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Impacts of land covers on stormwater runoff and urban development: A land use and parcel based regression approach

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Abstract

Extensive studies have shown that stormwater yield and quality in a city are heavily influenced by its land uses and land covers (LULC). However, the majority of these studies have been done at the major watershed levels using remote sensing data with only a few urban LULC types and at lower resolutions. This empirical study uses the City of Corvallis, Oregon in the U.S. as a case to establish robust regression relations between existing urban LULC and stormwater yield or quality at the land parcel level by environmental models and high-resolution spatial data. The environmental models are based on parcel-level hydrological conditions and spatial analysis to assess the watersheds and land parcels suitable for minimal stormwater yield and highest quality for single and mixed-use urban development scenarios containing buildings, roads & driveways, sidewalks & paths, parking lots and open spaces. This study not only can provide a novel approach for local jurisdictions to evaluate the impacts of public urban development plans on a built environment but can assist private property owners to estimate the impacts of their private development projects. In addition to analysing hydrological conditions and conducting green infrastructure design upon the completed urban land use plan in previous studies, the present work indicates the necessity and possibility to apply parcel-level hydrological spatial analysis to assist local land use planners and watershed managers in making informed decisions with regard to land development scenarios at the initial stage.

Introduction

From the land use perspective, a city's urban spatial development and form can be regarded as the process and outcome of physically adding, removing, changing, or retaining various buildings and pavements compatible with different land uses over time (Arnold and Gibbons, 1996). On the one hand, urban streets, roads, sidewalks and parking lots are largely paved with impermeable concrete or asphalt. On the other

hand, almost all traditionally constructed building rooftops are designed as rainwater resistant surfaces, regardless of whether they are flat or pitched. These impervious surfaces together form the city's extensive urbanised or built-up areas and drastically alter natural ecosystems. Extensive urban and environmental studies, particularly those on large cities or metros, have shown that these hard and water-proof surfaces literally constitute the urban form and generate greater discharge of stormwater runoff and nonpoint-source pollution, which are the main causes of urban flooding damage and water quality degradation (Forman and Alexander, 1998).

Small cities have grown rapidly in the U.S. since the 1950s in filling the urban-rural gap (Sýkora and Mulíček, 2017). Low-density built-up areas are added while expanding impervious surfaces (Kim and Li, 2016), and social-hydrological interactions are exacerbated in small cities (Lim, 2016; Zhou, 2019). However, the impacts of land parcels with different uses, single or mixed, with various buildings, rooftops and pavements, on stormwater runoff and quality in small cities are yet to be fully explored. This study, using the City of Corvallis, Oregon, a small but one of the best places for American middle-class families (Livability, 2018), as a test-bed, explores the impacts of urban land use and land cover (LULC) on stormwater yield and quality, which in turn, simulates urban development scenarios for major land uses, including residential, commercial and industrial, at the land parcel level. This study can provide insights into sustainable urban form and growth notably in relation to ecosystem services, enhance compatible land use policies and controls, and encourage the best and highest land development practices.

Specifically, this study has two objectives. The first is to establish reliable regression associations between existing land cover compositions of different land uses as independent variables, and urban stormwater yield and quality as dependent variables at the land parcel level for the entire city. The second is to identify suitable areas for water-sensitive urban land use development according to the City's future development scenarios. These goals are achieved through our environmental and regression models at the land parcel level. Parcel is the smallest unit of land ownership, which is the base for property taxes to governments and development decisions by property owners in the U.S. Land cover is used in this study to represent various land surface features including pavements, roofs and urban vegetation (Akbari et al., 2003). Land uses refer to planning regulatory categories in local zoning to secure public safety and welfare (Alfasi et al., 2012). This study concentrates on urban land uses of residence, commerce and industry. These are the main urban activity patterns and private sectors play a significant role in the development projects in these patterns (Nijkamp et al., 2002). Eutrophication due to the excessive non-point source of nitrogen and phosphorus in stormwater runoff has become a serious water pollution problem (Ma et al., 2011), and in environmental studies, land covers in residential, industrial and commercial zonings are considered to be major non-point nitrogen and phosphorus sources (Vitro et al., 2005). The use of land parcel data makes more accurate stormwater analyses for minimising possible negative impacts in public land use planning and for smart behaviours in private development. In this regard, our study makes novel contribution to the discourse of sustainable urban land use planning, policy, and practice for the City and beyond.

This paper is organised as follows. After the introduction in Section 1, the connection between urban land covers and stormwater as a concise literature is discussed in Section 2. We then present in Section 3 an environmental model that processes geographical, climatological and biophysical datasets for parcel-level stormwater yield and quality, which are regressed over key impervious land covers for major land uses. In Section 4, we discuss the model results and use the best regression relations to identify suitable areas for future urban development in the City, including single or mixed land use scenarios, on the basis of minimising negative stormwater impacts. Finally, in Section 5, we provide conclusions and directions for future research.

Section snippets

Connections between urban land covers and stormwater yield and quality

Urbanisation has been regarded as an important factor leading to various environment deteriorations (Lyu et al., 2018). In the physical urbanisation process, raw land is notably replaced by human land uses mostly consisting of impervious pavements and building roofs, which alter natural drainage patterns and affect the quantity and quality of stormwater runoff (Goonetilleke et al., 2005;Poelmeans, 2010). As identified in the existing research, the amount of stormwater yield is strongly and...

Study area

The City of Corvallis is located along the Willamette River in central western Oregon on the west coast of the U.S. (see Fig. 1a). Willamette River watershed supports a habitat for wildlife and is a recreation paradise for local citizens in the State of Oregon (see Fig. 1b; OPRD, 2007). The City's water basin comprises of 20 watersheds, color-coded as shown in Fig. 1b. Lewisburg, Frazier Creek, Dry Creek, Oak Creek and Jackson Creek watersheds are dominated by conservation lands and public...

Model results

Stormwater yield and quality are regressed over land covers for each watershed at the parcel level, and the results are grouped for investigation based on the parcel location in each of the 15 watersheds to determine regression relations between LULC and stormwater yield or quality under each watershed's specific climatological, geographic and biophysical conditions. The Willamette River and Northeast Corvallis watersheds are located along the Willamette River and on the edge of the City's UGB, ...

Conclusion and limitation

The impact of urbanisation notably with physical land cover changes on stormwater yield and quality have been studied extensively for multiple urban watersheds and/or a specific site mainly from the perspective of environmental engineering and geosciences. However, given their top-down approach, these studies draw attention mainly from government agencies or scientific communities for public policies but not from individual property owners whose development decisions directly cause stormwater...

CRediT authorship contribution statement

Long Zhou: Conceptualization, Methodology, Investigation, Writing - original draft, Writing - review & editing. **Guoqiang Shen:** Conceptualization, Investigation, Writing - review & editing. **Chaosu Li:** Data curation, Writing - review & editing. **Tian Chen:** Writing - review & editing. **Sihong Li:** Writing - review & editing. **Robert Brown:** Writing - review & editing....

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