Characterizing the urban waterlogging variation in highly urbanized coastal cities: A stepwise cluster analysis model approach

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Zhifeng Wu[1], Qifei Zhang[2], Yingbiao Chen[1], Hui Zhang[3], Paolo Tarolli[2]

[1] Guangzhou University, School of Geographical Sciences, Guangzhou University, 510006 Guangzhou (Guangdong), China

[2] University of Padova, Dept. of Land, Environment, Agriculture and Forestry, University of Padova, Agripolis, 35020 Legnaro (PD), Italy

[3] North China University of Water Resources and Electric Power, School of Surveying and Geo-informatics, 450046 Zhengzhou (Henan), China

Abstract

Urban waterlogging refers to the accumulated water disaster caused by the rainwater unable to be discharged through the drainage system in time, which affected by natural conditions and human activities. Due to the spatial heterogeneity of urban landscape and the non-linear interaction between influencing factors, in this work we propose a novel approach to characterize the urban waterlogging variation in highly urbanized areas by implementing the Stepwise Cluster Analysis Model (SCAM), which with consideration of both natural and anthropogenic variables. The SCAM is based on the theory of multivariate analysis of variance that can effectively capture the non-stationary and complex relationship between urban waterlogging and natural and anthropogenic factors. Furthermore, different land-use change and rainfall change scenarios are adopted to simulate the waterlogging density variation and thus to identify the future urban waterlogging-prone areas. The results demonstrate that the stepwise cluster analysis model (SCAM) successfully captures the nonlinear and discrete relationship between urban waterlogging and natural and anthropogenic factors. The SCAM provides accurate and detailed simulated results both in highly urbanized urban centers and suburban areas, which shows an excellent performance with a high classification accuracy and generalization capability. Under urbanization and precipitation scenarios, the sensitivity of watershed to land-use change scenarios and rainfall change scenarios was different. The watershed units located in the eastern and northern parts of the central urban district (urban fringe regions) were more sensitive to land-use change scenarios, while the historic urban districts (highly urbanized urban center) are more sensitive to rainfall change scenarios.

Introduction

Under the effects of global climate change and rapid urbanization, the low-lying coastal cities are vulnerable to urban waterlogging disasters, which seriously interrupt the sustainable development of society and economy (Zhang et al., 2018; Yu et al., 2018). However, as many researchers have pointed out, urban waterlogging is a complicated phenomenon which causes by the interaction of natural conditions (precipitation and topography) and human activities (land-use change). Due to the characteristics of great heterogeneity in highly urbanized areas, the relationship between urban waterlogging disasters and various influencing factors have been affected by non-linear and non-stationary problems. Therefore, this brings some difficulties to accurately identify and simulate the urban waterlogging variation.

Research Objectives

The objective of this study is to provide an effective approach to explore the spatial variation characteristics of urban waterlogging events and simulate the future waterlogging density variation to predict the future urban waterlogging susceptibility areas.

Methodologies

- The high-resolution DEM data and urban drainage network are used to divide the central urban district of Guangzhou into 468 watershed units as the analysis unit through the D-8 algorithm.
- The hierarchical partitioning analysis (HPA) is utilized to screen out the effective variables among SCAM input variables.
- The SCAM divides the effective variables into a cluster tree to capture the non-stationary and complex mechanism, so as to simulate the waterlogging events variation.
- The SCAM was evaluated and compared by three evaluation indexes (NSE, R^2, RMSE), and three commonly used machine learning models (logistic regression, RBF-artificial neural network, support vector machine)
- The CLUE-S model and nonparametric kernel density estimation methods are utilized to construct land-use change scenarios (i.e. the proportion of impervious surfaces remains unchanged, increasing by 10% and 20%) and climate change scenarios (i.e. accumulated precipitation recurrence intervals in 10, 25, 50, and 100 years)

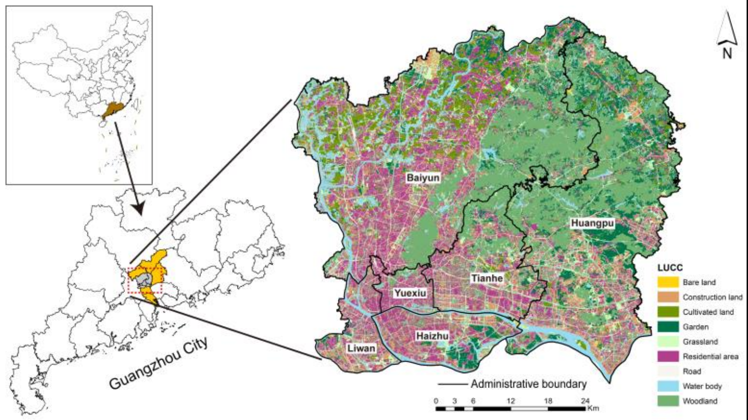

Fig.1 The geographic location of Guangzhou Central Urban Districts

Results & Analysis

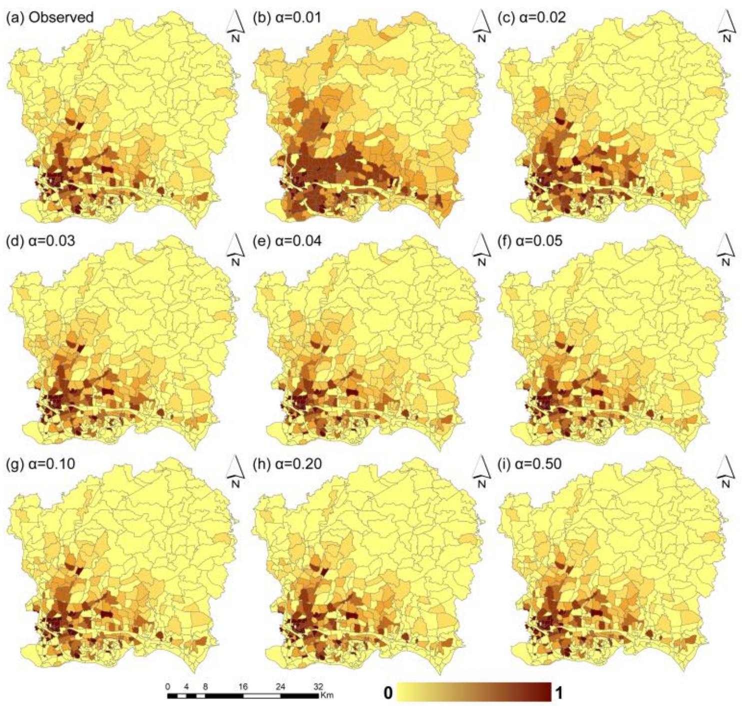

Fig.2 The spatial distribution of simulated urban waterlogging density under different significance levels. (a) Observed waterlogging density, (b)~(i) simulated waterlogging density at different significant levels

Table1 The performances of SCAM and compared models

Index	Calibration				Validation			
	LR	RBF-ANN	SVM	SCAM	LR	RBF-ANN	SVM	SCAM
NSE	0.5546	0.6777	0.8111	0.8522	0.4177	0.5862	0.7494	0.8034
R^2	0.6024	0.7563	0.8245	0.8722	0.5234	0.6127	0.6885	0.7234
RMSE	1.1137	0.9473	0.7253	0.6416	3.1560	2.1408	1.5615	0.9493

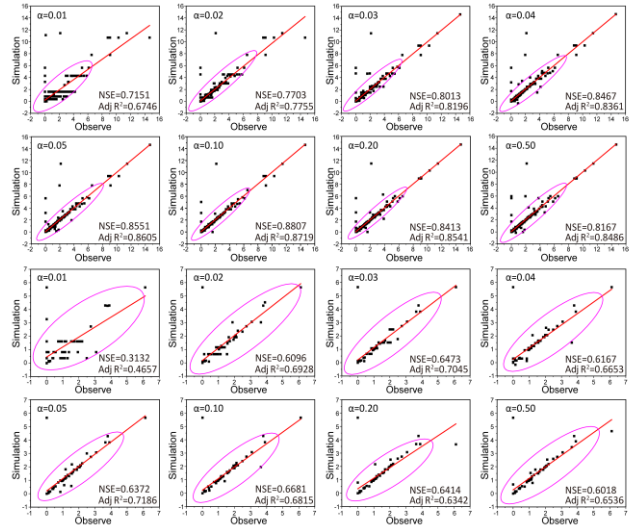

Fig.3 The NSE and scatter plots of simulated and observed waterlogging density

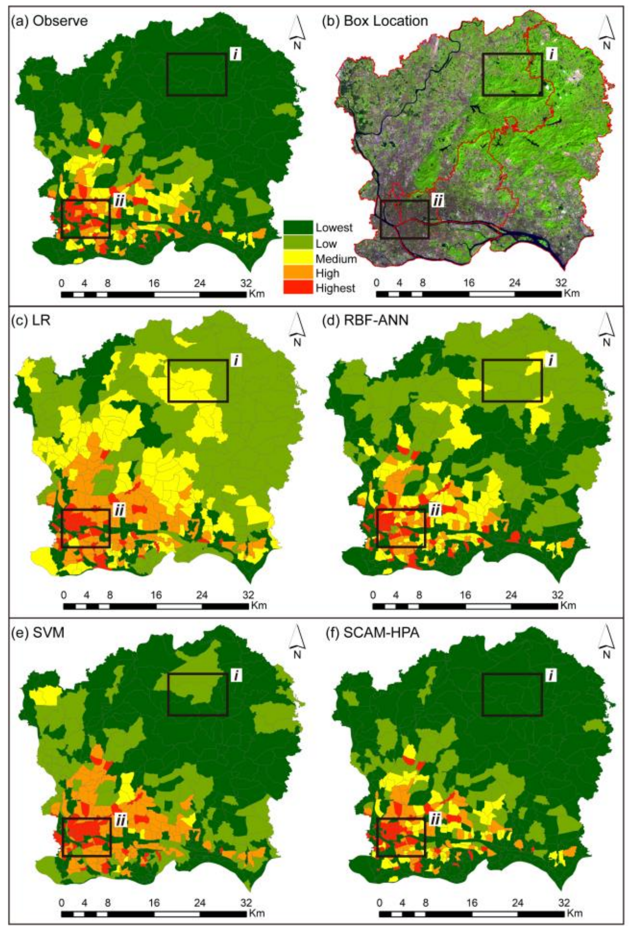

Fig.4 The simulated urban waterlogging density comparison

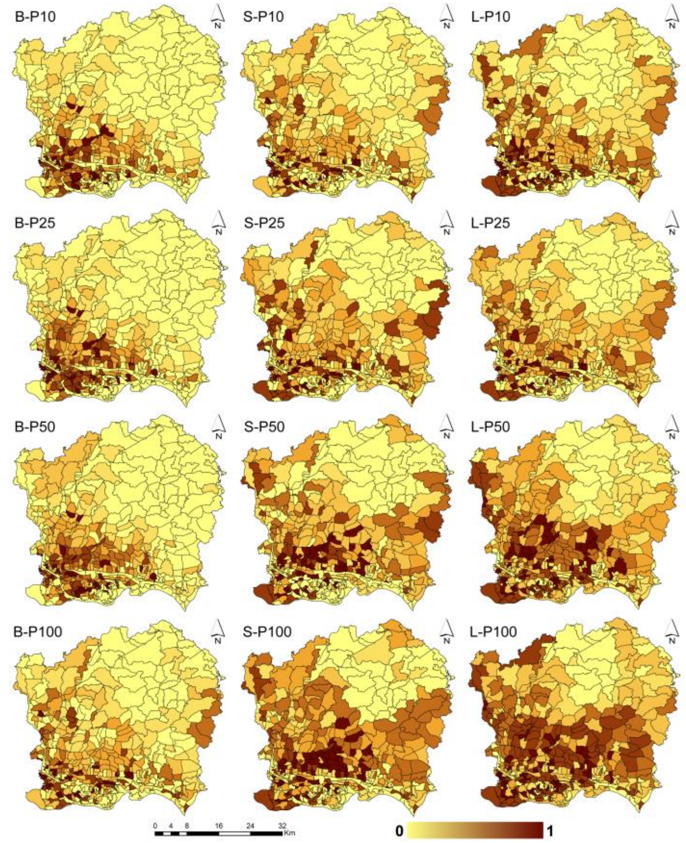

Fig.5 The spatial distribution of waterlogging density in different scenarios

Final Remarks

- The stepwise cluster analysis model (SCAM) can successfully capture the nonlinear and discrete mechanisms linking urban waterlogging to natural and anthropogenic factors, which provides accurate and detailed simulated results both in highly urbanized urban centers and suburban areas..
- The SCAM is outperformed the LR, RBF-ANN, and SVM models, which shows an excellent performance with a high classification accuracy and generalization capability. This result indicates that the SCAM is suitable for the simulation and prediction of urban waterlogging.
- With the increase of cumulative precipitation and impervious surface abundance, the urban waterlogging density increases significantly.
- Under different urbanization and precipitation scenarios, the watersheds have a great sensitivity variation, which provides important insights that different strategies should be developed to cope with different local conditions.

Reference

- Zhang, H., Cheng, J., Wu, Z., Li, C., Qin, J., & Liu, T. (2018). Effects of impervious surface on the spatial distribution of urban waterlogging risk spots at multiple scales in Guangzhou, South China. Sustainability (Switzerland), 10(5). Doi: 10.3390/su10051589.