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Advances in Research on the Impact of Land Use/Cover Changes on Watershed Hydrological Processes

Yutong Sun[1,2,3,4,5,6], Jing Zhang[1,2,3,4,5]

[1] SHAANXI AGRICULTURAL DEVELOPMENT GROUP CO,,LTD, China

[2] Institute of Land Engineering and Technology, Shaanxi Provincial Land Engineering Construction Group Co., Ltd., China

[3] Key Laboratory of Degraded and Unused Land Consolidation Engineering, Ministry of Natural Resources, China

[4] Shaanxi Provincial Land Consolidation Engineering Technology Research Center, China

[5] Land Engineering Technology Innovation Center, Ministry of Natural Resources, China

[6] Shaanxi Provincial Land Engineering Construction Group Co., Ltd., China

Abstract

Land use and land cover (LULC) changes have profound effects on watershed hydrological processes, influencing water availability, water quality, flood risks, and ecosystem services. Understanding these impacts is crucial for sustainable watershed management, particularly in the context of climate change and increasing anthropogenic pressures. This review synthesizes recent advancements in research on how land use and cover changes affect hydrological processes at the watershed scale. Specifically, we examine the mechanisms by which urbanization, deforestation, agricultural expansion, and other land-use activities alter runoff, infiltration, evapotranspiration, and groundwater recharge. Additionally, we explore the use of remote sensing, hydrological models, and spatial analysis in assessing the impacts of LULC changes. Finally, we provide recommendations for future research directions and management practices to mitigate negative impacts on watershed hydrology.

Keywords

Land Use; Soil Erosion; Sustainable Land Management.

1. Introduction

Land use and land cover (LULC) changes have long been recognized as significant drivers of alterations in watershed hydrological processes. These changes, often resulting from urbanization, deforestation, agricultural expansion, and other anthropogenic activities, can substantially modify the natural hydrological regime of a watershed. As human activities continue to intensify and climate patterns change, it is essential to understand the complex interactions between LULC and hydrological dynamics. Hydrological processes, such as runoff generation, infiltration, evapotranspiration, and groundwater recharge, are directly influenced by the type, extent, and arrangement of land cover types within a watershed. In turn, these processes have important implications for water resources management, flood mitigation, water quality, and ecosystem health.

This review aims to provide an overview of recent research progress on the impact of LULC changes on watershed hydrological processes, focusing on the mechanisms and methodologies used to assess these impacts.

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2. Mechanisms of Impact: How LULC Changes Affect Hydrological Processes

The transformation of land cover and land use directly influences various hydrological processes. Changes in vegetation cover, soil composition, land slope, and impervious surfaces all play critical roles in shaping the hydrological response of a watershed. Below, we discuss the main hydrological processes affected by LULC changes.

2.1. Runoff and Peak Discharge

Runoff is one of the most immediate hydrological responses to land use and cover changes. Urbanization, in particular, leads to the increase of impervious surfaces such as roads, buildings, and pavements, which prevent water from infiltrating into the soil. This leads to higher surface runoff and, consequently, an increase in peak discharge during rainfall events (Liu et al., 2019). Studies have shown that areas with high urbanization or extensive agricultural land use are characterized by significantly higher runoff coefficients compared to forested or natural landscapes (Chavez et al., 2018). In urbanized watersheds, the presence of drainage systems, such as storm sewers, further accelerates runoff and reduces the time for water to reach water bodies, exacerbating flood risks.

Conversely, areas with forested or grassland cover typically exhibit lower runoff due to increased infiltration capacity and evapotranspiration rates. Vegetation, particularly forests, helps to slow down the flow of water through the soil, reducing the overall runoff and its associated impacts on downstream water bodies (Liu et al., 2020).

2.2. Infiltration and Groundwater Recharge

Land use changes also affect infiltration rates, which are crucial for groundwater recharge and the regulation of baseflow. In urbanized and agricultural areas, soil compaction, reduced vegetation cover, and the replacement of natural surfaces with impervious materials diminish the infiltration capacity of the land (Zhang et al., 2017). Reduced infiltration leads to decreased groundwater recharge, which can have long-term effects on groundwater resources and streamflow, especially during dry periods.

On the other hand, land uses such as forest cover and wetlands promote higher infiltration rates, facilitating groundwater recharge and maintaining baseflow during periods of low precipitation (Zhao et al., 2019). Forests, in particular, are known to enhance soil porosity and water retention capacity, thereby improving the hydrological functioning of the watershed.

2.3. Evapotranspiration

Evapotranspiration (ET), the combined process of evaporation from soil and transpiration by plants, is another critical hydrological component influenced by land use changes. Vegetation cover, particularly forests and wetlands, contributes to higher ET rates due to the substantial water demand for plant growth. Conversely, agricultural and urban areas tend to have lower ET rates, with agricultural crops typically having a higher water demand than natural vegetation but often suffering from water stress due to irrigation limitations or changes in soil conditions (Gao et al., 2020).

Urbanization also alters local microclimates, which can further reduce ET due to changes in temperature, humidity, and wind speed. As such, the conversion of natural landscapes to urban areas can lead to a decrease in regional ET, altering local and regional hydrological cycles.

2.4. Water Quality

Changes in land use and land cover can also influence water quality through changes in runoff and the movement of pollutants. In urbanized areas, runoff often carries higher concentrations of pollutants, including heavy metals, nutrients, and sediments, which can degrade water

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quality in nearby rivers and lakes (Yang et al., 2017). Similarly, agricultural expansion leads to the increased use of fertilizers and pesticides, which can run off into water bodies, further compromising water quality.

In contrast, forested and wetland areas tend to improve water quality by filtering pollutants before they reach surface waters. Vegetation in these areas can trap sediments, absorb nutrients, and degrade harmful chemicals, thus enhancing the water quality of downstream water bodies (Xu et al., 2020).

3. Methodologies for Assessing LULC Impacts on Hydrological Processes

Understanding the impact of LULC changes on hydrological processes requires advanced methods that integrate field measurements, remote sensing technologies, and hydrological models. In recent years, several methodologies have been developed to assess these impacts.

3.1. Remote Sensing and GIS

Remote sensing and geographic information systems (GIS) have proven to be invaluable tools in tracking and analyzing land use and cover changes. Satellite imagery provides a means of observing large-scale land cover dynamics over time, allowing researchers to quantify changes in vegetation, urbanization, and other land use types at regular intervals. Remote sensing data can be integrated with GIS to create spatially explicit models that simulate the effects of LULC changes on hydrological processes, such as runoff, infiltration, and evapotranspiration (Wang et al., 2020).

3.2. Hydrological Modeling

Hydrological models, such as the Soil and Water Assessment Tool (SWAT), the Hydrologic Simulation Program-Fortran (HSPF), and the Integrated Water Resources Management (IWRM) models, are widely used to simulate the effects of LULC changes on watershed hydrology. These models incorporate land use, climate data, and other hydrological parameters to simulate runoff, groundwater flow, and other processes under different LULC scenarios. Recent advances in model calibration and validation, along with increased computational power, have enhanced the accuracy of these models in predicting the impacts of LULC changes on hydrological behavior (Roe et al., 2018).

3.3. Hydrological Field Experiments

Field experiments and monitoring stations continue to provide essential data for understanding how LULC changes affect hydrological processes at a local scale. These experiments help to assess the effects of different land uses on runoff, infiltration, and water quality through direct measurements. For example, researchers can measure streamflow, soil moisture, and precipitation across different land use types to evaluate the impacts of land use changes on hydrological dynamics.

4. Case Studies of LULC Impacts on Watershed Hydrology

A number of case studies from different parts of the world provide insights into the impacts of LULC changes on watershed hydrology. For instance, studies in the Amazon basin have highlighted the role of deforestation in reducing evapotranspiration and increasing surface runoff, contributing to altered streamflow patterns and increased flood risks (de Almeida et al., 2021). Similarly, research in urbanized watersheds in North America and Europe has shown a marked increase in peak discharge and flood frequency due to the expansion of impervious surfaces (Smith et al., 2019).

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In contrast, studies in regions with extensive forest or wetland cover, such as parts of Southeast Asia, have demonstrated the positive effects of maintaining natural landscapes for groundwater recharge and water quality protection (Zhang et al., 2022).

5. Conclusion and Future Directions

Land use and cover changes have significant and complex effects on watershed hydrological processes, influencing runoff, infiltration, evapotranspiration, groundwater recharge, and water quality. While urbanization and agricultural expansion often exacerbate water-related challenges such as flooding and water scarcity, maintaining natural land covers such as forests and wetlands can mitigate some of these impacts. Future research should continue to explore the mechanisms underlying these impacts through field experiments, remote sensing, and modeling approaches. Furthermore, integrated watershed management strategies that incorporate land use planning, hydrological forecasting, and ecosystem restoration will be essential for ensuring the sustainability of water resources in the face of continued LULC changes.

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