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Evaluation of the impact of land use changes on rainfall-runoff processes and sediments transport

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Many parts of the world have been experiencing population growth and an increase of socio-economic welfare over the last decades. These changes implied increasing human concentration infrastructures in confined areas. As a result, there is a worldwide tendency for cities to sprawl towards rural areas. This implies changes to land use and to landscape patterns within catchments. Deforestation, decreasing of agricultural areas and urbanization will have important consequences on hydrological processes, which makes catchments particularly sensible to natural hazards like floods, especially in small urbanizing catchments.

Land use change processes can influence hydrological processes (e.g. evapo-transpiration reduction, limitation of infiltration capacity due to the increase of impervious surfaces), leading to the concentration of water fluxes downstream, increasing river runoff, enhanced peak flows and accelerated transport of pollutants and sediments from urban areas.

Forecasting the sign and magnitude of the impacts of land use changes on rainfall-runoff process is the main goal of the present work. Hydrological changes can modify soil erosion rates, which will affect nutrients relocation and water quality (Blake et al. 2003).

This study is based on field work performed at a small urbanized catchment located in central Portugal: Ribeira dos Covões. Rainfall-runoff relationships were assessed in forested and deforested areas, agricultural areas, including tilled and abandoned areas, and in built-up areas where, as a result of urban sprawl, the soil suffers drastic changes on its cover and properties.

The study was performed at the plot scale (0.15 m^2), trough rainfall simulations: rain intensity 43±3 mm h^{-1}. Christiansen coefficient was 83±6%. The experiments were done during one hour to achieve a stable runoff generation. During the experiment, soil moisture content was assessed every minute, and runoff volume was measured all 15 minutes after it starts. To characterize the different land uses and the different plots, some soil properties were measured: slope, soil cover, soil organic content (0-2 and 2-5 cm depth), soil moisture content before the experiment (0-2, 2-4 and 5-7 cm depth), water repellence, texture, bulk density, soil resistance to torsion and penetration. The amount of sediments coming out with runoff where also measured, along with its organic content.

The experiments revealed a very high infiltration capacity, always exceeding rainfall intensity in agriculture areas. A few differences were found in forest and deforested areas, where runoff was in the 30-37% range. The higher values presented by deforested areas might be the result of soil water repellence properties and the increase amount of litter layer overlaying the mineral soil, as a result of clear-felling. In fact, eucalyptus bark tends to concentrate rainfall, which could explain the later runoff start (10 minutes after the rainfall simulation start, by contrast with the 4 minutes observed at forest areas). Deforested plots also showed a longer runoff period, ended 12 minutes after the rainfall simulation end.

The highest runoff volumes were found in construction areas. They varied between 45% and 40% of total rainfall, in a sandy soil and in a clay soil, respectively. Despite the lower amount of runoff found in clay soil, the surface was crusted, which promote preferential water flows, explaining the later runoff start (after 9 minutes of rain) comparing with flat areas (3 minutes). In clay soils the soil moisture content at the end of the experiments varied between 31% and 36% (v/v), while in sandy soils they were lower (14% - 24%).

Forest areas promote a lower erosion rate: 4.6 g h^{-1} m^{-2}, while deforested areas have erosion rates twice as high (9.8 g h^{-1} m^{-2}), despite a higher litter accumulation. This is thought to be a consequence of mechanic intervention. In highly disturbed areas, such as the construction sites, where runoff rates are high, erosion rates can be as high as 91.8 g h^{-1} m^{-2} in flat areas ($<$1º). Erosion rates increase with slope angles, attaining 307.4 g h^{-1} m^{-2} for steep slopes (23º). In some places the sediments losses reached 55% of organic content, which point out the important role of runoff processes in nutrients transport and relocation inside a catchment.

These results indicate that runoff generation and soil loss is significantly higher in build-up areas.