of removing vegetation, most building detection methods fuse LIDAR data with multi-spectral images for vegetation indices and relatively few approaches use only LIDAR data (Xuelian et al., 2009). The latest airborne laser scanning technology allows the capture of very dense 3D point clouds from the terrain and surface features (Bayram et al., 2016; Lim, et al., 2003; Wehr and Lohr, 1999).

Airborne LIDAR is one of the most effective and reliable means of terrain data collection. Using LIDAR data for DEM generation is becoming a standard practice in spatially related areas (Gazioğlu et al., 2014). However, the effective processing of the raw LIDAR data and the generation of an efficient and high-quality DEM remain big challenges. Coordination and planning of equitable use constitute integrated watershed management, taking into account the sustainability of water resources and other natural resources, vital ecosystems, and increasing social and economic prosperity. As a result of increasing population and economic sector activities, water demand is increasing while as a result of global climate change, a significant decrease in water resources is expected. Considering the growing environmental problems, a comprehensive integrated watershed management planning is required for environmental sustainability. This planning needs to be managed by establishing a strong spatial and temporal relationship. Areas surrounded by natural boundaries controlling hydrological borders are defined as basin. The basin is the most suitable structure for ensuring that all natural resources, in other words, the ecosystem, are used as integrated and sustainable, not only water but also the water that is between the source of a river and the place where it ends. So, the determination of basin boundaries is of great importance for the proper management of water resources.

Similarly, the accuracy of the terrain model used to determine the basin characteristics such as basin sub-areas, water flow directions, and drainage networks affect the accuracy of the basin model. Decision support systems need to be formulated in order to achieve sustainable management of basins. Classical mapping methods are insufficient in terms of process and data density for project of large areas. Airborne LIDAR technology can be used effectively in basin modelling with a wide application area. Digital elevation models (DEMs) generated from LIDAR technologies are more available in the hydrology, not only for hydraulic applications in all scales hydrologic applications.

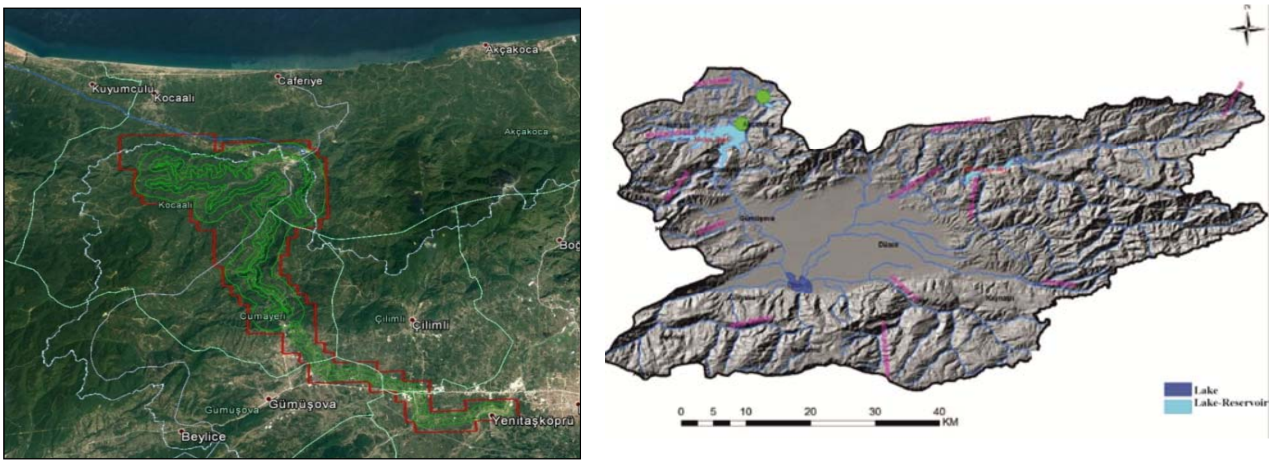


Figure 1. Study area (URL 1).

Study Area

The study area shown in Figure 1 includes the boundaries of the Melen Basin which has total 2 317 km^2. A large part of the Melen River Lower Basin (80%) is located in the province of Düzce and its districts, except for Akçakoca. Nearly all the districts of Düzce Province are located within the boundaries of the basin except for Akçakoca. A small part of the Akçakoca District (constituting 3% of the whole basin) is in the basin. Land use of the Melen basin; 52% of the basin is forested and 26% is grassland and pasture and 18% is agricultural. The potential of surface water resources of the Melen River Sub-Basin is ~1.6 billion m^3/yr. The most important aquifer in the basin is the alluvium of the Düzce plain and has a very wide spread area. Total alluvium thickness is over 200 m. There are pressurized aquifer zones under the upper free aquifer. The groundwater operating reserve of the basin is determined as 120 hm^3/yr (URL 1).

After the completion of field works (ground control points and control areas, GPS and total station measurements), airborne LIDAR data acquisition was started. Laser point density 16 points /m2, 400 kHz laser data frequency, average flight height 500m, 60° angle of view, 80-knot flight speed, 50% longitudinal overlap LIDAR flight lines were formed during the LIDAR data acquisition process. Laser coordinate and intensity values obtained during the flight, GPS-IMU values and digital camera images were stored at disks for data processing and so moved to the office environment.

Airborne LIDAR Systems

The Laser scanner, camera, IMU (Inertial Measurement System) and GPS receiver are used together with an aircraft. An intense, high-accuracy data set is obtained by together balancing the laser signals and turns, GPS signals, IMU and ground stations data. This las data set is then divided into relevant classes of land such as ground, vegetation, and building. LIDAR measurement systems are mounted on a Helicopter Bell Bell Ranger 206 type with a POD. The Riegl Q680i laser scanner scans the area in parallel scanning lines because of the rotating mirror. The wavelength of the laser is infrared (1064 nm) and the beam divergence in the spectrum is less than 0.5 mrad and the scanning speed can reach up to 200 scan lines depending on the flight planning. The GPS device in the system can receive L1 and L2 band GPS and GLONASS signals. It is mounted on the tail of the helicopter to prevent signal interruption. IMU device measure the angular (ϕ, ψ *and* ω) and positional (x, y, z) changes of the aircraft with its gyroscope and accelerometers. The SMU (Sensor Management Unit) includes flight plans, IMU recording units, and the flight is managed by this unit. IGI's 60 Megapixel digital camera was used to create orthophoto images. In our project, a 50 mm focal length lens and 8956x6708 pixels colour images with pixel size of 6 mm were obtained and total image data approximately 250 GB. A data of 300 to 350 GB normally recorded for an average of 6-hour flight daily. Figure 2 shows component of the airborne laser system.

Laser Point Cloud Pre-Process Steps

LIDAR softwares can be divided into two categories: pre-processing software and post-processing software. The pre-processing software is mainly used by data providers. This type of software is capable of visualizing the point cloud quickly and effectively, adapting the geoid and coordinate systems and supporting various output formats. The post-processing software is supposed to have diverse data processing and information extraction functions; however, the core function is filtering the point cloud into the ground and non-ground returns (Chen., Q, 2007). After the point clouds are classified, the ground returns can be used to generating a DEM. The canopy returns can be used to extract forest structural information, and the building returns can be used to model the building shapes. The first stage of the LIDAR data evaluation process is the evaluation of GPS / IMU data and the creation of trajectory. Thus, X, Y, Z position information and roll, pitch, yaw angular orientation of LIDAR flight lines are calculated. The flight trajectory on the basin are shown in Figure 3.

Figure 2. Data acquisition system – LiDAR.

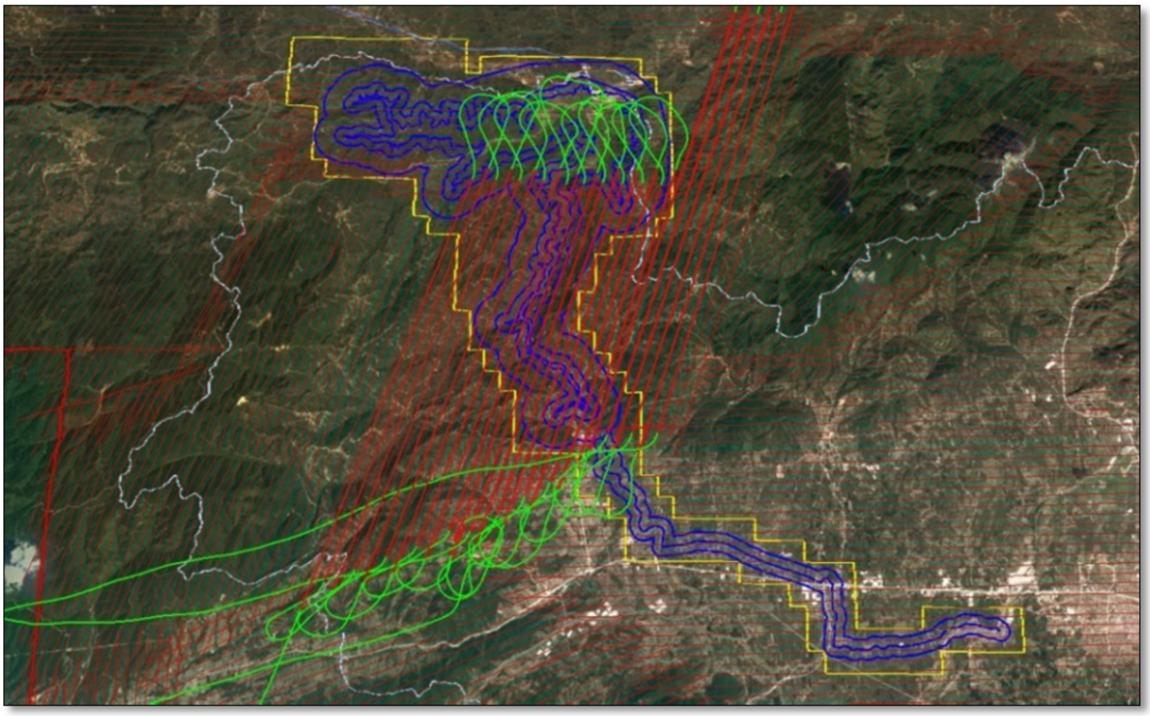


Figure 3. Trajectory data

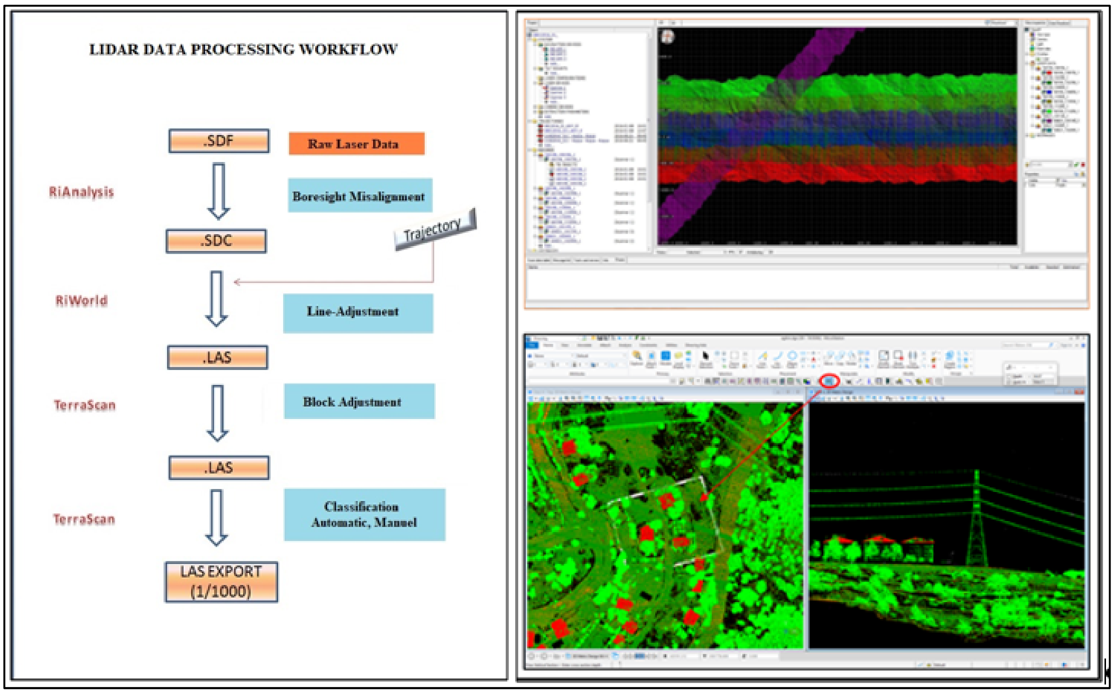
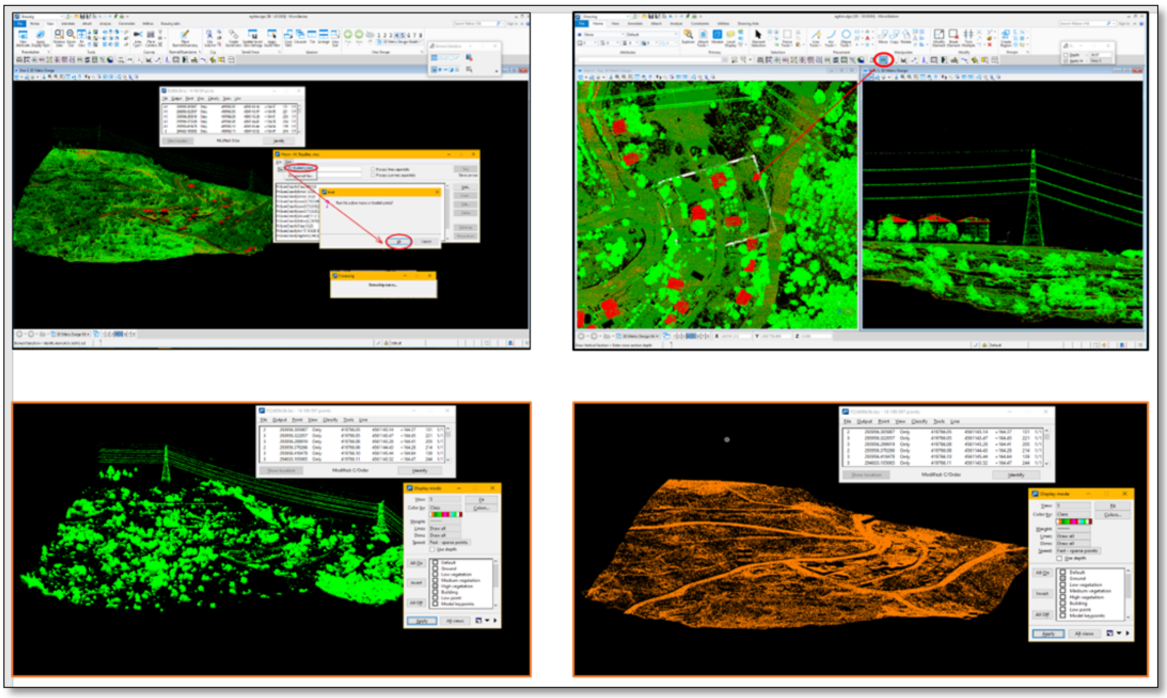


Figure 4. LIDAR data pre-processing steps



Figure

Figure 5. Classification steps

Raw LIDAR point cloud data (SDF format) was pre-processed in RiAnalyse software. At this step, laser pulses and full wavelength analysis were done ready for the next step. In this analysis, data is obtained in SDC format. This step is followed by the boresight misalignment phase. After the Boresight values are obtained column stabilization is performed. Balanced LIDAR flight columns are created in RiProcess software using undulations parameters. The data converted to orthometric height are exported las format in the form of flight stripe and saved in the respective folders. The LIDAR data pre-processing and the column balancing step are shown in Figure 4.

The absolute accuracy analysis of the LIDAR data is performed in at least 2 regions for each trajectory in the field using the flat area and the control points taken from the building roofs. At this step, it is mainly used to determine the control areas of playgrounds, school gardens, and asphalt roads. The horizontal and vertical accuracy values are calculated by comparing LIDAR point cloud and control points.

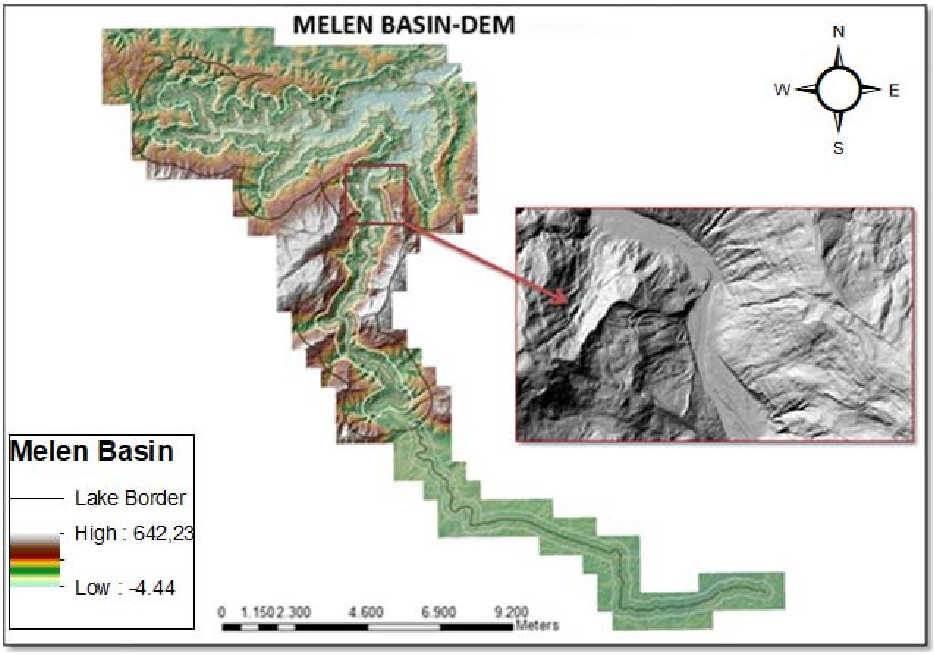


Figure 6. DEM- Melen basin

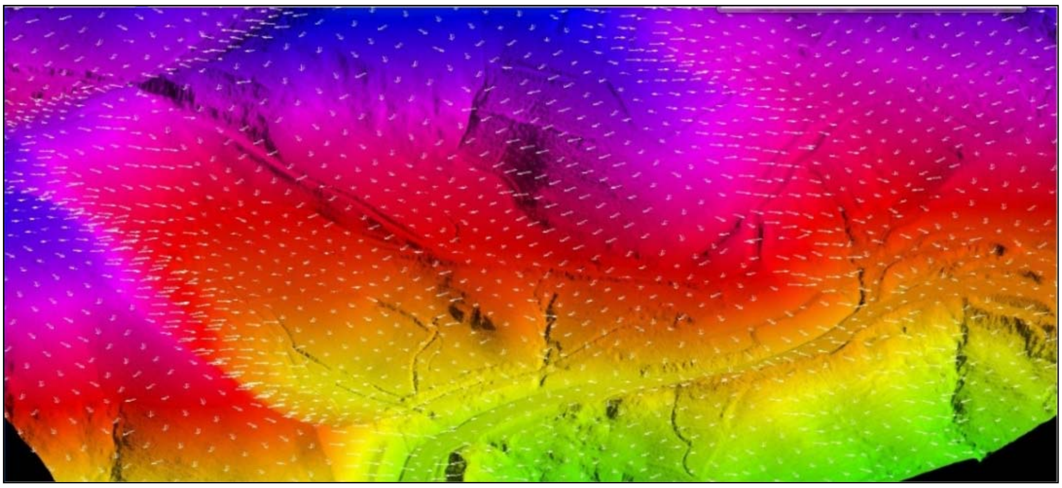


Figure 7. Slope map

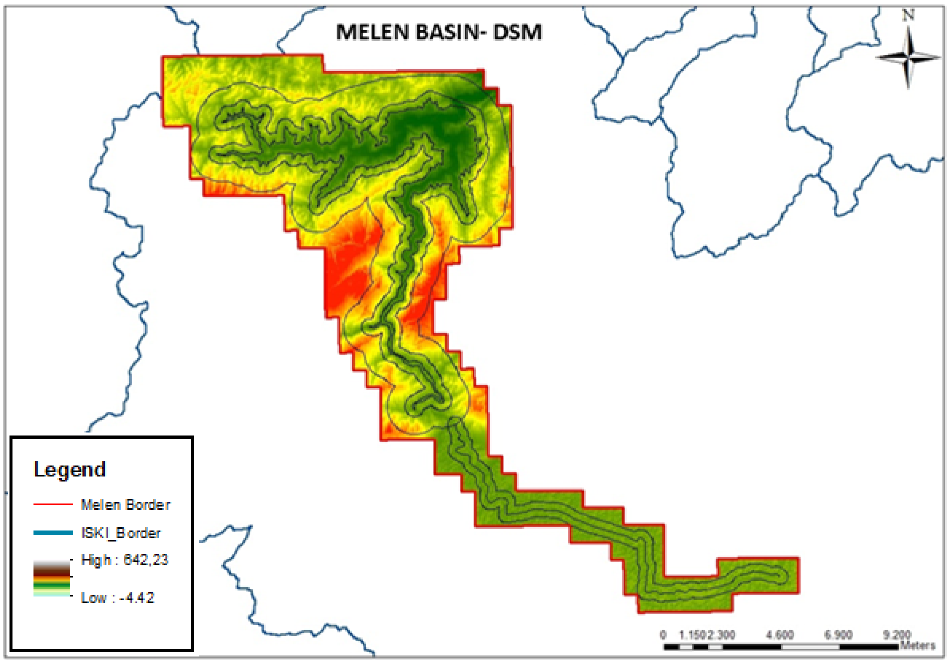


Figure 8. DSM-Melen basin

Laser Point Cloud Post-Process Steps and Products

The Melen basin area consists of 395 units of 1/1000 scale maps. 1/1000 scale base map of this area is produced by using balanced and classified las data, digital elevation model, digital surface model and contour line. The LIDAR data in las format contains millions of points and each points is reflected from the object on earth. The classes to which these points belong must be determined in high accuracy. This process can be done through two methods: automatic and manual. These points are automatically classified using macros and based on a certain algorithm. For the earth that does not have a standard structure, 100 % accuracy cannot be achieved by using a certain standard macro. Figure 5 shows the classification process of las data obtained using the terraScan module of terrasolid software and the control processes performed by sectioning.

The point cloud provided by LIDAR technology is classified in the microStation software and divided into non-ground and non-location points. After the point cloud data classification processing, DEM, DSM and nDSM (normalized surface model; including only vegetation, trees, buildings on the land) height models were produced using TerraModeler software. The nDSM product is mainly used as the basic data for the determination of tree lengths, trunk diameters and timber volume in forest management. Figure 6 is a digital elevation model created using the ground data of the basin area, and Figure 7 shows the basin slope map obtained using DEM data. Figure 8 shows the coloured surface of the basin area (DSM).

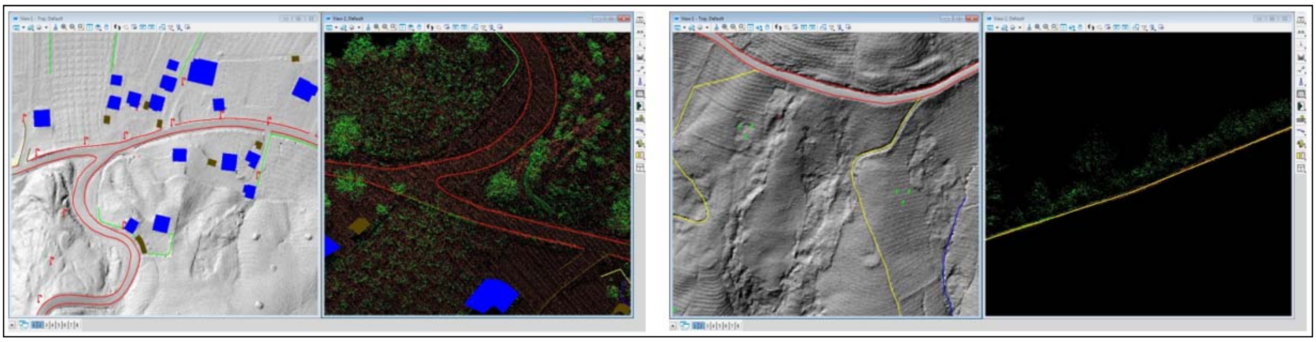


Figure 9. Drawing of roads and paths

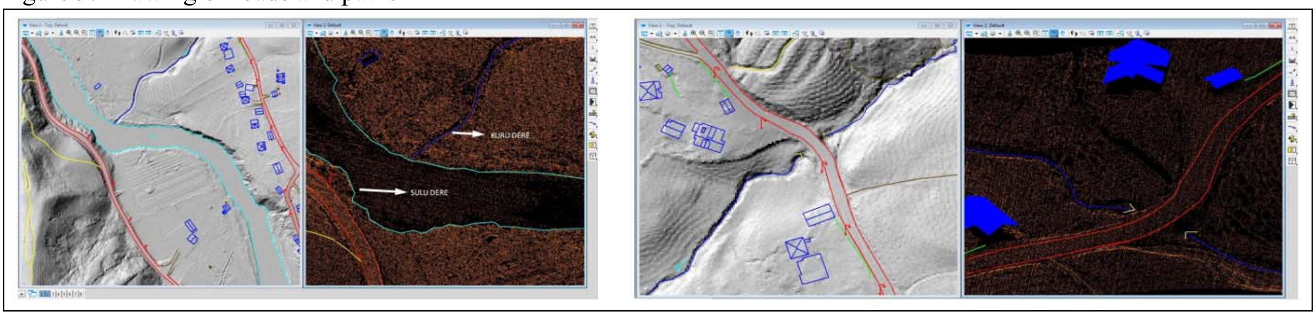


Figure 10. The Drawing of river and streams

The base map includes information such as map height, curves, buildings, natural water resources, streams, seas, forests, sub and superstructure projects, art structures, cadastral plots. This level of information content can be obtained from the LIDAR data and provides the minimum position accuracy values expected from the map. The digital images taken with the LIDAR data are used for the correct interpretation of the objects. The building can be obtained automatically from the LIDAR point cloud which has been completed and then 3D building vectors can be created. These buildings can be used as a residential, commercial, school, religious facility etc. by using existing base maps or field information or can be divided into layers. Buildings in the basin area were produced at the LoD2 level and 3D CAD and solid models were generated. The classification accuracy of the building class in LIDAR point cloud data is important at this stage. The accuracy of the building class, which is automatically obtained by using macros, is increased by taking small sections and making visual analyses. 3D CAD models of automatically vectorised buildings can be developed with 3D editing and exported in CityGML format. Asphalt and soil roads are double lines; the ground roads are as a single line and digitized separately (Figure 9). Similarly, bridges, viaducts and forest borders are drawn in 3D. If there is no agricultural area around it, as forest boundary, the agricultural area is indicated as property limit. In order to determine the property boundary, it is necessary to extraction the ground class and use a high vegetation class to draw the boundaries.

The large river, wet and dry streams are drawn according to the direction of flow of water. At the same time, the CAD drawings of the slots can be formed as shown in Figure 10.

By using the medium vegetation class, wire mesh and fences in urban areas are determined and their drawings are made on the ground class. High voltage lines are determined by taking sections in high vegetation class and pylon symbol is placed on ground class. Then the lines between the pylons are combined and the symbol is defined on it. Medium voltage lines (transformer), electricity poles, GSM stations are also determined by taking the cross-sections of high vegetation class. According to the large-scale map construction regulation, the contour lines are drawn intervals 5 m in a 1/5000 scale, 2 m in a 1/2000 scale, 1m in a 1/1000 and 1/500 scales indicating the roughness of the terrain. Contour lines do not intersect river, channel, road etc., with the closed details, slope borders so on with double stripes details and building. An example of a 3D base map containing the contour lines is shown in Figure 11.

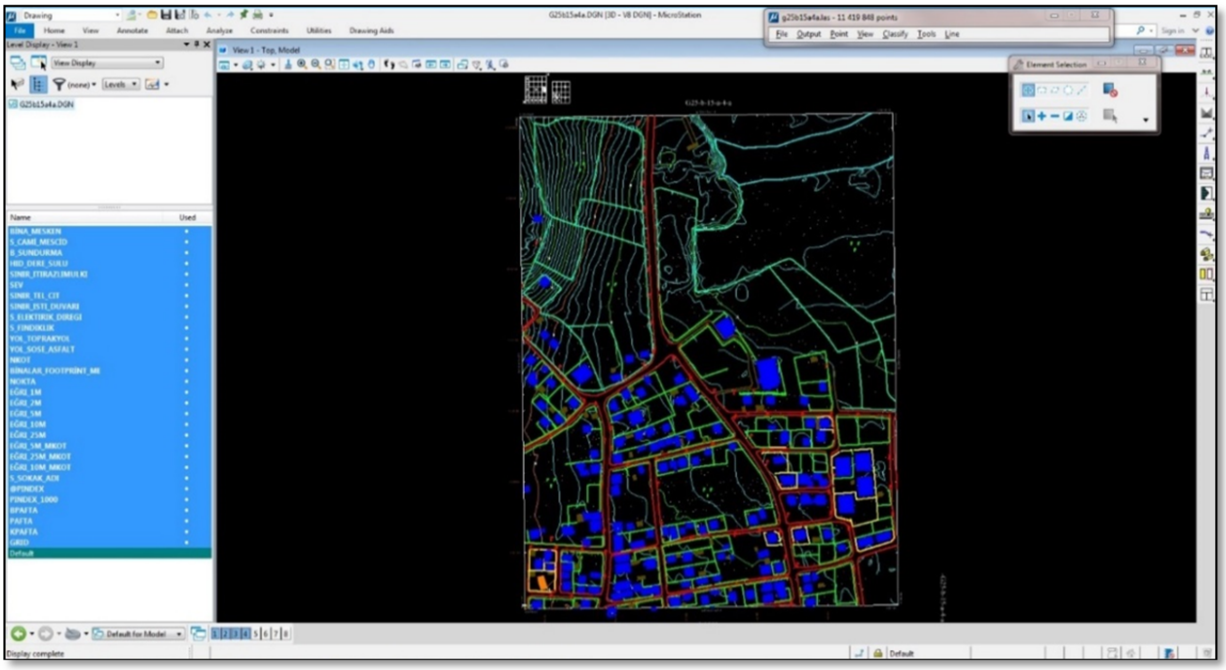


Figure 11. 3D base map

3D Basin Modelling

The basic modelling principles that we have followed, including the analytical equations considered for the simulation of the geological processes have been described in detail by Hantschel & Kauerauf (2009). In order to establish the morphological structure of the basin, the water boundaries must be determined first. For this purpose, water flow directions have been determined for each grid on the high accuracy digital elevation model obtained from airborne LIDAR data. The basin outer boundaries were extracted from these flow directions, then the drainage network was determined and the lower basin was formed (Figure 12).

In the determination of the drainage network, flat area, sudden height change, and obstacles to flow direction should be taken into consideration. While this problem is present in the digital terrain model obtained by classical methods, it is seen very little in the surface model obtained from airborne LIDAR data. Flow accumulations calculated after faulty pit formation and peak value correction. For this, flow rates corresponding to each cell were calculated according to the flow direction of the grids on the flow directions model. Flow direction and flow accumulation model are used to calculate basin boundaries, drainage networks, and sub-basin boundaries. The process of extracting the basin characteristics is given in Figure 13.

3D digital surface model of melen basin was formed by using all classes of point cloud data. The foundation of a decision support system for integrated basin management was prepared with the basin characteristic details calculated using this model. Figure 14 shows the drainage networks on the 3D DEM data of the basin. Figure 15 illustrates drainage networks in DSM data including trees and other objects.

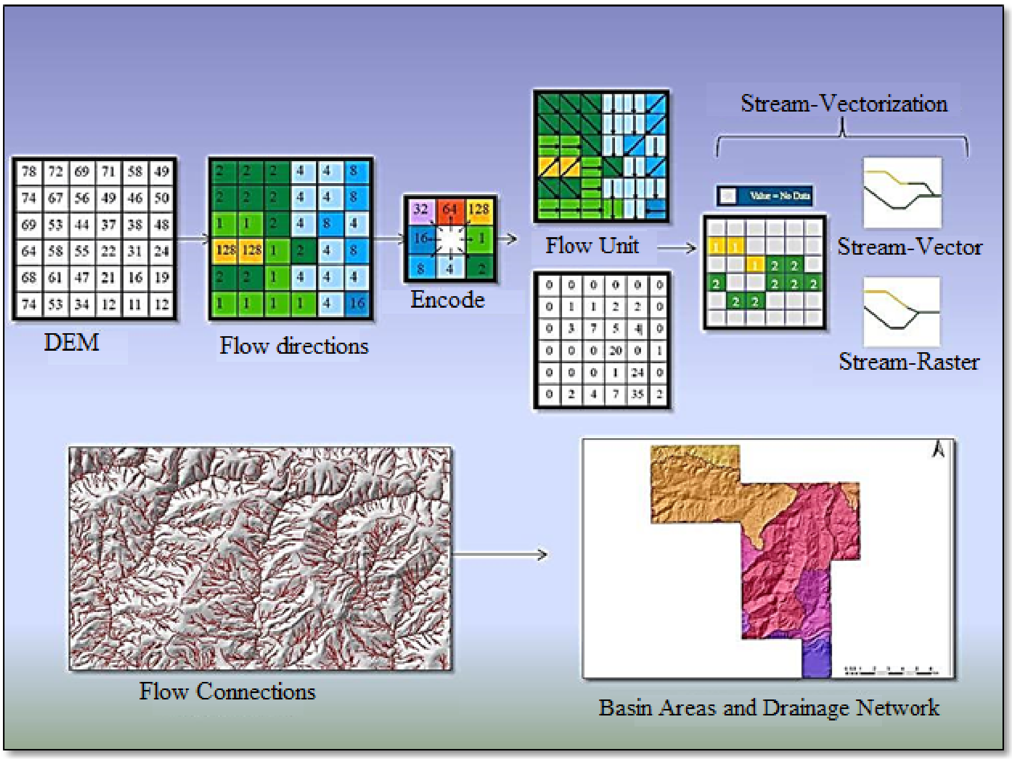


Figure 12. Drainage network workflow.

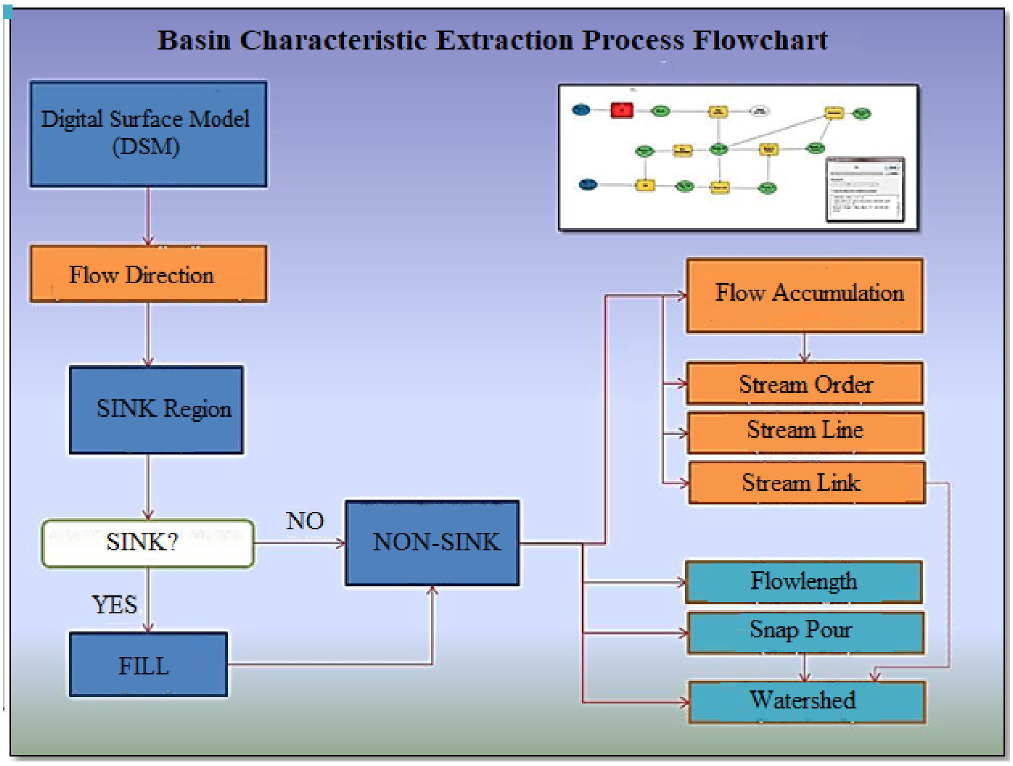


Figure 13. Basin characteristic flowchart.

The ground class is used in the calculation of the aspect map which is one of the important functions of the basin characteristics (Figure 16). The four main directions and the intermediate directions are calculated as angular spaces formed according to the north angle. As a result, the north, south, east, west and mediate directions of the existing slopes are indicated by 25 cm grid intervals. For land use protection and sustainability of soil quality, the planning and control of the precipitation to the surface flow will be a positive contribution to basin management. The ability to control the volume, velocity and slope of the surface flow allows for the analysis of the possibilities of smaller volumes and natural topography, rather than the creation of large volume ponds or reservoirs. The drainage networks formed are grouped according to their hierarchical structures. Designing small reservoir areas in the second and third degree water collection lines and construction design depending on the state of the surface gain a different dimension in terms of basin water management.

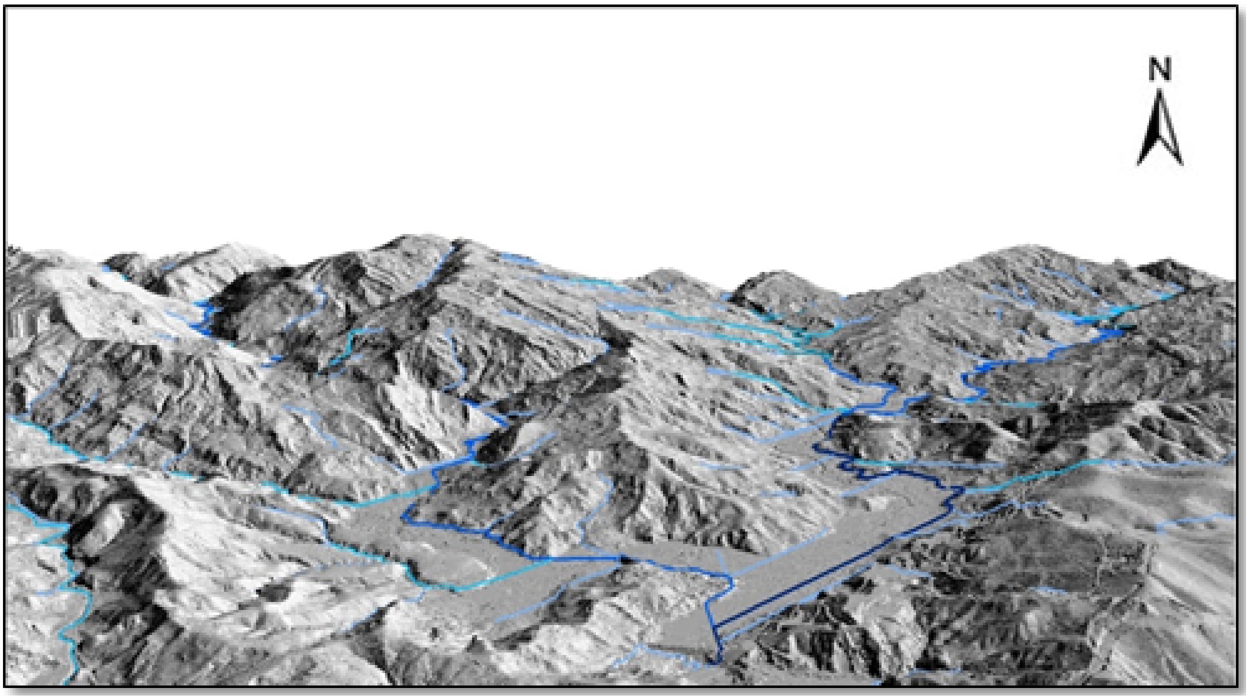


Figure 14. 3D DEM and drainage networks.

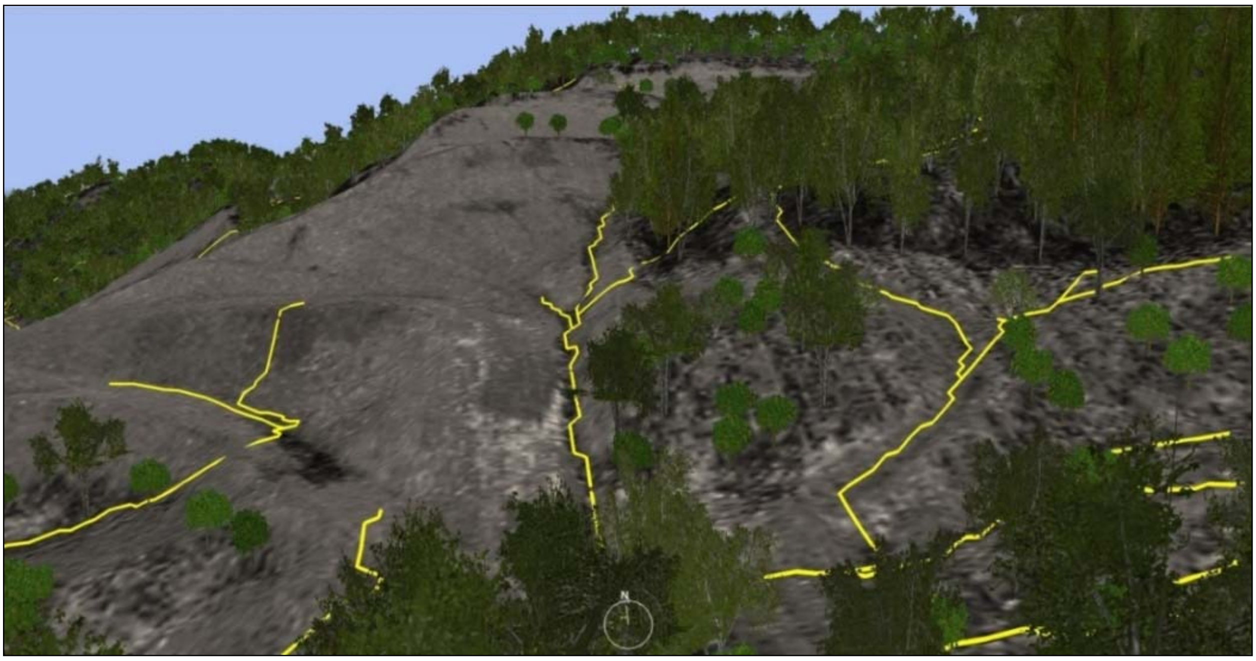


Figure 15. DSM and drainage networks.

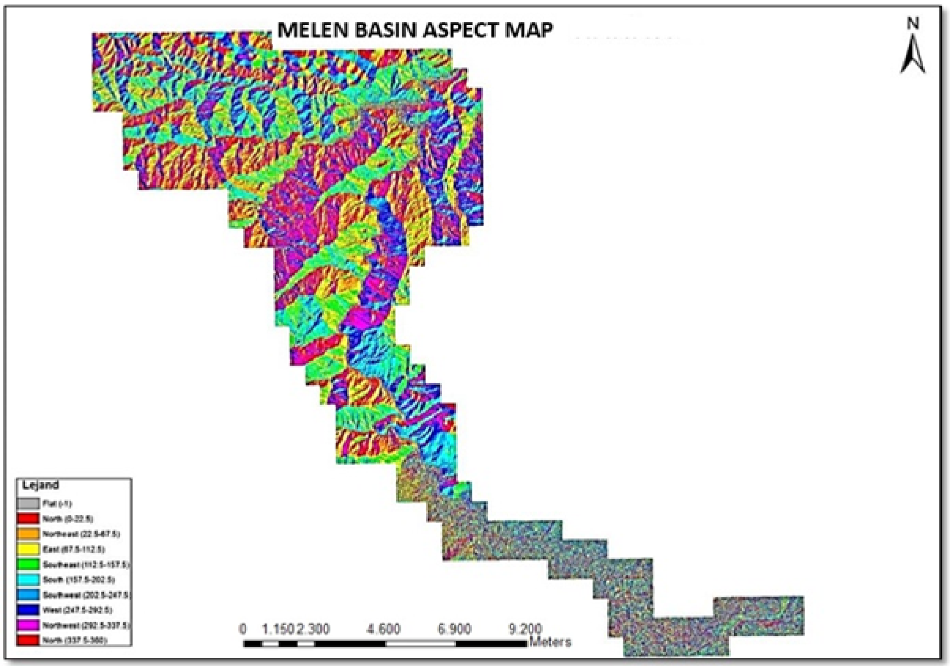


Fig 16. Aspect map

Conclusion

In this study, water flow directions are shown which play an important role in demonstrating the basin area using digital elevation model and drainage networks. With the precision digital elevation model, flow directions and drainage network representations for the basin area were also observed to be fast and accurate. The use of DEM data in the GIS environment will ensure that data is always easily accessible in the watershed areas. This study has demonstrated that the enhanced precision and resolution of LIDAR data compared with traditional DEMs, can improve our understanding of how a landscape forms and evolves. LIDAR-derived DEMs are becoming increasingly available in the hydrology and hydraulics area. Integrated water resource management requires a wide range of resources and a strong knowledge infrastructure than various sectors in both planning and implementation. The determination of basin areas in the integrated basin management and the land model created are critical for hydrological applications. Classical mapping techniques could not provide sufficient accuracy and precision to obtain terrain model. The widespread use of LIDAR technologies has brought a different perspective to the studies in this field. Basically, digital photogrammetry, stereo satellite imagery, available maps, radar interferometry, and LIDAR technology are used in the production of land models. Airborne LIDAR technology is the perfect data for the extraction of all details with full-wave form capability for studies such as obtaining difficult access areas and sub-forest topography. In particular, waterworks and embankments must be extracted from LIDAR data and superimposed onto DTM as hard break lines in order to describe correctly the continuity of these structures. The digital topographic surface model, line maps, the slope map for the 3D basin modelling, which is generated by using laser data with high densities, contributes incomparably to the classical methods in terms of both information content and geometric accuracy.

This study demonstrates that LIDAR technologies have made significant progress in becoming a valuable tool in the process of morphological inventory which is very important in basin modelling. At the same time, the high resolution digital elevation models (DEMs) produced by LIDAR technology will be widely used in different scales in hydrology and basin modelling application.

Various applications can be developed to connect improperly disconnected flow paths or streams in a DEM with methods such as a bridge or a pathway to be developed by means of LIDAR technologies. It is considered that this development will benefit the detection of hot spots which may be a problem on the basis management. The most important one of the fields of use of LIDAR technology is the bathymetric mapping and it is considered that mapping the depths of the rivers, which are often neglected in basin mapping, will contribute greatly to the solution of many hydraulic problems of the basin. It is obvious that if employees play a more active role in hardware and software development, they will also contribute to the improvement of data quality, especially in terms of resolution.

Terrestrial surfaces due to urban developments are rapidly transmitted to natural stream channels or man-made ditches and culverts of sewerage systems, damaging the stream ecological system and threatening public health. The most important responsibility of modern urbanism is the production of the hydrological risks of these natural and man-made elements. In this context, fast, safe and high resolution analyses are needed in the regions where the cities are in the demand for growth. Although it is not possible to determine the full spectrum of all basin features by LIDAR technologies, this study offers the possibility of using

LIDAR technologies in the Basin Mapping. This study confirmed that LIDAR technologies will be widely used in the production of forest covered basins which are not suitable for aerial photography.

The UAVs are widely used in geographies where existing remote sensed data is limited, particularly for on-site inspection or for the purpose of providing data generation for high-risk areas. The use of UAVs combined with LIDAR technologies, the ability to provide high spatial and temporal resolution data for small-to-medium-sized geographic scopes, transforms the discipline of remote sensing, in particular, to economic and logistical reasons.

The increasing popularity of machine learning results in more widespread automation systems. The use of LIDAR technology in the automotive industry indicates that similar contingencies will become more widespread in urban life in the near future.

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