Impacts of Land Use and Land Cover Change in a Mediterranean Mountainous Area on Surface Runoff During the Period 1945 – 2018

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Abstract. Changes in land use and land coverage strongly interrelated with changes in runoff. The effects of land use and land cover change on peak surface runoff and sediment loss, was investigated in a mountainous catchment, namely Lakka catchment located in Thessalia region in Greece.Most of the Lakka catchment is covered by pastures, agricultural, forest and seminatural areas. Land cover of the study area for the years 1945, 1960, 1996, 2007 and 2018 was captured by the method of the photointerpretation, using the appropriate pairs of the aerial photographs and the stereoscopic glasses (SA030-4X), and by the method resulting from the use of the datasets produced by the Copernicus land cover program. The aim of the study is to investigate the evolution of peak runoff discharge during the period 1945-2018, against a background of land use and land cover change. The Natural Resources Conservation Service – CNmethod was utilized in order to estimate peak runoff discharge while the sediment transfer was also estimated. Agricultural land area was found to be significantly increased, against forest and seminatural areas during the study period, resulting to an increase of peak surface runoff, which may cause flood problems in the downstream areas.

Keywords: Land use and land cover change; Surface runoff; Photointerpretation; Aerial photographs; NRCS-CN method

1. Introduction

Land use and land cover (LULC) changes one of the most important components of global environmental change (Prusty et al., 2021). LULC constitutes the foremost driver of hydrologic processes, influencing the flow regimes in a catchment (Psilovikos et. al. 2003; Munoth and Goyal, 2020; Zhang et al., 2021). LULC changes are attributed to natural causes and most commonly to anthropogenic activities such as urbanization, deforestation and agricultural expansion, resulting in changes of canopy interception, surface roughness and infiltration rates (da Silva et al., 2018). Interactions among these factors can cause a confounding effect in volume and timing of peak surface runoff. Increase in impervious areas can result into increase in streamflow, which results in recurrent and severe flooding.

In addition, land use changes can modify the geomorphological processes within the river bed, altering the sediment delivery of a catchment. LULC changes can act as triggers for mountainous soil erosion increase and was proved to have greater impacts on sediment yield compared to climate change effects (Mueller et al., 2009).The investigation of LULC change effects on erosion constitutes an essential procedure within the framework of soil-water conservation and river health protection (Mourtzios et al., 2009;Ebabu et al., 2019). The quantification of the LULC change effects on sediment yield is crucial for soil-water resources development and land use management.

Assessment of the impacts of LULC changes on streamflow dynamics has been a major research issue for foresters and engineers during the recent years. Several studies have been carried out worldwide focusing on the relationship between changes in land use and changes in streamflow. However, a strong correlated relationship between land use types and runoff mechanisms has not been established yet, due to the intricacy of hydrological processes (Anand et al., 2018; Huo et al., 2021). The current study aims to identify changes in streamflow by employing the Natural Resources Conservation Service – CN (NRCS-CN) method over a mountainous Mediterranean catchment, where LULC has been significantly changed over the last 70 years. In summary, the specific objectives of this study are to (i) determine the LULC changes in the Lakka catchment in Central Greece from 1945 to 2018 using aerial photographs and land cover raster data; and (ii) quantify the impacts of LULC changes on streamflow.

2. Methods and Results

2.1. Site description

The Lakka catchment is situated between 22º08'48" – 22º11'25" E longitude and 40º08'05" – 40º05'13" N latitude in ThessalyRegion inNorth-Central Greece, and it covers an area of 13,03 km^2(Figure 1).The elevation of the catchment ranges from 653 m to 1,441 m, with an average value of 940 ma.m.s.l. The climate in the study area is Mediterranean-influenced subarctic (Dsc, Köppen classification system). The average annual rainfall is 522,90 mm/year, with the average rainfall of wet (October to March) and dry (April to September) periods equal to 272.16 mm/ 6 months and 250.74 mm/6 months, respectively. The average monthly temperature is11.12°C,with the average temperature of cold (October to March) and hot (April to September) periods equal to 5,58 °C and 16,67 °C, respectively. According to the hydrolithological map that was developed in the framework of the River Basin Management Plan for the Water District of Thessalia (Greek National Water Committee,2014), the soil in the catchment has high runoff potential and very low infiltration rates when thoroughly wetted. The average slope of the catchment and the Lakka River is 41% and 35%, respectively. Most of the catchment’s area is covered by pastures, agricultural, forest and seminatural areas. The population of the wider area decreased by almost 20% during the last decade. The main economic activities in the study area are agriculture and livestock.

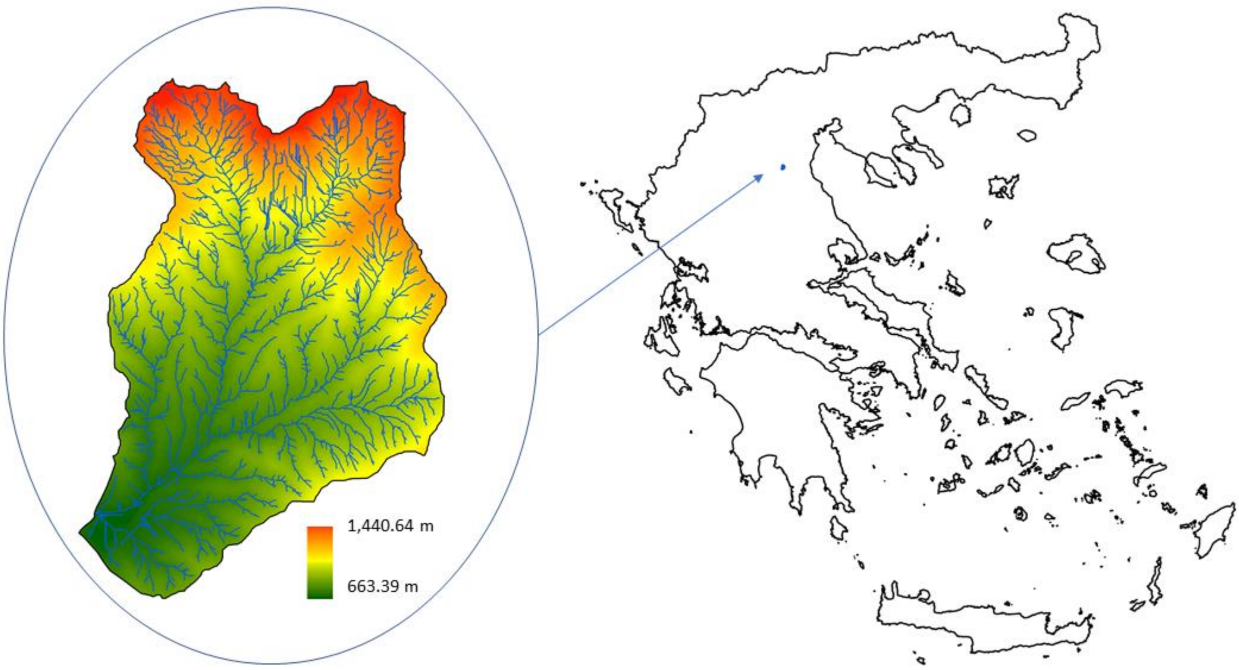

Figure 1. Lakka catchment and its situation in North-Central Greece.

2.2. Land use and land cover changes

The assessment of the land cover over time and the land use changes in targeted time periods provides a useful tool for the researcher to assess the water potential of the area and its relevance to the upcoming spatial changes in form and use. Targeted chronological periods included the years 1945, 1960, 1996, 2007 and 2018. The choice of these years was not random, on the contrary they were related to the availability of the relevant pairs of aerial photographs, but also to the fact that in these years, in Greece, the most significant changes in land form and land use are found to occur historically.

The stereoscopic observation (photointerpretation) of pairs of aerial photographs was performed using the model SA030-4X of stereoscopic glasses. It is pointed out that the observation was made by an individual, in order to keep the subjective judgment itself, in order to avoid increasing the error of subjective perception. In addition, the method resulting from the use of the datasets produced by the Copernicus land cover program has been used in recent years. The delimitation of the geospatial entities and the further evaluation of the land cover and land use data was implemented using the Esri ArcGIS pro software.The temporal variation of land use in the study area for the period 1945-2018 is depicted in Figure 2 and presented in Table 1.

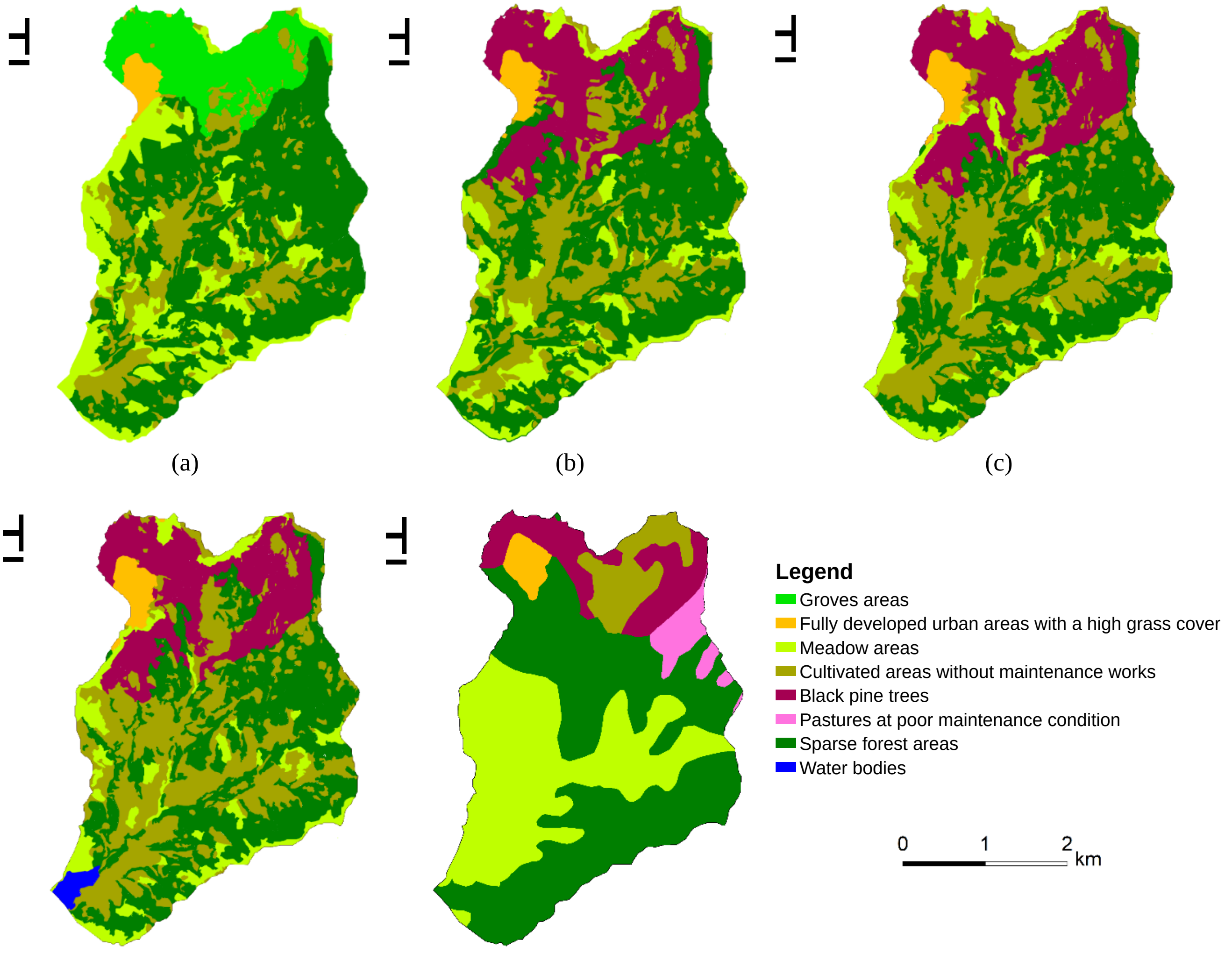

Figure 2. Temporal variation of land use in Lakka catchment for the years: (a) 1945, (b) 1960, (c) 1996, (d) 2007 and (e) 2018.

Table 1. Temporal variation of land use in Lakka catchment.

Land use area (km^2)	Year 1945	Year 1960	Year 1996	Year 2007	Year 2018
Groves areas	1.92	0.00	0.00	0.00	0.00
Fully developed urban areas with a high grass cover	0.21	0.26	0.28	0.28	0.29
Meadow areas	2.23	1.76	1.46	1.24	4.15
Cultivated areas without maintenance works	2.83	3.38	3.88	4.61	0.85
Black pine trees	0.00	2.59	2.47	2.45	1.28
Pastures at poor maintenance conditions	0.00	0.00	0.00	0.00	0.46
Sparse forest areas	5.85	5.05	4.95	4.32	6.01
Water bodies	0.00	0.00	0.00	0.14	0.00

Table 1 presents a quite large decrease of cultivatedareas in recent years, in favor of both meadow areas and pastures. This change can be attributed to the significant increase of the livestock sector at about 30% which occurred during the last decade in the wider study area (Katsada, 2019).

2.3. Impacts of land use and land cover changes on streamflow

The Natural Resources Conservation Service Curve Number (NRCS-CN) method (SCS, 1972)constitutes one of the most widely used method for accurate estimation of surface runoff in ungauged catchments and was used in the current research study. The method takes into account the catchment parameters along with rainfall intensity and a parameter named Curve Number (CN) which is related to soil type and land use.

The catchment parameters areremained stable as well as the rainfall intensity and depth which were calculated for a particular rainfall event under a return period of 50 years.Considering the land use change in the study area presented in Table 1, the CN parameter was calculated equal to 84.43, 85.24, 85.34, 86.23 and 83.14 and thus, the simulated 50-years volume of peak surface runoff was calculated equal to 36.17 m^3/s, 37.82 m^3/s, 38.03 m^3/s, 39.90 m^3/s and 33.63 m^3/s for the years 1945, 1960, 1996, 2007 and 2018, respectively.

The Stiny – Herheulidzemethod that is widely used in Greece (Kastridis and Kamperidou, 2015) was then used for the sediment discharge calculation considering the slope, the torrential rate of the basin and the relative density of transported sediments (Kotoulas, 1997).

The 50-years peak volume of surface runoff including the sediment transportwas finally calculated for each of the study time periods as presented in Table 2. The time of peak volume appearance was calculated equal to 2 hours in all cases.

Table 2. Temporal variation of 50-years peak surface runoff in Lakka catchment.

Years	Peak volume (m^3/s)
Year 1945	41.91
Year 1960	43.82
Year 1996	44.07
Year 2007	46.23
Year 2018	38.97

3. Discussion

According to the stereoscopic observation of the relevant pairs of aerial photographs in combination with the use of the method resulting from the use of the datasets produced by the Copernicus land cover program and the use of the NRCS-CN method, the following conclusions were drawn. Specifically, from the year 1945 to the year 2018, there was a significant increase in the meadow areas, black pine trees and pastures, in contrast to the cultivated areas. Important factors in this variation and the dynamics of the types of areas are the political will and the socio-economic status of each chronological period. The above changes resulted to a decrease in surface runoff at about 15,70% and 7,02% between the years 2007-2018 and 1945-2018, respectively.

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