Spatial characters of road network in Beijing and its relations with runoff risk based on GIS

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ABSTRACT: Urbanization increases the urban area of storm flood disaster risk, the quantitative study of urban rainfall runoff characteristics, can provide a scientific basis for the scientific planning and management of the city. Rings with the area of Beijing as the research object, by using GIS technology to extract the rings in land cover information, combined with the functions of the different regions use partition. On the basis, combining with SCS-CN hydrological models in the study area have been analyzed for different rainfall return period of rainfall runoff distribution characteristics, and quantitative identification of the risk area of flow produce rings in Beijing area. Rings in runoff yield risk pattern shows a center of high and low around the circular distribution, high flow risk zones mostly distributed in the center of the city's commercial and residential areas, low flow risk zones are mainly large park and natural green space, distributed between the fourth and the rings.

1. Instruction

Rapid urban growth is a key concern for local authorities and urban planners, with the intensification of human activities, road as a transport function of the carrier, has become one of most man-made ecosystem landscape. Pluvial flash flood is among the most common and destructive natural hazards, resulting in considerable direct losses and increasing indirect impacts, especially in the urbanized areas around the world. Pluvial flash flood is a rapid flood caused by heavy rain and can be distinguished from a regular pluvial flood by a short timescale, generally less than six hours. It is usually by their very fast evolution and occurs within minutes or a few hours of excessive rainfall.

Road systems for the human society bring huge benefits, at the same time, various negative effects on ecosystem and environment are increasingly apparent. As a network of artificial structures, roads throughout the various types of landscape, not only hindered the ecological process of original between adjacent patches, but also increased the landscape fragmentation, surrounding ecosystem.

In our country, land area affected by the road network is also accounted for more than 18%, and these effects have long been overlooked. Road ecology has become an important frontier in ecology. Compare to other road, urban road network density has a bigger density, and its topology structure is more complicated. The development of urban road occupied the urban ecological land space in a certain extent. At the same time, road as impervious surface, has reduced the urban rainwater intercept and infiltration capacity significantly. It made the more vulnerable to the threat from the heavy rain. The result is increased rainfall producing flow, increasing the risk from urban areas storm flood disasters. In recent years, In the Beijing area also has carried out a large number of hydrological researches, but research mostly focused on community scale. And the quantitative analysis of urban road network with urban ecological environment factors are rarely, especially from the angle of road
network spatial character. This study takes Beijing as study area, made use of GIS and RS method, establish spatial database, through the road system different sizes of grid, research the spatial correlation on road network and yield water.

2. Materials and Methods

2.1 Description of study area
This study takes Beijing as research area; it is the large city which has the largest man-made construction area in China. As statistics, there has 21.516 million inhabitant in 2014. Recent years, Beijing urban road construction develops rapidly. Road network density increase steadily. Road total mileage increased from 2470 km to 6355 km in recent 10 years. Road area increased by 350.2 hm2 to 939.5 hm2; it is 2.57 times and 2.68 times higher than a decade ago respectively. Road network density reached 2.8 square meters per capita. Beijing city road network is given priority to with ring. It built up from two to six ring expressway successively. Other roads were built up rely on these ring expressway, and form the geographic parallel mesh structure, connect the inside ring road with outside ring road. This study takes five ring road as in boundary (E:116°12′~116°32′, N: 39°45′~40°10′), the area is about 859 km².

![Fig.1 Location of Study area](image)

2.2 Data
Road spatial data extracted by object-oriented method from 2009 Quick-Bird image data. An original GIS-based road network dataset used in this study came from published maps from press. It was further rectified to match well with a fore mentioned visual interpreting in online maps (e.g. Google and Baidu). The urban roadway was structured according to functions, such as transportation and service. There are three types of road in this area, including the main roads (30–40 m wide), secondary main roads (20–24 m wide) and side roads (14–18 m wide).
2.3 Approach

2.3.1 Urban road information extraction
Urban land use and land cover type is complicated, there is high spatial heterogeneity. For the low level city road, the low resolution and spectrum are difficult to the information extraction. This study takes high resolution remote sensing image as data sources. The author use ENVI 5.0 EX object-oriented feature extraction feature information.

2.3.2 Grid division
The author according the different demand of scale-effect analysis and based on the different spatial resolution of different spatial database, combined with actual situation of road network density in the study area. The author makes use of ArcGIS software to divide spatial grid. The length of side from 1km ×1km; Naming the serial number from northeast to southwest.

2.3.3 SCS-CN Model
In the early 1950s, the United States department of agriculture (USDA) natural resources conservation service (NRCS) developed a method for estimating the volume of direct of runoff from rainfall. This method which is often referred to as the CN method was empirically developed for small agricultural watersheds. Analysis of storm event rainfall and runoff records indicates that there is a threshold that must be exceeded before runoff occurs. The storm must satisfy interception, depression storage, and infiltration volume before the onset of runoff. The standard SCS-CN model is based on the following relationship between rainfall, \( P \) (mm), and runoff, \( Q \) (mm):

\[
Q = \frac{(P-I_a)^2}{P-I_a + S}
\]

\( I_a \) is all loss before runoff begins. It includes water retained in surface depression, water intercepted by vegetation, evaporation, and infiltration. \( I_a \) is highly variable but generally is related with soil and land cover parameters. To remove the necessity for an independent estimation of \( I_a \).

A linear relationship between \( I_a \) and \( S \), through studies of many small agricultural catchments, \( I_a \) was found to be approximated by empirical equations such as \( I_a=0.2S \).

By removing \( I_a \) as an independent parameter, a combination of \( S \) and \( P \) to produce a unique runoff amount can be approximated. Substituting \( I_a=0.2S \) gives

\[
Q = \frac{(P-0.2S)^2}{(P+0.8S)}
\]

The variable \( S \), which varies with antecedent soil moisture and other variable, can be estimated as

\[
S = \frac{25400}{CN} - 254
\]

Where \( CN \) is a dimensionless catchment parameter ranging from 0 to 100. A \( CN \) of 100 represents a limiting condition of perfectly impermeable catchment with zero retention, in which all rainfall becomes runoff. A \( CN \) of zero conceptually represents of other extreme, with the catchment abstracting all rainfall and with no runoff regard less of the rainfall amount.

2.3.4 Spatial cluster and spatial outlier analysis
Spatial autocorrelation analysis aims to evaluate the level of spatial dependence of spatial association among observed values \( x_i \) of variable \( X \), which describes the similarity of neighboring observations. There are two primary types of spatial autocorrelation: global spatial autocorrelation and local spatial autocorrelation. Anselin proposed the local Moran’s I as a local spatial autocorrelation method to deal with the issue of global spatial autocorrelation which could not well quantify relationships in all parts of the study area in sufficient detail. The local Moran's I was defined as:
\[ I_i = \frac{x_j - \overline{x}}{\delta^2} \sum_{j=1, j \neq i} \left[ \sigma_j\left(x - x_j\right)\right] \]

where \(x_i\) is the observed value of variable \(X\) at location \(i\), \(\overline{x}\) is the average value of variable \(X\) for a sample size of \(n\), \(X_j\) is the value of the variable \(X\) around location \(i\) (where \(i \neq j\)), and \(\delta^2\) is the variance of \(X\), and \(w_{ij}\) is a weight value that represents proximity relationships between location \(i\) and neighboring location \(j\). In general, \(w_{ij}\) is a function of distance; in the present study, \(w_{ij}\) was defined using the inverse distance weighting. The Moran’s I can be positive, negative, or equal to zero. A high positive Moran’s I suggest that surrounding features have similar values. If a group of adjacent features linked to high values of Moran’s I suggest a cluster of similarly high or low values. A high negative Moran’s I for a feature indicates that surrounding features have different values, and a feature linked to a negative Moran’s I suggests a different value relative to its neighbors. The zero Moran’s I suggests a cluster of random values.

3. Results and discussion

3.1 Spatial characteristics of runoff under grids

In order to facilitate calculation of road density, the author make use of road nodes by intersection of road. Area weighted node can be express the distribution of different scale intersection in the space. Higher level of of nodes are mainly distributed in the expressway, large hub from the expressway with Arterial roads. In view of the road network density, results shows that the second central area is low density area, between the 2nd and 4th ring road network on regional distribution, 4th ring road, especially near the south of the 5th rings within the 4th ring road density decreased significantly. Different sizes of urban forest parks and water form the sizes the low density of road network area, set in the study area landscape road system. Node density spatial distribution pattern is consistent with the trend of road network density.

Fig.2 Spatial distribution of area weighted nodes in the study area

Fig.3 Road network based on the spatial grid 1km×1km

Compare to other function areas, between 4th ring road with 5th ring road has highest proportion of irrigation and water. So it has higher to intercept he infiltrate to the rainfall. on the other hand, area inside of 4th ring road has a large of rate of impervious surface, less vegetation and water aea decrease in interception of precipitation and infiltration, increased the proportion of runoff yield in this region.
Fig. 4 Grade distribution of runoff coefficients under precipitation.

There is a significant difference exists during functional areas. Taking 2012 precipitation as an example, about 85% of low risk area for green area, accounted for 65% for all rings of Beijing green area are mainly distributed in the 4th ring, also includes a few large park space in urban central area scattered distribution. The rest of the other areas mainly distributed in the middle stream flow risk area and middle risk area, and green areas in the high flow risk only accounted for 0.27. Highly flow risk area mainly distributed within the 4th ring road, the main functional area mainly distributed within the 4th ring road, the functional areas constitute as high density residential area, industrial land, factories and business areas, respectively.

3.2 Spatial autocorrelation and scale dependence

Fig. 5 LISA map for runoff risk analysis in Beijing’s five-ring areas.
Rings in Beijing area within the runoff yield risk area of spatial autocorrelation analysis Moran’s I coefficient was 0.12 (p<0.001), indicating that the pattern of runoff yield risk in the Beijing rings present significant agglomeration features. As shown in Fig.5, the red areas (HH region) is the flow of rings in areas of high risk, is in the core area in urban. The regional comprehensive runoff coefficient of 0.75, the main land use types for high density residential area and commercial use area. Blue area (LL region) is also the low flow risk zones, mainly along with five rings along the circular distribution, the main composition is the rings around the big parks and forest land and its surrounding spread of residential area. The area’s comprehensive runoff coefficient is 0.50, is far lower than the high yield risk accumulation.

Making full use of the city’s advantages to alleviate the pressures of the high-risk area drainage. Based on landscape ecology theory of the “source-sink”, HH area can be seen as “source” area of urban runoff, and spread in the region of the HH area surrounding of LH can be regard as urban runoff “sink” area, nearby building between HH and LH area “drainage gallery”; HH regional flow of rainwater can be quickly passed to the LH area, surrounding the use of urban green space area to receive the rain, not only can alleviate the risk of high risk area, can be also reduce the construction cost, improve the urban water conservation function, to maximize the urban artificial and natural green space area.

4. Conclusions
The early stage of the construction of city road system and carrying traffic flow during the whole life cycle of the late are closely related to the intensity of human activities. This study takes the center area in 5th ring area as research region, analyzed the characteristics of urban road grid space, quantitative study of urban rainfall runoff character, can provide a scientific basis for the scientific planning and management of the city. Combined with SCS-CN experience model of Beijing’s rings in different functional areas of rainfall runoff process simulation analysis.

Beijing urban rings region comprehensive runoff coefficient increases with the increase of rainfall return period. Distribution and function of different grade runoff yield risk data constitute differences. Flow low risk area are mainly distributed in the 4th ring, internal composition mainly in green function, middle and upper stream risk data located within the 4th ring road, in the majority with commercial and residential area. Municipal level 4 road gradation ratio results show that too much emphasis on the construction of expressway and main road in the study area, result in the same road network density. Road ecology and urban ecology of the cross is the inevitable trend of discipline development and solve the present ecological environment in the city’s increasingly prominent problem o the times, and its application in the domain of influence in the field of city road ecology to urban construction ecological environment problem produced by providing and solution, for the further construction of eco-friendly city road system to provide the new way of thinking and quantitative index.

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