A Review of Researches on Plant Configuration and Decontamination Efficiency of Rain Gardens in China

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Abstract. Rain garden is a low-impact development method that uses topographic design to store and purify rainwater, and then adjust rainwater to reuse rainwater. The plants in the rain garden are the key components of its function of storing and purifying rainwater. This article refers to the CNKI database literature about the selection and planting effects of rainwater garden plants as of October 2019. Using literature measurement analysis and content analysis methods, we found that: 1) The research on rainwater garden plants has been increasing and deepening, involving various disciplines; 2) Research on the configuration of rainwater garden plants has gradually shifted from qualitative research to quantitative research; 3) The types of rainwater garden plants that can be selected are diverse, and scientific configuration methods can improve efficiency; 4) Most research literature on plant purification in the aquatic or wet plants on the removal and purification of nitrogen, phosphorus, heavy metals and other pollutants and other aspects. Finally, it discusses the deficiencies of the rainwater garden plant research, and looks forward to its future research direction, aiming to provide reference for the rainwater garden plant selection and rainwater garden scientific construction in China.

1. Introduction

With the continuous development of urbanization, environmental problems are becoming increasingly prominent. The development mode of low efficiency and high energy consumption has restricted the development speed. With the continuous improvement of ecological development awareness, green infrastructure construction has also received more and more attention. As an important ecologically sustainable green infrastructure in urban construction, the rain garden has been vigorously promoted and applied in recent years. Rain garden can effectively purify pollutants in rainwater, reduce total runoff, peak flow and runoff speed. It has good landscape and ecological functions [1]. As an important part of the rain garden, plants play a key role in the realization of ecological functions such as rain retention, water purification, and the shaping of landscape effects. Therefore, the related research on rain garden plants in China is gradually deepening. Based on the quantitative analysis and content analysis of existing literature, this article explores the current research status of rain garden plants in China. By summing up experience and discovering deficiencies, it provides scientific reference for in-depth study of this subject.

2. Bibliometric analysis of rain garden plants

2.1 Data sources and selection
After consulting the literature and related works, it is believed that the research on rain gardens in China is often accompanied by concepts such as "ecological detention ponds", "low-impact development", and "sponge cities". After searching these keywords, it was found that the results were not only excessive, but also had a low correlation with the rain garden plants. Therefore, only the keywords with the theme of "rain garden" are selected, and the "ecological retention pool" is added in the precise filtering search to make the search results simple and effective. As of the end of October 2019, the search results found that 596 search results were accurately retrieved from the academic journals, conference papers, and master's doctoral dissertations of the China Knowledge Resource Database with the theme "rain garden" and "plants". These 596 articles were screened and identified as related to rain garden plants. A precise search based on "theme as 'rain garden' or containing 'ecological detention ponds' and 'keywords as' plants' or including' plant configuration ", or 'abstract as' rain garden plants', yielded 102 search results. The research content of these results is directly related to rain garden plants and closely related in content. Therefore, 592 search results were mainly analyzed by bibliometric analysis, and 102 related research trends were confirmed. 100 articles of directly related literature were used as the object of in-depth research and content analysis for careful reading and comparison. At the same time, some articles on sponge city, low-impact development and green infrastructure also involve the planting and selection of rain garden plants, which are also included in the content analysis.

2.2 Data analysis
Based on bibliometrics, 592 Literature related to Rain Garden Plants (RGPR) and 102 Rain garden Literature with "Plant / Plant Arrangement as Keyword"(RGP)were analyzed in different dimensions. Analysis, the conclusions are as follows:

2.2.1 Annual publication volume and trend. As shown in Fig1, China 's research on rain gardens began to involve plants in 2007. Special research focused on the design elements of the rain garden 's "plants" has appeared since 2010. RGPR and RGP have an inclusive relationship and the growth trend of the amount of papers is converging. Since then, the annual volume of papers has steadily increased. In 2014, the number of papers posted after the “Sponge City” proposal surged, reaching a peak in 2017, after which the growth rate of papers had slowed. As of the end of October 2019, there were 58 papers in the RGPR field and 173 predicted CNKI; 9 papers in the RGP field and 37 predicted CNKI; according to the existing data and time points, the predicted CNKI may be too much optimism. It can be seen that China's research on rain garden plants has experienced initial sprouts and rapid growth. At present, the research fever has decreased, but it is still a hot topic of research.

2.2.2 Resource types and literature sources. As shown in Fig 2, RGPR resources are mainly Chinese academic journals and excellent master's theses, accounting for 45.6% and 48.5% of the total, respectively. The largest number of master's thesis is 287, which is even higher than the total of 270 published in all Chinese academic journals. The total number of outstanding doctoral dissertations published was the same as the total number of dissertations in domestic conferences, which were 13 and 14, respectively. The rest are published in academic journals and newspapers. The composition of
RGP resource type is simple. It consists of excellent master's thesis, Chinese academic journals, and domestic conference papers. The proportion of master's thesis is still up to 74%. It can be seen that the types of research literature resources on rain garden plants in China are dominated by "Excellent Master Thesis" and "Chinese Academic Journals". Correspondingly, the sources of RGPR documents are mainly journals and excellent dissertations, and research units with 5 or more publications are selected for ranking(Fig 4). "Modern Gardening" contains the most RGPR. Xi'an University of Architecture and Technology and Beijing Forestry University in the rain garden plant aspects of the master and doctoral thesis far more than other schools, indicating that the above three have a high degree of attention to the rain garden plant, formed a certain amount of literature accumulation.

Fig.3 Subject Classification and Research Level of "RGPR" Literature in CNKI (2007-October 2019)

Fig.4 Keyword Co-occurrence Matrix Analysis of Rainwater Garden Plants in CNKI (Form CNKI)

2.2.3 Subject Classification and Others. As shown in Fig 3, by categorizing and analyzing the disciplines of RGPR, it can be seen that 51% of the literature belongs to the urban and rural planning and municipal areas; most of the rain garden plant literature belongs to these four areas: urban and rural planning and municipal, hydraulic engineering, ornamental horticulture and gardens and urban economy, which indicates that there are many scholars studying rain garden plants in these four fields. Few literatures are related to the atmosphere, education, clinical medicine, etc., their joint points with rain garden plants, such as: its purification of the atmosphere, its popularization of science, aromatherapy, etc.; These documents are set out in terms of different subject backgrounds, indicating areas that deserve further research and development.
At the same time, after collation of the relevant literature of rain garden plants, as shown in Fig 5, it was found that there were 59 articles supported by the fund, of which 33 were supported by the National Natural Science Foundation of China. The National Natural Science Foundation of China has played an important role in promoting this project. From the keyword co-occurrence matrix analysis of rain garden plants in CNKI, it can be seen that the keywords of sponge city, landscape design, low-impact development, rainwater utilization, garden plants, and plant configuration are closely related to this topic. Sponge city and landscape design are the focus of this topic.

3. Rain garden plant configuration

3.1 Rain garden plant concept and characteristics

The rain garden is also called Bioretention basins. It is a landscape depression that filters rainwater runoff through soil and plants and penetrates into the underlying soil and uses physical, biological, and chemical treatment processes to remove runoff pollutants [2]. Rain garden plants are suitable for the construction of rain gardens and can help rain gardens achieve complete functions. Firstly, the survival of rain garden plants is mainly affected by the characteristics of the rain garden itself, that is, the flow characteristics and pollutant characteristics of the rain garden [3]. Therefore, rain garden plants generally have a certain resistance to drought and waterlogging, can resist the impact of a certain intensity of water flow, and have the characteristics of purifying water quality and being resistant to pollution. Secondly, rain garden plants are an important component of the rain garden landscape, so they need to be ornamental. Finally, as a part of the construction of rain gardens, plants must be considered that the difficulty of obtaining and cost control. Therefore, it is the best choice to obtain plant varieties that are easy to obtain and low in price.

| Type          | Name                                                                 |
|---------------|----------------------------------------------------------------------|
| Aquatic plants| Phragmites communis [26-27], Typha orientalis [27-28], Acorus calamus L. [29], Iris L. [30], Hedychium coronarium Koen [31], Scirpus validus Vahl [32], Zizania latifolia [33], Arundo donax [29,34], Sagittaria trifolia L. [35] |
| Floating plants| Eichhornia crassipes [36], Salvinia natans [37], Lemna L. [38], Azolla filiculoides [28], Pistia stratiotes [39], Nymphoides peltata [40] |
| Submerged plants| Ceratophyllum L. [41], Vallisneria natans (Lour.) Harv [34-42], Potamogeton maackianus A. Benn. [42], Hydrilla Rich. [40], Myriophyllum verticillatum L. [43] |
| Wet plants    | Canna indica L. [34,44], Lythrum salicaria L. [34], Juncus L. [45], Thalia dealbata. [39], Paspalidium flavidum [46], Polygonum lapathifolium L. [47] |
| Xerophytes    | Graptophyllum [49], Leersia hexandra Swartz [49-50], Rohdea Roth [51], Nerium oleander [53] |

3.2 Selection and configuration of rain garden plants

3.2.1 Study on Selection Principles of Rain garden Plants. Xiang [3] et al. have been mentioned, Wan [4] first summarized the requirements in terms of stress resistance, purification efficiency, high ornamental value, easy management and ecological security. Liu [5] proposed: 1) preferentially select native plants and appropriately match alien species; 2) choose plants with developed root systems, lush stems and leaves, and strong purification ability; 3) choose plants that are resistant to waterlogging and have certain drought resistance; 4) choose plants that can be planted with each other to improve decontamination and ornamental value. Wang [1] et al. Proposed that perennial and evergreen plants should be selected as far as possible to reduce the maintenance cost, and corresponding plants should be selected according to the different characteristics of the water storage area, buffer zone and marginal area. Yan [6] and others proposed in Shenyang area that the plants with
heavy metal absorbing and degrading ability should be selected for the characteristics of heavy metal containing precipitation in this area. Similarly, taking cold regions as the research objects, Zhong [7] proposed that plants with strong cold tolerance should be selected appropriately, and 11 suitable herbaceous plants were finally selected. The principle of rain garden plant selection is described by an abstract qualitative description, which is gradually refined, and then there are screening principles applicable to different regions and selection weights for different focuses.

3.2.2 Research on Construction of Rain garden Plant Selection and Evaluation System Based on Analytic Hierarchy Process. Cai [8] used common plants in Beijing as a research object, and constructed a rain garden evaluation system from three aspects: plant resistance, ornamental value, and ecological value. Finally, 24 rain garden excellent species and 42 rain gardens better species were selected. It also provided a method for scientific evaluation of rain garden plant selection. Ma [9-10] et al., took Shanghai Gongkang Rain garden and Hangzhou Changqiaoxi Water Ecological Restoration Park as research objects, and explored the selection characteristics of rain garden plants in Jiangsu, Zhejiang, and Shanghai. Wu [11] et al. took the healthy ecological park of Qunli rain garden as the research, and constructed a cold rain garden evaluation system from four aspects: plant growth characteristics, ornamental characteristics, ecological adaptability, and economy. Han [12] took Ya'an area as an example, constructed a plant evaluation system from 3 criterion layers and 9 index layers, and concluded that the factors with larger weights and the preferred selection of rain gardens in Ya'an area, carefully selected plants, etc. Feng [13] took the Beijing area as an example, discussed the plant landscape evaluation research of low-impact development facilities, and proposed an AHP evaluation system constructed by four layers and the 10 influencing factors. The four layers include the target layer, the constraint layer, the standard layer, the lowest layer. The evaluation results of the plant landscape of the biological detention facility and the planting grass ditch are presented.

3.2.3 Arrangement of Rain garden Plants. Wan [4] proposed that the plant configuration of the rain garden should be: 1) analysis based on the characteristics of the community; 2) configuration based on the decontamination characteristics of the plant; 3) configuration based on the type of plant demand for nutrients; Liu [5] gave a detailed elaboration of the principles of plant configuration from the perspective of the construction of rain gardens with two purposes: "for the purpose of controlling runoff pollution" and "for the purpose of controlling runoff flow". Wang [14] discussed the rain garden plants in the residential area; Bai [15] discussed the configuration process of the rain garden plants from the perspective of the color of the flower border; Dun [16] analyzed and summarized the construction methods of rain garden plant communities based on the climatic characteristics of Nanchang, and listed some suitable assemblies. Zhang [17] discussed the configuration of rain gardens in humid, semi-humid and arid regions under different hydrological conditions; Zhang [17] discussed the study on the disposition of rain gardens in humid, sub-humid and arid areas under different hydrological conditions, and the different configuration principles of rain garden plants under aesthetic and functional conditions. Further, Yuan [18] et al. proposed that the application of the new naturalistic herb landscape to rain gardens; in the plant configuration, appropriate amount of deep-rooted species should be selected for mixed planting; the different structures of the rain garden should be matched with the selection habitat, and the plant configuration should be in pursuit of "orderly chaos". By imitating the plant configuration in the natural habitat, in order to obtain an efficient and stable rain garden plant system.

4. Decontamination effectiveness of rain garden plants
The sources of rainwater pollutants in cities are complex, and the pollution levels are not low compared to typical urban domestic sewage [19]. In particular, the concentration of pollutants in the initial rainwater runoff is even much higher than the national Class V water discharge standards [20]. Moreover, the chemical composition of rainfall in different seasons at the same location is also very
different [21-24]. Plants are one of the key factors for rainwater purification in rain garden [25], the purification function of plants is the focus and difficulty of research. According to the habitat and decontamination characteristics of plant planting, it is of great practical value to optimize the rain garden system. Plants can be classified according to their requirements and adaptation to the water condition in the habitat: aquatic plants (erect plants, floating plants and floating leaf plants, submerged plants), wet plants and xerophytes [25]. Different plants have different effects on adsorption and removal of pollutants due to growth morphology and root distribution. Common plants with water purification capabilities are shown in Table 1.

4.1 Total suspended solids and solid particulate matter
Total suspended solids (TSS) is a good indicator of the presence of organic matter, nitrogen, phosphorus nutrients, and heavy metals [53]. Existing researches on rain gardens and artificial wetlands show that plants have a very obvious effect on the removal of TSS. Xi [54] studied the combination of 9 aquatic plants. The removal rate of total solid suspended matter reached 54% after a period of operation. Wu Jian [55] and other researches proposed that the turf buffer has the strongest ability to intercept runoff pollutants, and the 12m-long Bermuda test has a retention rate of about 70% for solid suspended solids (SS). Dong [43] and other experiments on myriophyllum treatment of various levels of aquaculture wastewater, the total average removal rate of SS by different plant combinations was as high as 81.3%. In addition to the plant's direct adsorption, plants can also enhance the further degradation of suspended solids and particulate matter by microorganisms through the rhizosphere effect [41].

4.2 COD and nutrients such as N and P
Under different water conditions, the absorption of TP, TN and COD by plants changed significantly. Xu [56] took calamus, water hyacinth, water bamboo, and reed bamboo as research objects. Through indoor hydroponic experiments and outdoor pool plot experiments, the absorption characteristics and application characteristics of nitrogen and phosphorus of the above four plants under different pollution concentrations and different application scenarios were obtained. Yu [33] studied the growth of scirpus triqueter, phragmites australis and zizania latifolia under different aeration depths and the removal effect of nitrogen and phosphorus in water. Xiao [55] studied the effect and mechanism of plants treating urban black-smelly river water in biological tanks with different aeration levels and different planting densities. Yu [57] found that the interception effect of aquatic plants in ecological canals on nitrogen and phosphorus non-point source pollution in agricultural areas found that in seasonal changes of water bodies, the total nitrogen, ammonia nitrogen and phosphorus concentrations were highest in winter. Li [58] discussed the effect of different pH on nitrogen and phosphorus absorption when using aquatic plants to treat sewage. It should be noted that the purification effect of plants in rain gardens is often not as ideal as under artificial wetlands. Soil, padding, and hydraulic retention time will greatly affect its removal effect [59].

4.3 Enrichment and removal of heavy metals
Heavy metals usually accompany precipitation with two forms of pollution to the receiving water body and soil. Dissolved heavy metals can be directly absorbed by plants or adsorbed by the filler layer medium. Granular heavy metals are usually attached to total suspended matter (TSS), which are intercepted and decomposed by the plant system on the ground, and then absorbed by plants [60]. It is generally believed that in order of the aquatic plants' enrichment ability, submerged plants are the best, and emergent plants are the weakest. Common emergent plants with significant effects on heavy metal enrichment are Phragmitas comunis [27], Typha angustata [26], etc. The floating plants include Lemna minor [61], Eichhornia crassipes [62], etc. Submerged plants such as Potamogeton maackianus A. Benn. [63] and Vallisneria natans (Lour.) Hara [35]; wet plants such as Canna indica [45], Juncus effusus [46]; xerophytes such as Alternanthera philoxeroides (Mart.) Griseb. [62], Leersiahexandra Swartz [50]. In
addition, heavy metal extraction or treatment of the harvested plants to prevent secondary pollution from dead plant bodies is an important issue affecting the sustainable removal of heavy metals.

5. Conclusions
The research on plants in rain gardens in China has developed rapidly in recent years, and the amount of publication has slowed down but is still rising, and related research is gradually deepening. The relevant literature mainly comes from excellent master thesis and journals, which indicates that there are too many systematic studies on this topic, and there is still much room for special research in specific subdivided fields. The literature on rain garden plants covers a wide range of disciplines. Researchers mainly come from urban and rural planning and municipal administration, water conservancy engineering, ornamental horticulture and gardening. The study of a few scholars from other backgrounds is helpful to inspire different research ideas. In addition, through the analysis of the co-occurrence matrix of the research fund and keywords, it is concluded that the “National Natural Science Fund” has greatly promoted this research. Sponge city and landscape design are the main focus of this research and the main application direction.

Through the study on the principles of the arrangement of rain garden plants, it is concluded that the selection principles of rain garden plants are gradually becoming clear. With reference to the current state of foreign research, more specific screening manuals need to be developed in various regions based on their own phenological conditions. The introduction of the analytic hierarchy process has promoted the scientific evaluation of the planting effect of rain garden plants, which is conducive to the scientific formulation of plant allocation plans. However, the disadvantage is that under different configuration densities and different configuration modes, there are fewer studies on the continuity, decontamination effect and peak retention effect of rain garden, and there is a lack of qualitative experimental research.

In terms of decontamination efficiency of rain garden plants, three aspects of solid suspended solids, chemical oxygen demand, nitrogen, phosphorus nutrients, and heavy metals were analyzed significantly, and common plants with decontamination effects under different habitat conditions were summarized. The decontamination plants currently studied are mostly wetland plants. However, in the application scenario of rain garden, necessary xerophytes and even large trees are also very potential targets for decontamination, so we should pay attention to and strengthen research in this area.

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