Study on the Improvement of Ecological Environment in the Space of Shanghai Primary and Secondary Schools by Rain Gardens

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Abstract. Low Impact Development (LID) is a technology of rainstorm management and water pollution treatment developed in the late 1990s. As one of the LID measures, rain gardens can alleviate the urban rainstorm in Shanghai. Aiming at the low rate of environment utilization in the spaces of Shanghai primary and secondary schools, this paper proposes to collect the rainwater runoff from buildings and roads in the form of rain garden. We try to use artistic design techniques, and establish the campus environment with the value of rain and flood management, sustainability and biodiversity. The study results show that the sample rain garden covers an area of 310m² with a water storage depth of 30mm, and has recorded 6 short-term heavy rainfalls and 1 overflow in 1 year. The biodiversity has increased by 70%.

Keywords: Rain Garden, Low Impact Development, Campus Space, Sustainable Development, Biodiversity.

1. Introduction
The problem of rainstorm in modern cities is severe, and the consequent problems such as flooded road and urban flood caused by rainstorm are outstanding. A great deal of hardened ground accompanied by urbanization has replaced the original green plants, soil and rivers. The urban rainfall has not been effectively utilized, but becomes the main cause of urban water accumulation and other problems. In the design concept against the disaster of urban flood, there are “Low Impact Development, LID” and “Green Infrastructure, GI” [1-2] proposed by scholars of the United States, “Water Sensitive Urban Design, WSUD”[3], proposed by scholars of Australia and the Middle East, “Active Beautiful and Clean Waters Programme, ABC” [4] proposed by scholars of Singapore, “Rainfall storage and infiltration” [5] proposed by scholars of Japan, and the “Technical Guideline for Sponge City Construction”[6] proposed by scholars of China in 2014, all of which emphasize the reduction of rainstorm hazards by natural factors, so that the cities can return to the natural state as much as possible, and develop the sustainable utilization of water resources as much as possible. Rain garden is one of the main technical means.

Based on a large number of previous studies: firstly, rain gardens can effectively store and absorb the rainwater runoff, purify the rainwater, and slowly restore the hydrological process after urbanization to a level close to that before development with a natural method of lowest carbon [7]; secondly, a large amount of irrigation water is consuming a large amount of water resources. The consumption of
irrigation water in some residential areas even reaches 26% of the total amount in such areas. The rain gardens can alleviate the waste of water resources and form an effective and sustainable cyclic utilization. Thirdly, the rain gardens are also beneficial to the survival of wild animals and the formation of biodiversity. The application of native plant species has a good effect on attracting insects and birds, and helps to form a benign food chain.

2. Research coverage and methodology

The study area is designed in a primary school campus in Shanghai, with an area of rain garden of 310m², in which the planting is dominated by the native plants of Shanghai with water-resistant vegetation. The mean annual temperature in Shanghai is 15 ~ 22°C, and the mean annual rainfall is 1,166.1mm. The soil in the study area is silty sand with sand content more then 50% and clay content less than 30%.

The main coverage of the study includes:
1) Effect of rain garden on reducing rainwater runoff and recycling water resources;
2) Enhancement of rain garden on biodiversity of urban campuses;
3) Ecological and artistic effects of rain garden on the students' visual perception.

2.1. Measurement of rainwater runoff

In the study area, the rainwater input position, water storage depth and rainwater outflow position have been measured for the areas of ordinary road pavement, gravel pavement with 5cm matrix and rain garden with silty sand layer respectively. The formula to determine the ratio of rainwater runoff is as follows:

\[ \text{Ratio of rainwater runoff} = \frac{\text{total water quantity at inlet}}{\text{total water quantity at outlet}} \]  

Through the measurement of rainwater runoff on the surfaces of different materials, the effect of rain garden on reducing rainwater runoff can be determined. At the same time, according to the rainwater collection system shown in Fig. 1, the amount of rainwater collection is determined by the remote water meter, so as to judge the ratio of rainwater collection and utilization.

\[ \text{Ratio of rainwater utilization} = \frac{\text{total water consumption before collection}-\text{total water consumption after collection}}{\text{collected amount of rainwater}} \]  

For the purpose to truly achieve sustainable utilization of water resources, the design must be accepted by the daily users. If the maintenance cost after production is too high, it will lose its own value. Therefore, the ecological landscape needs to have multiple functions and benefits, which combines the rainwater planning with maximum benefits to promote the sustainable development of the landscape.

2.2. Determination of biodiversity

Before the construction of the study area, data were collected for the biological species in the designated area, and only the number of such species was determined. In the study area, Iris tectorum, Nelumbo nucifera, Cannanindica, Lythrum salicaria, Nymphaea tetragona, Myriophyllum spicatum, Phragmites australis, Typha orientalis, Arundo donax, Carex argyi, Oenanthe javanica, Sagittaria trifolia, Alilsma orientale and other local water-resistant species in Shanghai have been planted, and the rain garden was designed in combination with the woodland and shrub. We led the students to make all kinds of insect stations, bird nests and feeders. After the study area had been constructed for one year, we collected the number of biological species again, and compared the results.

The data collection is mainly aimed at the common birds, mammals and insects in the city. By comparing the data before and after construction, we have understood the impact of rain garden on biodiversity, and established the habitat value of rain garden.

3. Conclusion and recommendation

Because of the large hardened area in the primary and secondary schools, especially in low-lying areas, it is inclinable to suffer waterlogging, resulting in rain-flood problems. The rain gardens can solve the
problems of waterlogging and lack of naturality on the campuses at the same time. Most primary and secondary schools have defects such as single biodiversity and insufficient utilization rate of green space. Therefore, the measured results show that the rain garden has good permeability, and can alleviate the problem of water accumulation in campus. The rain garden can also provide habitat for many kinds of birds and invertebrates, and enhance the naturality of campus and the engagement of green space.

3.1. Permeability of rain garden
According to the inflow and outflow records of precipitation process in different areas (see Table 1), it can be known that short-term water accumulation will be formed in rain garden when the rainfall intensity is too high, and the water accumulated will be absorbed after the rainfall intensity decreasing.

| Time (min) | Precipitation (mm) | Inlet flow (ml) | Water storage depth of asphalt pavement (mm) | Water storage depth of gravel surface (mm) | Water storage depth of rain garden (mm) |
|------------|--------------------|----------------|-------------------------------------------|------------------------------------------|----------------------------------------|
| 30         | 5.8                | 2600           | 4.2                                       | 2.4                                      | 1.3                                    |
| 60         | 12.1               | 5500           | 9.1                                       | 5.6                                      | 4.2                                    |
| 90         | 7.6                | 5800           | 11.6                                      | 7.4                                      | 5.1                                    |
| 120        | 2.8                | 1300           | 6.2                                       | 2.3                                      | 2.1                                    |

According to the measured results of precipitation and water storage depth, the rain garden in a small area has stronger penetration and storage capacity than the asphalt pavement and gravel pavement with the same area. In the process of short-term heavy rainfall, the rain garden forms water accumulation in a short time, and then be absorbed rapidly after the rainfall decreases. Compared with the traditional asphalt pavement, the gravel surface also shows higher penetration. Because the rain garden has a certain water storage depth, it has more advantages in flood control than the traditional asphalt pavement and gravel surface. The design can form a flood control network in the areas with poor drainage performance from points to areas.

3.2. Establishment of biodiversity in rain garden
By comparing the biological species in the area before and after the construction of rain garden (see Table 2), it can be seen that the rain garden has great influence on the establishment of biological habitat.

| Category of species | Number of original species | Number of current species | Ratio of enhancement |
|---------------------|---------------------------|--------------------------|----------------------|
| Flowering and fruiting plants | 10 | 32 | 220% |
| Chilopoda | 2 | 3 | 50% |
| Mollusc | 3 | 5 | 66.7% |
| Insects | 7 | 11 | 57.1% |
| Birds | 2 | 3 | 50% |
| Rodents | 1 | 1 | 0% |

This study investigated the native plants and non-native plants in two areas respectively, and the results showed that there was little difference in biodiversity between these areas. However, the number of flowering and fruiting plants has significantly improved the establishment of biodiversity in these areas. Therefore, it can be concluded that the native tree species are more suitable for the local environment, and it is desirable to plant native plants. However, the negative judgment that the
application of non-native plants will reduce the establishment of local biodiversity obviously needs to be determined according to the actual plant species.

3.3. Suggestions on rain garden in the primary and secondary schools

In the environmental spaces of primary and secondary schools, the establishment of rain gardens has higher sustainability and utilization rate. The schools can use the rain gardens to develop practical courses combined with the classes, which can not only improve the students' learning enthusiasm and the utilization rate of environmental spaces, but also improve the benefits of ecological environment.

3.3.1. Provide a site of flexible design for the campus and even the community. Subject to the conclusion, the rain garden has good permeability. The design can combine the green spaces of primary and secondary schools and the small green spaces at street corners in the whole area to form a rain-flood management network, and reduce the rainstorm hazards.

3.3.2. Recycle the running out rainwater. The design can collect rainwater through the drainage pipe network, irrigate the plants in the rain garden, and avoid the waste of water resources.

3.3.3. Create good visual sense and play places for the teachers and students. The environmental spaces of primary and secondary schools should pay more attention to engagement, and the traditional hardened space cannot give a good visual sense. The rain garden can better provide biodiversity and increase various outdoor activities combined with the classes, which is conducive to the all-round development of students.

3.3.4. Enhance urban biodiversity. The people gathering in cities result in that the wildlife cannot develop effective habitats. The campuses of primary and secondary schools can avoid the activities of external persons, and provide a good habitat environment for the creatures by establishment of insect stations organized by the schools.

4. Conclusion

The existence of water in the campus environment can enhance the people's visual perception and attract a large number of creatures to visit and develop habitats. The construction of rain garden is not only for environmental aesthetics or ornamental value, but also to provide the students with knowledge: water is not cheap or infinite, and water resources are extremely precious to us; water is potential to have destructive power and is not controlled by human beings at will; and water can provide a good habitat for most creatures.

The establishment of rain garden does not need to sacrifice the school spaces or interests, but only provides a new environmental space model for the schools to better enhance the efficiency of environmental spaces. It can collect, guide, transfer and utilize various water resources, use them to irrigate abundant vegetation, and attract the creatures to develop habitats. By this research, we hope to combine the form of rain garden to provide an environmental space with higher quality for the urban primary and secondary schools and a better learning environment for the students.

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