

Simulation and Evaluation of Low Impact Development of Urban Residential District Based on SWMM and GIS

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Abstract. In this study, simulation and evaluation of low impact development in resident district was carried out based on Storm Water Management Model (SWMM) and GIS method. In our model, we added 3 kinds of low impact development facilities, namely permeable pavement, rainwater garden, and green roof. These facilities are used alone or in combination. The model was run under five different rainfall reappearing periods. The simulation results using low impact development facilities were compared with simulation results under the current situation and undeveloped state. The results show that the total amount of runoff was greatly reduced by using various types of low impact development facilities in the urban residential district. The maximum reduction rate was using permeable pavement, reached 29.9%, followed was using rainwater garden, and the worst was using green roof. The lowest cost of reduction of the total amount of runoff was using permeable pavement, the followed was using rainwater garden, and the highest was using green roof. The combination scheme of various low impact development facilities has the highest efficiency of reducing total amount of runoff, and the lowest cost, which considering of the actual situation of the study area. The study indicated that application of low impact development facilities can reduce surface runoff effectively, which should be a useful way for prevention of urban waterlogging.

1. Introduction

In recent years, with the rapid development of urbanization in China, city impervious areas were increased sharply, and urban water environment was greatly changed. Urban waterlogging has become a serious environmental disaster. Especially in the residential district of the city, the urban waterlogging resulting in ground flooding, traffic jams, underground submerging, and interruption of utilities pipeline such as gas, electricity. Urban waterlogging seriously impacted on people's life and property safety. In the past, the control schemes of urban waterlogging were focused on drainage. Those schemes can achieve a certain effect in the short term, but cannot solve the problem fundamentally.

Low impact development model (LID) can simulate the natural hydrological conditions as much as possible. It emphasized the combination of small scale, sustainable, low energy consumption, and the combination of landscape design and land development [1]. It can effectively repair hydrological mechanism which was destroyed by the urban drainage system [2-3]. Therefore, LID has been widely used in the control and utilization of rain flood in developed countries in recent years [4-6].

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The SWMM model was developed by the national environmental protection agency. It was mainly used to simulate the rainfall-runoff process of a single precipitation event or a long series of rainfall series. SWMM included hydrological, hydraulic and water quality modules. LID module was increased in the latest version of SWMM5.0 [7-8]. It can simulate 5 kinds of low impact development measures, such as bioretention, infiltration ditch, permeable pavement, rain barrels, and vegetation swales. Other LID measures, such as filter belt, down concave type green space, green roof, can be simulated by the parameters transformation.

Therefore, we simulated low impact development in resident district by SWMM and GIS.

2. Materials and Method

2.1 Study area and data source

The study area, Zhonghaikangcheng District, is located at Tianhe District of Guangzhou City, China. The elevation ranges is from 2.66 to 10.05 m above mean sea level, higher at the northeast, and lower at southwest. It covers the area of approximately 25,400 m². The study area enjoys a humid subtropical climate with abundant rainfall. The annual average temperature is between 21 and 24°C, and the annual mean precipitation reaches 1,721.5 mm. The annual rainfall is concentrated in June to September. Winter is short, mild and relatively dry, while summers are long, hot and very wet.

The data used in the study area mainly include the QuickBird 0.61 m remote sensing image at 2013 (used to extract the land use type), the topographic map of Guangzhou with a scale of 1:10,000 (used to build DEM, and to extract elevation and slope), construction planning map of the study area with a scale of 1:10,000 (used to adjust sub catchments).

2.2 Method

We simulated of the low impact development of urban residential areas based on SWMM and GIS. The main steps included: generalization of the study area, design of heavy rain process line, setting of LID scenes.

2.2.1 Generalization of the study area

First, we extracted landuse/landcover types of the study area. They data sources are topographic map of Guangzhou with a scale of 10,000, QuickBird 0.61 m remote sensing image at 2013, and data of field investigation. There were 4 landuse types: greenbelt, water area, roof, and road (Figure 1). We used graphic editing and spatial analysis functions of ArcGIS 10.2 to carry out the task.

Second, we extracted DEM from topographic map of Guangzhou. Then we divided sub catchments based on DEM, and adjusted the boundary of sub catchments according to road traffic map. The study area is divided into 38 sub catchments, and each sub catchment area has a water node. The parameters of sub catchments can be obtained by spatial analysis functions ArcGIS 10.2.

Finally, we built drainage network of the study area. Drainage pipes are mainly distributed at the boundary of each sub catchment. Some pipes must be adjusted according to terrain of corresponding sub catchment. 77 drainage pipes and 84 pipeline nodes were built, including 83 inspection wells, 1 export nodes. The parameters of drainage pipes and nodes can also be obtained by ArcGIS 10.2.

The Generalized Map of study area is as Figure 1.

2.2.2 Design of heavy rain process line

The study area is located in Guangzhou City, and the formula of rainstorm intensity is as follow:

$$q = \frac{2424.17(1 + 0.553 \lg T)}{(t + 11.0)^{0.668}}$$

Where q is heavy rain intensity (L/s • ha), T is the reappearing period (a), and t is the rainfall duration (min).

We designed the heavy rain process line of the study area based on formula of rainstorm intensity of Guangzhou City and Chicago rain type. The reappearing periods are 1, 5, 10, 50 and 100 years. The interval is 5 minutes.

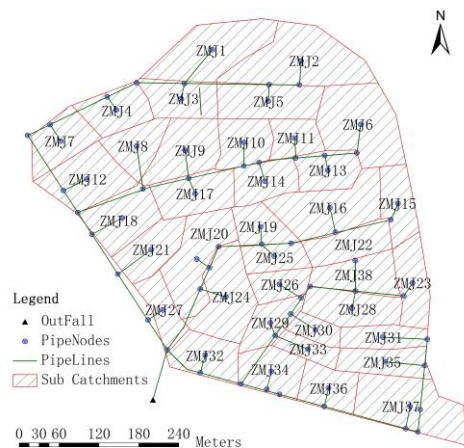


Figure.1 Generalized Map of the study area

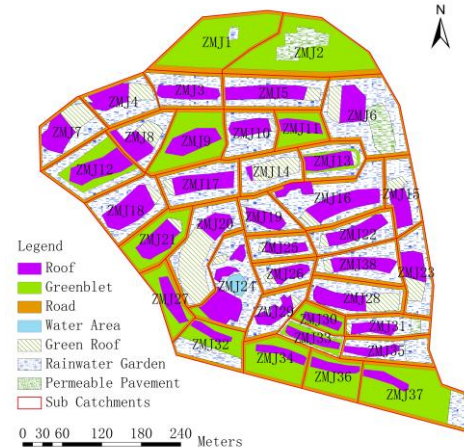


Figure.2 Combination Scheme of LIDS

2.2.3 Setting of LID scene

After analysis of the actual situation of the study area, we selected 3 kinds of LID facilities, such as green roof, permeable pavement, and rainwater garden. There were 5 scenarios: 1) Undeveloped state, all the ground of the study area is green; 2) Current status, the study area was developed; 3) All greenbelt were transferred to rainwater garden, do not add any other LID facilities; 4) All road and were transferred to permeable pavement, do not add any other LID facilities; 5) All roof were transferred to green roof, do not add any other LID facilities. 6) Combination scheme of 3 kinds of LID, according to comparison of the efficiency of cutting the amount of total runoff, cost, and the actual situation of each sub catchment area.

The combination scheme (Figure.2) is: area of green roof is 14056.2m² (13.3% of total roof), area of permeable pavement is 57431.1 m² (64.9% of total road), area of rainwater garden is 52921.9m² (78.1% of total greenbelt).

3. Result and Discussion

Under different reappearing periods, the simulation results of total runoff and reduction percentage as shown in Table 1, by using different LID scenarios. The comparison of cost of reduction under different scenarios is shown in Table 2.

Table 1 Runoff simulation results under different reappearing periods
(Scenarios: 1. Undeveloped; 2. Current status; 3. Using green roof separately; 4. Using permeable pavement separately; 5. Using rain-water garden separately; 6. Combination of 3 kinds of LID facilities)

Scenarios	Total runoff(m ³)					Reduction percent of total runoff (%)				
	P=1	P=5	P=10	P=50	P=100	P=1	P=5	P=10	P=50	P=100
1	5415.6	10867.8	13,317.60	19114.2	21645					
2	12826.8	18859.8	21473.4	27556.8	30182.4					
3	10920.6	16963.8	19584.6	25667.4	28294.8	14.5	10.1	8.5	6.9	6.3
4	8496.0	13012.8	15040.8	19801.2	21921.6	33.5	31.0	29.7	28.1	27.4
5	9323.4	14524.8	16875.6	22561.8	25077.6	27.0	23.0	21.1	18.1	16.9
6	5402.4	9672.6	15040.8	16570.8	18840.6	57.9	48.7	30.0	39.9	37.6

Table 2 Comparison of cost of reduced total runoff under different scenarios

Using green roof separately	Using permeable pavement separately	Using rainwater garden separately	Combination of 3 kinds of LID facilities
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Area (m ²)	80851.8	87311.2	85241.8	124409.2
Entire cost(10 ⁴ Yuan)	2162.8	1309.7	1022.9	1859.0
Reduced total runoff(m ³)	1893.6	6525.7	4507.2	13105.4
Cost of reduced total runoff(Yuan/m ³)	11421.6	2007.0	2269.5	1418.5

As seen from the tables, compared with the current situation (after development), the total runoff were reduced by using any LID facilities separately, or under combination sense. Under different scenarios, with the increase of the reappearing period of rainfall, the reduced proportion of total runoff decreased gradually. Reduction rate of total runoff by using permeable pavement is highest (29.9%), the second is using rainwater garden (21.2%), and the lowest is using green roof (9.7%). Cost of reduced total runoff by using permeable pavement is lowest (2007.0Yuan/m³), the second is using rainwater garden (2269.5 Yuan/m³), and the highest is using green roof (11421.6 Yuan/m³). Compared with the application of one LID separately, reduction effect of total runoff is greatly improved by combination of 3kinds LID facilities. Average reduction rate reached 42.8%. Cost of reduced total runoff is decreased significantly, is 1418.5 Yuan/m³. The cost of all program by using LID facilities is too high, more than 10 million Yuan.

4. Conclusions

Through this study, conclusions are as follows:

- (1) Total runoff was greatly reduced by using one LID facilities separately, or under combination scheme of 3 kinds of LID facilities. Therefore, we should vigorously promote the LID concept and measures in the construction of new urban areas and the transformation of the old city.
- (2) In practical work, we should consider the environment of urban residential district, cost of different LID facilities, and the drainage capacity of municipal pipe network. The optimal LID layout scheme must achieve the overall optimization of economic and social benefits.

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