HYDROLOGIC AND TOPOGRAPHIC PARAMETER DETERMINATION OF THE WATERSHEDS - A CASE STUDY FROM TURKEY

Dursun Zafer Seker[1], Ugur Alganci[1], Sinasi Kaya[1], Bahadir Celik[1] and Aysegul Tanik[2]
[1]ITU, Civil Engineering Faculty, Department of Geomatics Engineering 34469 Maslak Istanbul, Turkey
Email: (seker, alganci, kayasina, bcelik)@itu.edu.tr
[2] ITU, Civil Engineering Faculty, Department of Environmental Engineering, Maslak 34469, İstanbul, Turkey
Email: tanika@itu.edu.tr

KEY WORDS: Remote sensing, GIS, watershed, hydrologic parameters, topographic parameters.

ABSTRACT: In this study, topographic, hydrologic and land use/cover parameters of Melen Watershed, Turkey, were determined using remote sensing and GIS techniques. Melen Watershed located in Duzce Province supplies an important amount of water demand of the megacity Istanbul. Initially, height, slope and aspect maps of the watershed were determined using ASTER GDEM v2 DEM data. Then, flow accumulation, flow direction and synthetic drainage network information were extracted using a hydrologic modelling tool in GIS environment. All these data were used to determine sub-basin characteristics of the watershed and three sub-basins were extracted with their boundary vector data. Lastly, land use/cover maps of the basin were produced from 2010 and 2015 dated Landsat satellite images multi-temporally using supervised classification method. The study aims to provide basic geospatial data on the watershed of concern that may further be used in the watershed modelling studies and in defining the watershed according to its characteristics.

1. INTRODUCTION

Accurate delineation of a watershed and precise determination of the topographic watershed parameters provides valuable information for effective management of watersheds in a sustainable manner. Such vulnerable environments are of utmost importance, as is the case in the selected watershed of concern, due to its important water resources from where water is abstracted for drinking purposes. In order to keep the water resources from any pollution threat, surrounding land resources and receiving water movements on the land till they end in the main water body need to be carefully examined. Topographic parameters such as height difference, slope and aspect have great impact on the hydrological processes of a watershed and/or sub-watersheds. Moreover, flow accumulation and flow direction information derived from these topographic data makes it possible to construct synthetic drainage networks and to define the corresponding hydrologic sub-basins.

Land use / land cover (LULC) properties of the water basins have also influence on the hydrology and on the other environmental characteristics. Precise documentation and illustration of the available, obtained and produced data form the watershed information system which may further be utilized as input data for watershed modelling studies. At this stage, two modern tools of technology, GIS and Remote Sensing (RS) technologies play a significant role. GIS is a useful tool during the design, calibration and calculation steps in watershed modelling. Actually hydrologic models concern with surface run-off while GIS brings out valuable aspect to these models by providing representations of the spatial information of the watersheds (Bakir and Xingnan, 2008). Moreover, RS platforms provide necessary data for the determination of all the above mentioned parameters. Digital elevation models (DEM) derived from satellite images are used for hydrologic and topographic parameter determination while multispectral mono images are used for LULC determination in a fast, accurate and reliable way compared to classical terrestrial methods (Kumar and Singhal, 1999; Yuan et al., 2005; Cheng et al., 2006; Dudhani et al., 2006; Saraf and Kumar, 2006; Daniel et al., 2011; Erturk et al., 2012).

1.1 Aim and Scope of the Study

Melen Watershed is determined as the major water resource that can compensate Istanbul's water demand in the future. In the Istanbul Water Supply and Wastewater Disposal Master Plan (IMC, 1999), it is estimated that more than 52% of Istanbul's water need will be provided from the Melen System after 2010. Great Istanbul Drinking Water 2nd Stage Project of Melen System is now being carried out by the State Hydraulic Works (DSI) to supply water to Istanbul. As the subcomponent of the Melen System Project, Büyük Melen Watershed Integrated Protection and Water Management Master Plan is an integrated management system aiming to protect, improve and maintain the water quality of the Melen River. It is estimated that Istanbul's population in year 2040 will reach to 17 million and thus, the annual water demand will be 1997 hm³. The project has been prepared by DSI and the construction works started in 2001. The 1st stage is put into operation in October 2007. Since then, water is transferred to Istanbul via Melen Regulator by means of a pipeline that is 105 km in length. 700 000 m³ water is now supplied daily to the megacity. The 2nd stage involves the Melen Dam that will store 694 million m³ of water. Its construction will be completed towards the end of 2016.

The main focus of this study is to delineate the Melen Watershed, its sub-basin boundaries and synthetic drainage network, produce topographic and hydrologic parameter maps and detect the LULC changes in the basin between years 2010 and 2015. Results of this study aims to provide valuable and up- to- date spatial information of the basin which subjected to changes after the realization of the 1st stage of the Great Melen System project. Provided information certainly can be used as a basic geospatial data for further complex hydrologic analysis that usually supplies feedback and input data to modelling studies.

2. STUDY AREA

Melen Watershed located at the western part of the Black Sea Region (latitudes 41° 5' 00" N to 40° 40' 00" N and longitudes 30° 50' 00" E to 31° 40' 00" E) covers a total area of 2,437 km^2. Majority of the watershed lies within the administrative boundaries of the Duzce Province, while the remaining areas fall in the provinces of Sakarya, Bolu and Zonguldak. On the other hand, almost all the Duzce Province, except for the Akcakoca District, is included in the Melen Watershed. Part of Akcakoca falling within the watershed constitutes just 3% of the watershed. The geographical location of the watershed is given in Figure 1. The overall topography of Melen Watershed is comprised of mountains, plain and plateaus. Duzce Province is located in the west of the Black Sea Coast Mountains. Duzce Plain having an average altitude of 130 m is roughly a square with an area of 360 km^2 (23 km east-west and 20 km north-south) and is filled with alluvial accumulations suitable for agricultural activities.

Figure 1. Geographical location and satellite view of the Melen Watershed (image data ©2016 Google)

3. METHODOLOGY AND DATA USED

In this study, 2010 dated Landsat 5 TM and 2015 dated Landsat 8 OLI satellite images were used for LULC classification. Imaging period was selected as summer – beginning autumn in order to delineate the different land use/cover information successfully. The ASTER Global Digital Elevation Model (GDEM) v.2 was used for the topographic and hydrologic parameter analysis. According to a validation report prepared by Tachikawa et al. (2011)

horizontal and vertical accuracy of ASTER GDEM is approximately between 6.1m and 15.1m on a global basis.

3.1. Pre-processing of Satellite Images

Landsat series satellites are delivered as Level 1T terrain corrected imagery by USGS which means that these images mostly do not need to be geometrically corrected. However, radiometric calibration was applied to images and they were converted to TOA reflectance in order to minimize the illumination differences due to seasonal variations in the two inspection dates. Satellite images were then subset to acquire the images of watershed borders.

3.2. Topographic Parameter Determination

Topographic parameters of a watershed play an important role in understanding the hydrological progress of a basin. Slope parameter is an important factor that affects the surface run-off. Run-off tends to increase due to increment in slope if geology and soil properties are considered as persistent. Aspect is another factor that affects the run-off. Water demand of vegetation and humidity characteristics of the soil are subject to change due to aspect of the terrain; thus, changes the surface run-off. Moreover, aspect and slope together determines the drainage network that in turn characterizes the hydrologic structure and are used to produce flow accumulation and flow direction data (Alganci et al., 2008).

Slope and aspect data were produced from ASTER GDEM elevation data. Sink filling process was applied to DEM data in order to minimize pits and ponds that can occur at production and interpolation steps of DEMs (Ashe, 2003). After sink filling, slope and aspect data were produced in GIS environment as shown in Figure 2.

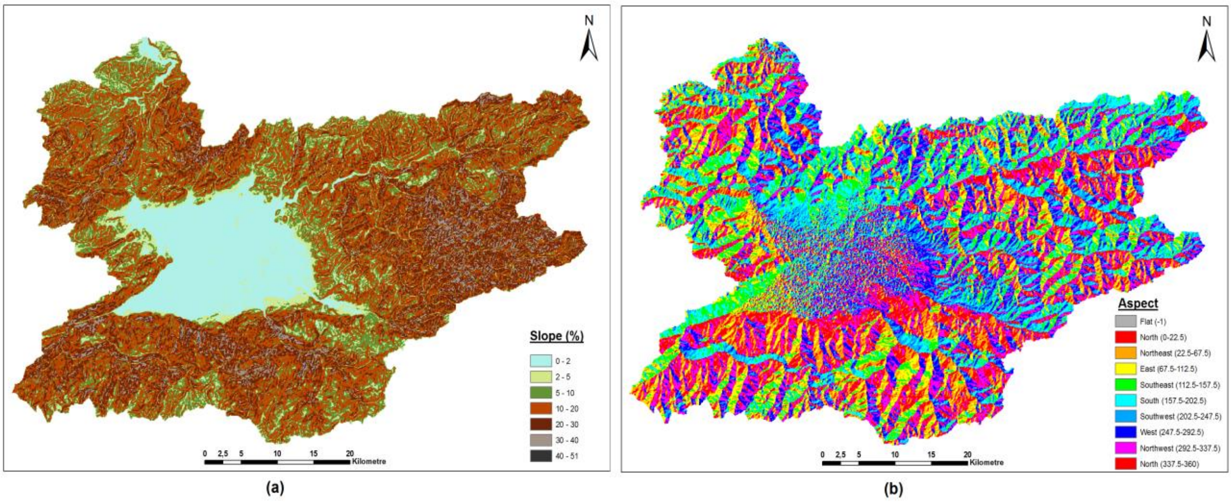

Figure 2. Topographic parameter maps from ASTER GDEM a) slope, b) aspect

3.3. Hydrologic Parameter Determination

Flow direction map was computed by calculation of the steepest slope and by encoding the eight possible flow directions into each cell towards its surrounding cells. Then, flow direction data was used to generate the flow accumulation map. On the other hand, the flow accumulation map was generated by addressing each cell of the DEM, and by counting the number of upstream cells that contribute to that cell (Hammouri and El Naqa, 2007). Figure 3 shows the flow direction and flow accumulation maps of the watershed generated according to the mentioned pathways.

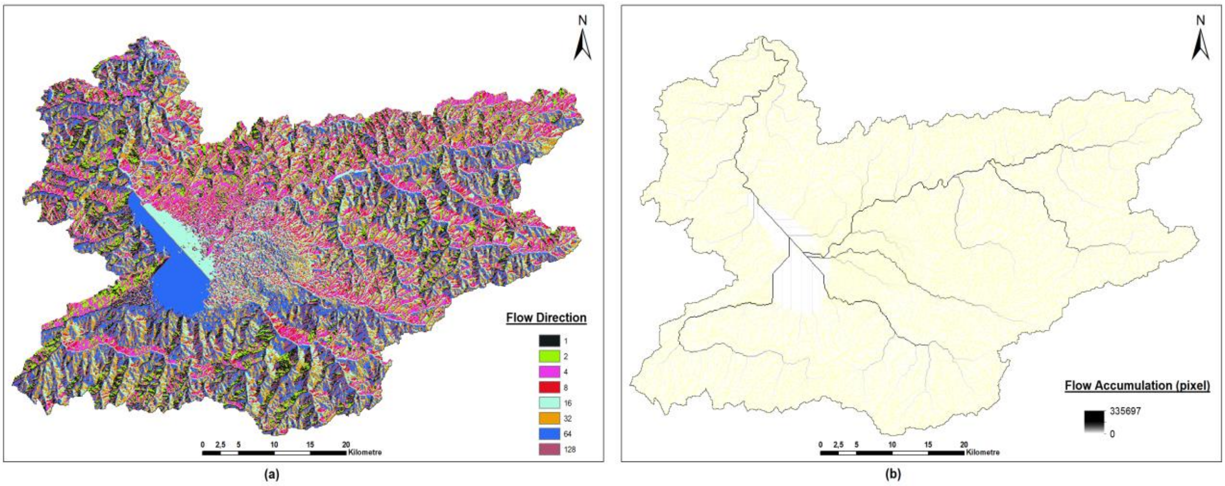

Figure 3. Hydrologic parameter maps a) flow direction, b) flow accumulation

3.4. Drainage Network and Sub-basin Delineation

Flow direction and accumulation maps were then used to delineate the stream network. Possible outlets were determined with the use of DEM and synthetic drainage network and sub- basins were determined according to the outlet and pour points. Figure 4 illustrates these produced outlet points, synthetic drainage network and the corresponding three sub-basins.

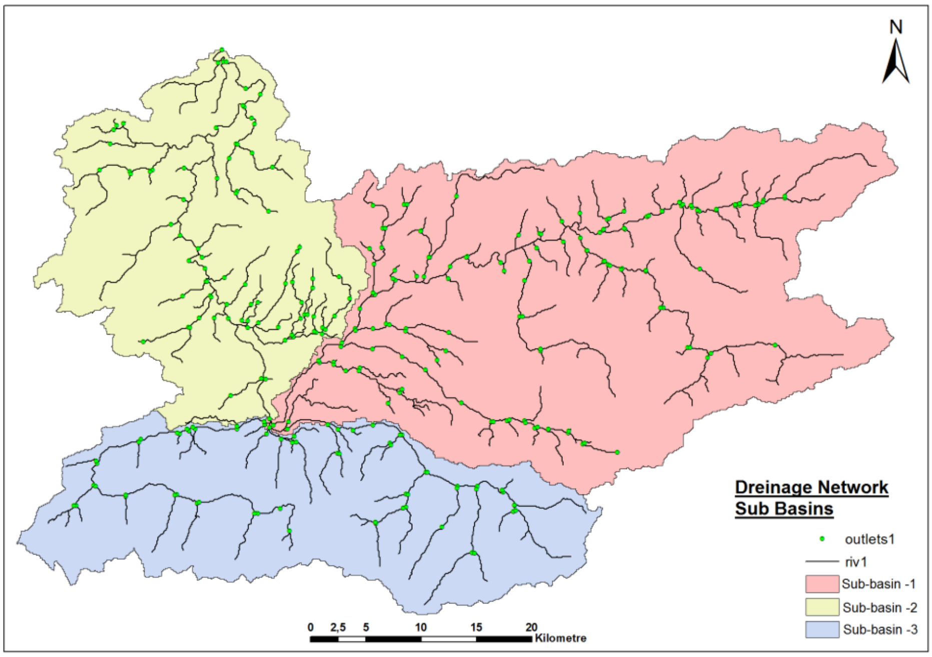

Figure 4. Produced outlet points, synthetic drainage network and sub- basins of the watershed

3.5. Land use/land cover (LULC) Classification

In order to determine the LULC of the Melen Watershed in 2010 and 2015, maximum likelihood supervised classification was applied to Landsat images. LULC classes were selected according to CORINE classification system determined by European Environmental Agency and by considering the spectral and spatial resolution characteristics of the satellite images. Clusters were recorded to obtain four LULC classes which are namely artificial surfaces, forests/semi natural areas, water and agricultural land. Resulting LULC maps were given in Figure 5 for the inspected years.

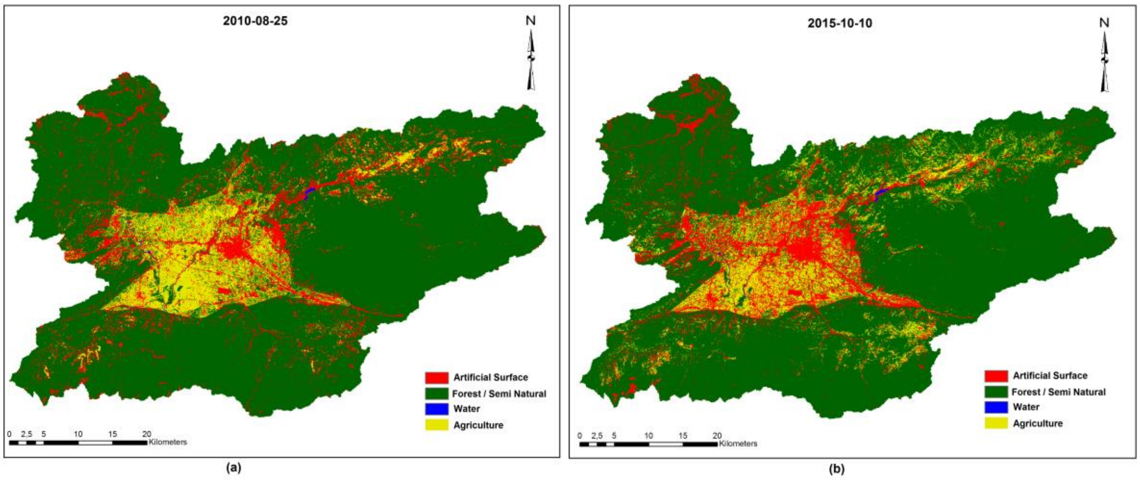

Figure 5. LULC maps produced from classification results of: a) 2010 dated image and b) 2015 dated image

Point based accuracy assessment was done to evaluate the performance of the classification results. The number of required control points was calculated according to binomial sampling method. Calculation 246 control points were needed for an accuracy analysis with an expected 80% accuracy regarding 95% confidence level. Control points were distributed according to stratified random sampling method considering the areal information of each class (Van Deusen, 1996). Class labels of the control points and their corresponding ground references were identified in order to form error matrices (Foody, 2002). User and producer accuracy metrics (Story and Congalton, 1986) and kappa statistics (Cohen, 1960) were derived from these matrices. According to accuracy assessment results, overall classification accuracy for 2010 dated image was 88.03% and kappa accuracy was 0.7802 whereas the overall classification accuracy of 2015 dated image was 90.49% and kappa accuracy was 0.8177. After achieving satisfactory accuracy results, areal information of classes were extracted from classification results of the images. Tabular areal information of LULC classes for two examined dates is given in Table 1.

Table 1. Areal statistics of LULC classes according to classification results.

Classes	**Area in 2010 (ha)**	**Area in 2015 (ha)**
Artificial Surfaces	23,202.36	30,659.45
Forests / Semi Natural land	188,077.90	187,997.80
Water	322.92	287.74
Agricultural land	33,544.82	26,203.01
Total:	245,148.00	245,148.00

4. RESULTS AND CONCLUSIONS

Producing up- to- date and accurate information about hydrologic – topographic structure and LULC information is crucial in such watersheds that supplies water to crowded cities. Provided information can serve as basic spatial data for hydrology analysis such as run- off determination and for environmental analysis such as water quality and water pollution. In this study, hydrologic and topographic situation of the Melen Watershed was determined; followed by producing outlet points, synthetic drainage network and sub- basin boundaries using satellite based DEM data and GIS techniques. Moreover, multi-temporal LULC information was derived from satellite images using classification methods.

According to the results of LULC classification, there is a noticeable increase in artificial surface class and majority of this increase is related to changes from agricultural land to artificial surfaces. When the spatial extent of this change is analyzed with synthetic drainage and sub-basin map of the watershed, it can be observed that LULC change has possible effects on all three sub- basins and center of the change also matches with main connections of the drainage network. These results lead to the assumption that hydrologic structure and water quality has been adversely affected. Increase in artificial surface also tends to increase the surface run- off in an uncontrolled way and may result in floods in rainy seasons. Moreover, increase in the domestic pollution loads in parallel to increase in artificial surfaces tends to decrease the existing water quality. These assumptions can be validated with more complex hydrologic and water quality models and analysis and thus, valuable outputs can be provided to policy makers to sustainably manage this important watershed.

References

Alganci, U., Coskun, H.G., Usta, G., Agiralioglu, N., Cigizoglu, K., Aksoy, H., Yilmaz L., Eris, E., 2008. Hydrological Modeling of Ungauged Basins using Remote Sensing and GIS: A Case Study of Solaklı Watershed in Turkey, Proceedings of the 28th EARSeL Symposium and Workshops, pp. 305 – 312, 2-5 June, Istanbul, Turkey.

Ashe, R., 2003, Investigating runoff source area for an irrigation drain system using ArcHydro tools, in Proceedings of the Twenty-Third Annual ESRI User Conference, San Diego.

Bakir, M., Xingnan, Z., 2008. GIS-based hydrological modelling: a comparative study of HEC-HMS and the Xinangjiang model, Twelfth International Water Technology Conference, IWTC12 2008 Alexandria, Egypt

Cheng, Q., Ko, C., Yuan, Y., Ge, Y., Zhang, S., 2006. GIS modelling for predicting river runoff volume in ungauged drainages in Greater Toronto Area, Canada. Computers & Geosciences, 32, pp. 1108–1119.

Cohen, J., 1960. A coefficient of agreement for nominal scales. Educational and Psychological Measurement, 20, pp. 37–46.

Daniel, E.B., Camp, J.V., LeBoeuf, E.J., Penrod, J.R., Dobbins, J.P., Abkowitz, M.D., 2011. Watershed modeling and its applications: a state-of-the-art review. The Open Hydrology Journal, 5, pp. 26-50.

Dudhani, S., Sinha, A.K., Inamdar, S.S., 2006. Assessment of small hydropower potential using Remote Sensing data for sustainable development in India. Energy Policy, 34, pp. 3195–3205.

Erturk, A., Alganci, U., Tanik, A., Seker, D.Z., 2012. Determination of Land-use dynamics in a lagoon watershed by remotely sensed data. Fresenius Environmental Bulletin, 21(10a), pp. 3052-3058.

Foody, G.M., 2002. Status of land cover classification accuracy assessment. Remote Sensing of Environment, 80, pp. 185–201.

Hammouri, N., El-Naqa, A., 2007. Hydrological modeling of ungauged wadis in arid environments using GIS: a case study of Wadi Madoneh in Jordan. Revista Mexicana de Ciencias Geológicas, 24 (2), pp. 185–193.

IMC, 1999. Istanbul Greater Municipality. Istanbul Water Supply and Wastewater Disposal Master Plan. Istanbul Master Plan Consortium. Istanbul 1999.

Kumar, A., Singhal, M.K., 1999. Hydropower assessment for small ungauged catchments in Himalayan Region using GIS techniques. Workshop on GIS applications in power sector. Map India

Saraf, A.K., Kumar, A., 2006. Spatial technologies in Himalayan small hydropower development. Himalayan small hydropower summit, Dehradun.

Story, M., Congalton, R.G., 1986. Accuracy assessment: A user's perspective. Photogrammetric Engineering & Remote Sensing, 52(3), pp. 397–399.

Tachikawa, T., Kaku, M., Iwasaki, A., Gesch, D., Oimoen, M., Zhang, Z., Danielson, J., Krieger, T., Curtis, B., Haase, J., Abrams, M., Crippen, R., Carabajal, C., 2011. ASTER Global Digital Elevation Model Version 2 – Summary of Validation Results. 27pp.

Van Deusen, P.C., 1996. Unbiased estimates of class proportions from thematic maps. Photogrammetric Engineering & Remote Sensing. 62 (4), pp. 409–412.

Yuan, F., Sawaya, K.E., Loeffelholz, B.C. and Bauer, M.E., 2005. Land cover classification and change analysis of the Twin Cities (Minnesota) Metropolitan Area by multitemporal Landsat remote sensing. Remote Sensing of Environment, 98(2005), pp. 317 – 328