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Article

Establishing the Evaluation Indexes of Sustainable Development of Green Livable City

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Abstract: A green city has ideal and modern urban development with extraordinary harmony of environment, ecology, economy, society, culture, and people. The coordination of human relations and green development has become a new development model for a modern society. Recently, the construction of a green city has aroused wide concern. Despite problems, the priority to coordinate the groups with different needs is needed to maintain the green development of cities. In this study, different levels of factors related to the construction of green cities were classified using the analytical hierarchy process (AHP). Qualitative and quantitative analyses were performed and the related green city construction standards were established.

Keywords: Green City, Evaluation, Sustainable Development

1. Introduction

City, as a physical space for human life, has a complex ecological system and guides human behaviors as being based on the lifeline of the natural environment and the flow of resources as well as the social system [1]. According to the requirements in green city (G.C.) construction, production, life, and environment need to be green to secure intensive and high-efficiency production space, habitable living space, and picturesque ecological space. Harmonizing human relations and green development has become important in the new development model of the modern world. The word ‘Green’ in “green development” is closely linked with sustainable development.

In 1987, on behalf of the World Commission on Environment and Development (WCED), Norwegian Prime Minister Ms. Brundtland formally proposed the concept of sustainable development in the report ‘Our Common Future’ and appealed for satisfying today’s demands under the premise of no harms to the needs of future generators [2]. Hu et al. pointed out that the development of green road is to stress the unity and coordination between economic development and environmental protection. In other words, green road refers to active and people-oriented sustainable development. Green development demands improving the utilization of energy resources and protecting and restoring the natural ecological system and process, to achieve the coevolution of humans and nature by harmonious coexistence [3]. The evaluation system of G.C. development is complex and mainly used at a city’s green development level, which provides an important basis for urban planning, construction, evaluation, and management [4]. Therefore, the evaluation system of urban green development reflects the city’s development status and provides a scientific basis for the governments to determine the development, plan, and decision of G.C. under the actual condition of China’s cities. Currently, the evaluation of China’s urban green development is still at an initial stage, and the related evaluation indexes of green development have not been systematically examined.

2. Determination of the Evaluation Indexes and System

Chinese scholars have conducted much research on the evaluation of urban green development. Four departments of the National Development and Reform Commission and the National Bureau of Statistics of the People’s Republic of China jointly released the Green Development Index System for measuring green development in various regions from the following aspects: resource utilization, environmental governance, environmental quality, ecological protection, growth quality, green living and public satisfaction index (PSI). China’s green development index, cooperatively proposed by the Institute of Economic and Resource Management, Beijing Normal University, and China Economic Climate Monitoring Center in the National Bureau of Statistics, included 44 indexes from three aspects of the greenness degree of economic growth, the bearing potential of resources and environment, and the support degree of government policies.

The United Nations Environment Program (UNEP) holds the opinion that green cities should be eco-friendly [5]. Kahn et al. stated that green cities should involve the standards of urban ecological environment quality, public health, and economy [6]. Earth

Day Network pointed out that green cities should have clean and efficient energy, transportation, and building facilities [7]. Zhang and Li suggested that green cities need healthy urban development and pattern featured by a prosperous green economy and green human environment [8]. Hsu and Cai stated that the worldwide attention to the development of public transport system can promote the development of G.C. [9]. Martino pointed out that a G.C. should focus on energy conservation and emission reduction and achieve zero carbon emission [10]. Yun-zhi confirmed the important role of urban green space construction in G.C. construction [11].

In this study, the temporal/spatial urban development condition in China, was investigated. According to the fundamental principles of comprehensiveness, scientificity, data accessibility, operability, and typicality, the G.C. evaluation model in G.C. Evaluation Index, Green Development Index System in Jiangsu, and TOP 50 in 2019 China's G.C. Index, were evaluated based on the characteristics and connotations of G.C., and then the evaluation index system was established. The evaluation index system of three-level G.C. development consists of 3 evaluation dimensions and 8 evaluation indexes. As shown in Fig. 1, the whole system includes three levels: the objective, the dimension, and the index layer.

The green development index system is based on the research and summary of domestic and foreign green development and sustainable development related theories and practical results, combined with the reality of China's growth and environmental protection, and was formulated in 2016 to measure the national and sub-regional green development indexes and there are six sub-indexes: resource utilization index, environmental governance index, environmental quality index, ecological protection index, growth quality index, and green life index [12,13]. Green development indicators are divided into positive and negative indicators according to the evaluation function, and are divided into absolute and relative indicators according to the nature of the indicator data. Each indicator needs to be dimensionlessly processed. The specific processing method is to convert the absolute number index into a relative number index, convert the reverse index into a positive index, convert the total control index into an annual growth control index, and then calculate the individual index.

Green Development Index System in Jiangsu focuses on Jiangsu's experience in promoting green buildings and green eco-city, including green ecological special planning, policy mechanisms, fundraising, technical standards systems, and promotion [14]. This paper introduces practical experience of demonstration districts in special planning guidance, policy mechanism development, green building development, and urban green infrastructure construction, taking the Nanjing Hexi Xincheng model district as an example.

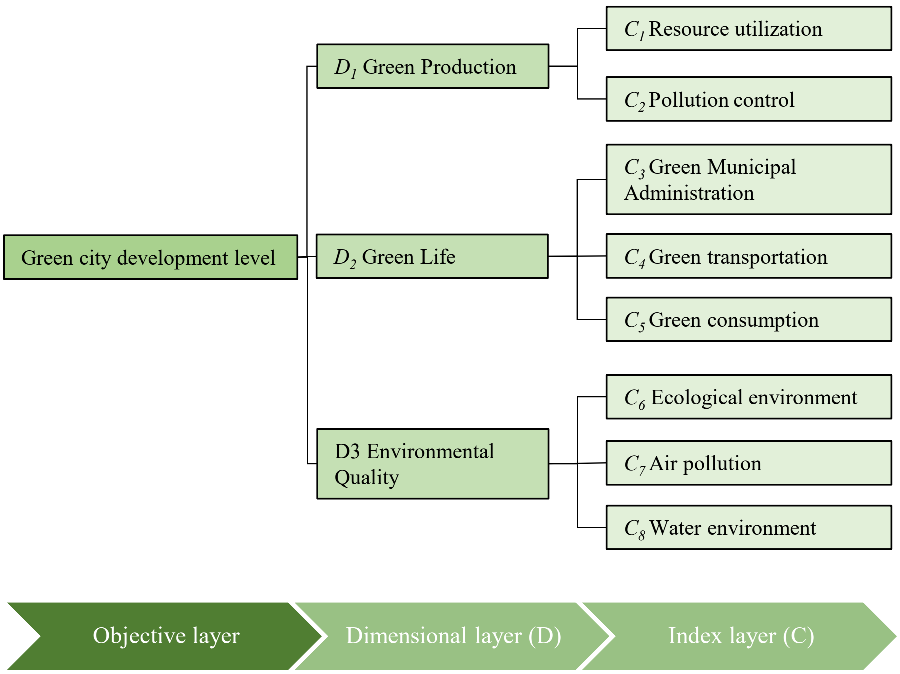

Fig. 1. The framework of G.C. sustainable development evaluation index system.

The 2019 China G.C. Index TOP50 report was compiled in 2019 by the Eco-Finance Research Center of Renmin University of China [15]. On the one hand, it truly reflects the level of green development of each city through publicly released data from relevant departments. It is a city's decision makers and related investors. Provide reference; on the other hand, we also hope that each city will adhere to the people-oriented approach on the road of promoting green development, and continuously improve the quality of the urban environment, the quality of life of citizens, and the competitiveness of the city.

3. Methods

Strategic planning, evaluation, education administration or policy research, has encountered how to choose the best program, how to establish an appropriate assessment index weight and other issues, the simple approach is to directly adopt or combine simple statistics (such as averages), to integrate the program sequence evaluation values and indicator weight values proposed by experts, although this method is simple, but it can not effectively eliminate the deliberate bias of the evaluators, serious differences between the evaluators and other issues, and affect the objectivity and stability of the entire evaluation results. For this kind of multi-criteria evaluation problem, scholars have developed a quantitative approach and a pairwise comparison method to integrate the objective best conclusions, such as AHP or ANP analysis, which have been widely used in various fields such as education administration, business management and decision science.

Now society is the result of a complex of problems, which in turn consist of a number of factors that interact, both tangible and intangible, qualitative or quantitative. In the past, the development of systems approaches has been extensively explored in social or behavioral sciences, allowing complex problems to be simplified while establishing their accurate results. For decision makers, accurate results help to understand things, but when faced with a choice, it is necessary to evaluate the scheme already with certain criteria to determine their priority and then find the appropriate option. The Hierarchical Analysis (AHP) and Delphi methods are a set of theories developed in this context, providing a solution to complex decision-making problems in the fields of ESC and management science.

There are many decision-making problems often encountered in daily life, such as supplier selection, curriculum design and planning, school evaluation, housing rental decision-making car business base location selection, key factors for the success of an industry operation, evaluation of ecological engineering on mountain roads, evaluation criteria for credit card audits... etc., all require planning methods (AHP or fuzzy AHP) assessment/evaluation methods (Delphi or Fuzzy Delphi) and evaluation tools.

When decision-making activities are carried out by decision-makers, because it is difficult to structure the evaluation criteria that affect decision-making issues, or the evaluation criteria have different characteristics of quantitative and qualitative, decision-makers are often unable to obtain sufficient information to make decisions.

AHP (Hierarchical Analysis) has gradually become a tool method for solving various decision-making problems, and its application is quite wide-ranging' in particular, forecasting, evaluation, judgment, planning matters, resource allocation, engineering planning and investment organization have achieved excellent results, Saaty (1980) classification has been applied to the following thirteen decision-making problems [16]:

(1) Setting Priorities. The prioritization of the guidelines can also be solved using DECENTL;
(2) Generating a Set of Alternatives;
(3) Choosing the Best Policy Alternative;
(4) Determining Requirements;
(5) Making Decision Using Benefits and costs;
(6) Allocating Resources;
(7) Predicting Outcomes–Risk Assessment.
(8) Measuring Performance;
(9) Designing a System;
(l0) Ensuring System Stability;
(ll) Optimizing;
(l2) Planning;
(l3) Conflict Resolution.

A literature review is the process of conducting a systematic survey and analysis of relevant literature in social research to understand the status of research in a specific field. In the context of urban social development, this study investigates the current status of green city evaluation through literature review, and establishes a novel evaluation index framework.

In the evaluation of urban development, the choice of multiple goals, multiple standards, and multiple attributes is meaningful. In the past two decades, the multi-criteria decision-making method has developed rapidly and has been used by many scholars in design, selection and evaluation. On the basis of multi-criteria evaluation, the decision maker first expresses the preference structure; then, obtains non-inferior solutions or ranks the order of alternative solutions. In general, multi-criteria decision-making methods can be divided into multi-objective decision-making (MODM) and multi-criteria decision-making (MCDM) methods. Using

MCDM, the optimal solution for each alternative solution can be determined by assessing the degree of relative importance of various attributes. Therefore, MCDM can be regarded as selection problem analysis, which is generally used to evaluate the selection of dimensions. The Analytic Hierarchy (AHP) method is suitable for urban development evaluation in this study because it can calculate the weights of various indicators in multi-attribute decision-making [17].

Analytic hierarchy process (AHP) is a hierarchical weighted decision analysis method proposed by Saaty [16]. The advantage of AHP is to mathematize the thinking process of decision-making using limited quantitative information based on in-depth analysis of essences, influencing factors, and inherent relations of the complex decision problems. It provides a simple and convenient decision-making method for multi-objective, multi-criterion, or no structural-property complex decision-making problems. AHP is devoted to decisions of complex systems that hardly are completely quantized. Many methods stemming from applied mathematics and operations research have proved useful to help decision-makers making informed decisions, and among these methods, there are also those requiring, as inputs, subjective judgments from a decision-maker or an expert. It is in this context that the AHP becomes a useful tool for analyzing decisions [18,19].

4.Computing Process of AHP

4.1. Establishing Pairwise Comparison Matrix

In addition to the objective level, the factors a the other levels should be compared based on the estimation of the important factors. Therefore, the questionnaire should be designed according to the score of pairwise comparison. The score scales should be designed by comparing each pair. In the present questionnaire, score 1 was defined as equal importance, suggesting two factors were at the same importance level; score 3, score 5, score 7, and score 9 were defined as 'important', 'quite important', 'extremely important', and 'absolutely important'. An example of the questionnaire by the experts is also given below.

For a set of n factors in the matrix, the comparison should be performed $n(n-1)/2$ times, and then compared results of n factors should be placed on the top of the pairwise comparison matrix A. Since there are n ratios on the diagonal for the comparison between the factors and themselves, the constants are all 1. The elements at the bottom of the matrix equal to the reciprocal of the values at the corresponding positions on the top. Therefore, the matric can be written as Eq. (1),

$$A = [a_{ij}] = \begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ 1/a_{12} & 1 & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ 1/a_{1n} & 1/a_{2n} & \dots & 1 \end{bmatrix} \tag{1}$$

Then, the sums of the columns are calculated. The normalized values are calculated by dividing the value of each element in the matrix by the sum of each column. Next, the mean of the row vectors is calculated, and the weight of each factor is obtained. The weight of each factor was included in the following matrix, Eq. (2),

$$A = [a_{ij}] = \begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ 1/a_{12} & 1 & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ 1/a_{1n} & 1/a_{2n} & \dots & 1 \end{bmatrix} = \begin{bmatrix} W_1/W_1 & W_1/W_2 & \dots & W_1/W_n \\ W_2/W_1 & W_2/W_2 & \dots & W_2/W_n \\ \dots & \dots & \dots & \dots \\ W_n/W_1 & W_n/W_2 & \dots & W_n/W_n \end{bmatrix} \tag{2}$$

where W_i denotes the weight of the element i, and a_{ij} denotes the ratio of the relative importance between two factors (i=1,2,…,n ; j=1,2,…,n). Further, the evaluation factors for sustainable development level of G.C..

$$a_{ij} = \frac{W_i}{W_j}, a_{ij} = \frac{1}{a_{ji}},$$

$$\mathrm{W}=[W_1, W_2, \dots, W_n]^T = \begin{bmatrix} W_1 \\ W_2 \\ \dots \\ W_n \end{bmatrix} \tag{3}$$

4.2. Calculation of Eigenvalue and Eigenvector

After the establishment of a pairwise comparison matrix, the eigenvalue and the eigenvector of the matrix are calculated to obtain the weights of the factors at different levels.

The eigenvector equals the normalization of the geometrical means of the multiplication of various elements in a column.

$$W_i = \frac{\left(\prod_{j=1}^{n} a_{ij}\right)^{\frac{1}{n}}}{\sum_{i=1}^{n}\left(\prod_{j=1}^{n} a_{ij}\right)^{\frac{1}{n}}}, i, j = 1, 2, \ldots, n \tag{4}$$

A new eigenvector *Wi*' is obtained by multiplying the pairwise comparison matrix *A* by the calculated eigenvector *Wi*. The division of each vector in *Wi'* by the corresponding vector in original Wi is calculated, and the arithmetic average of various values is obtained to calculate the value of λmax, as shown in Eqs. (5)–(7),

$$A \times W = \lambda_{max} \times W \tag{5}$$

$$A = \begin{bmatrix} W_1/W_1 & W_1/W_2 & \cdots & W_1/W_n \\ W_2/W_1 & W_2/W_2 & \cdots & W_2/W_n \\ \cdots & \cdots & \cdots & \cdots \\ W_n/W_1 & W_n/W_2 & \cdots & W_n/W_n \end{bmatrix} \times \begin{bmatrix} W_1 \\ W_2 \\ \cdots \\ W_n \end{bmatrix} = \begin{bmatrix} W_1' \\ W_2' \\ \cdots \\ W_n' \end{bmatrix} \quad 6)$$

where

$$\lambda_{max} = \frac{1}{n}\left(\frac{W_1'}{W_1} + \frac{W_2'}{W_2} + \ldots + \frac{W_n'}{W_n}\right) \tag{7}$$

4.3. Consistency Test

The values in the pairwise comparison matrix were set by the experts according to subjective judgment with influencing factors involved. It is difficult to achieve consistency. Therefore, the consistency test was conducted, and the consistency index (C.I.) was calculated for examining whether the pairwise comparison matrix of the expert answers was consistant.

The consistency index (C.I.) can be calculated as,

$$\text{C. I.} = \frac{\lambda_{max-n}}{n-1} \tag{8}$$

where λmax denotes the maximum eigenvalue of matrix A, and n denotes the number of the evaluation factors.

When the value of C.I. is 0, the importance degrees of n factors are completely consistent. When the value of C.I. is greater than 0, the judgments of various experts are different. A smaller value of the value of C.I. indicates the experts' answers are similar. It was suggested by Saaty that the optimal value of C.I. and the allowable. The positive reciprocal matrix at the evaluation dimension from 1 to 9 has a different random index (R.I.) in different orders, as shown in Table 1.

Table 1. Random index of different levels in AHP

NoO [1]	1	2	3	4	5	6	7	8	9
R. I	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45

[1] Number of orders (NoO)

For the matrix with the same orders, the consistency ratio is defined as the ratio of the value of C.I. to the value of R.I. maximum deviation should be 0.1 and 0.2.

$$\text{C.R.} = \frac{\text{C.I.}}{\text{R.I.}} \tag{9}$$

When the value of C.R. is lower than 0.1, the matrix shows a high consistency degree.

4. Results and Discussion

The evaluation indexes for the sustainable development level of the G.C. were designed with three dimensions: green production, green life, and environmental quality. Evaluation indicators are set up under each element, and then a three-level evaluation index system for the level of the G.C. was established.

In this study, the questionnaires from the experts of urban/rural planning, buildings, and environmental ecology were collected. Through analysis, three factors and nine indexes were compared. The integrative calculation and validation satisfied the consistency requirements (C.R. < 0.1). Table V lists the statistics of the values of the evaluator factors.

Environmental quality (D_3) has the greatest weight (0.480), followed by the weight of green life (D_2, 0.406), and finally by green production (D_1, 0.114) among 3 dimensions, as shown as Fig. 2.

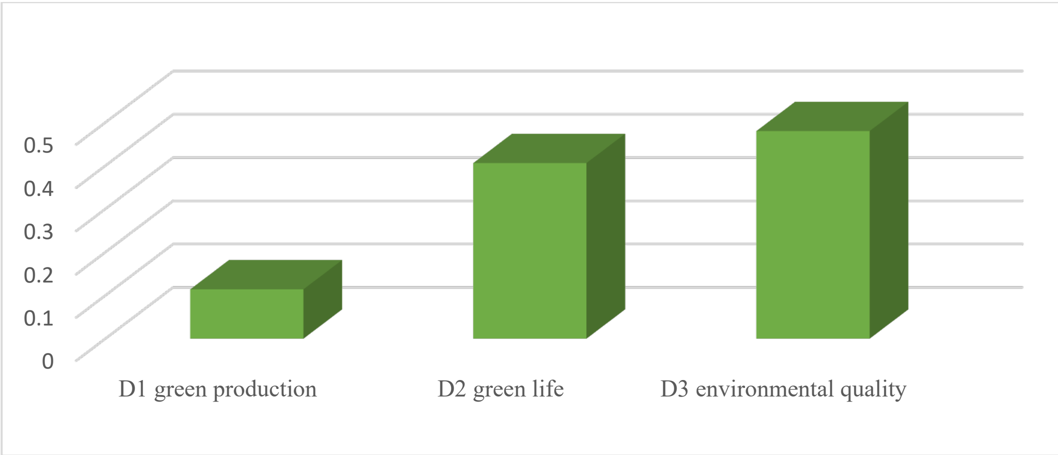

Fig. 2. Objective Layer.

Next, the weights of 8 indexes were analyzed. In the dimension D_1, the weight of resource utilization (C_1) was greatest (0.750), followed by the weight of pollution control (C_2), as shown as Fig. 3.

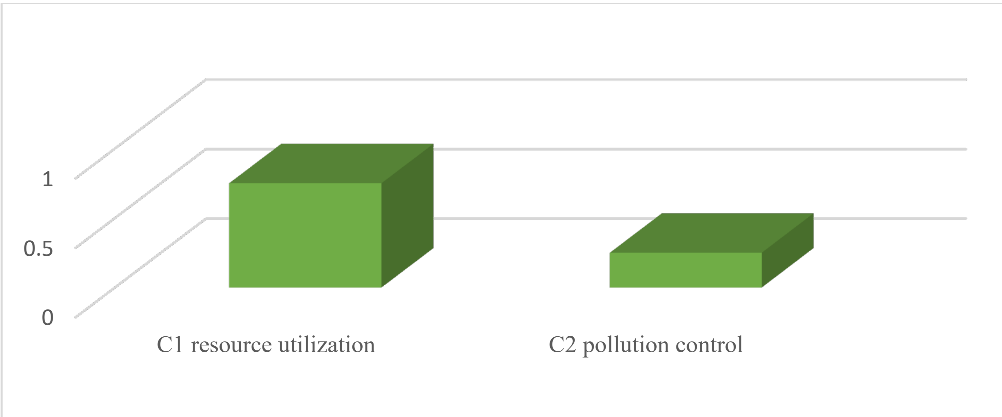

Fig. 3. Dimension D_1.

In the dimension D_2, the weight of green municipal administration (C_3) was greatest (0.634), followed by the weights of green transportation (C_4) and green consumption (C_5) , as shown as Fig. 4.

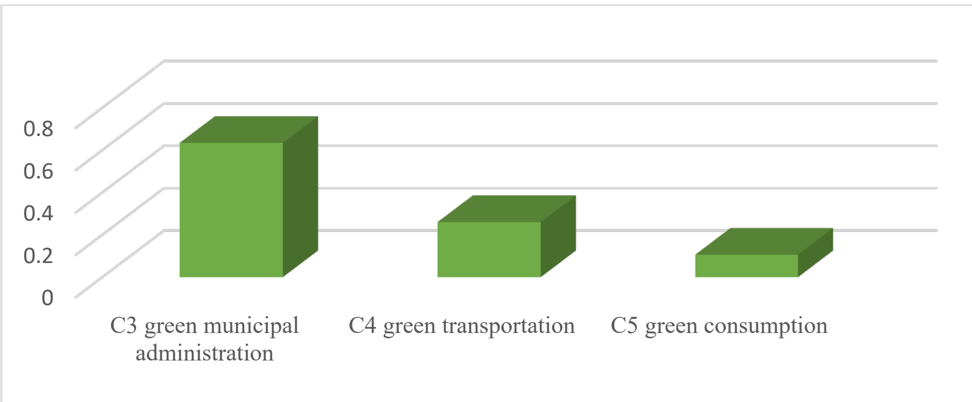

Fig. 4. Dimension D_2.

In the dimension of D_3, the weight of ecological environment (C_6) was greatest (0.634), followed by air environment (C_7) and water environment (C_8), as shown as Fig. 5.

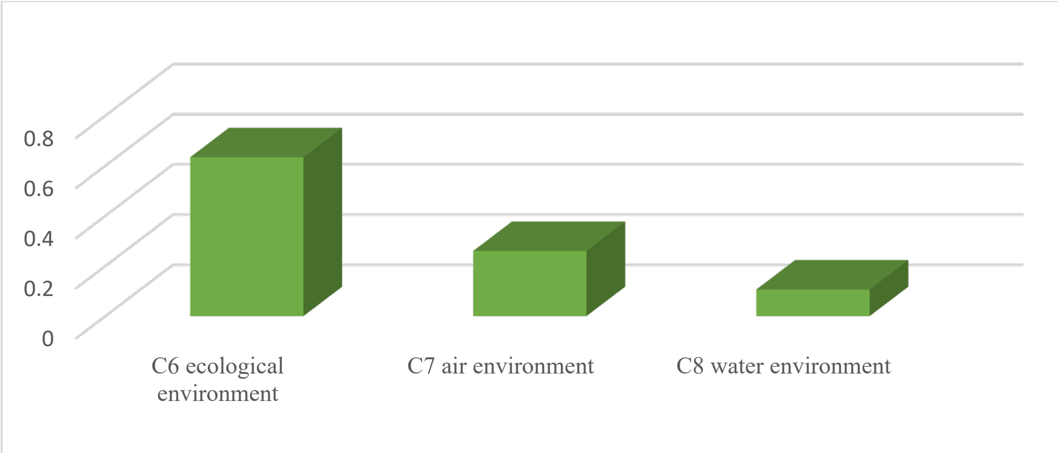

Fig. 5. Dimension D_3.

However, by combining all dimensions and indexes, it is found that the comprehensive weight of C_6 (0.304)>the comprehensive weight of C_3 (0.257) > the comprehensive weight of C_7 (0.125) > the comprehensive weight of C_4 (0.106) > the comprehensive weight of C_1 (0.085) > the comprehensive weight of C_8 (0.051) > the comprehensive weight of C_5 (0.043) > the comprehensive weight of C_2 (0.029). The result shows that environmental quality of ecological and air environment have the most significant effect on the sustainable development of the G.C., while green production has the least significant effect, as shown as Fig. 6.

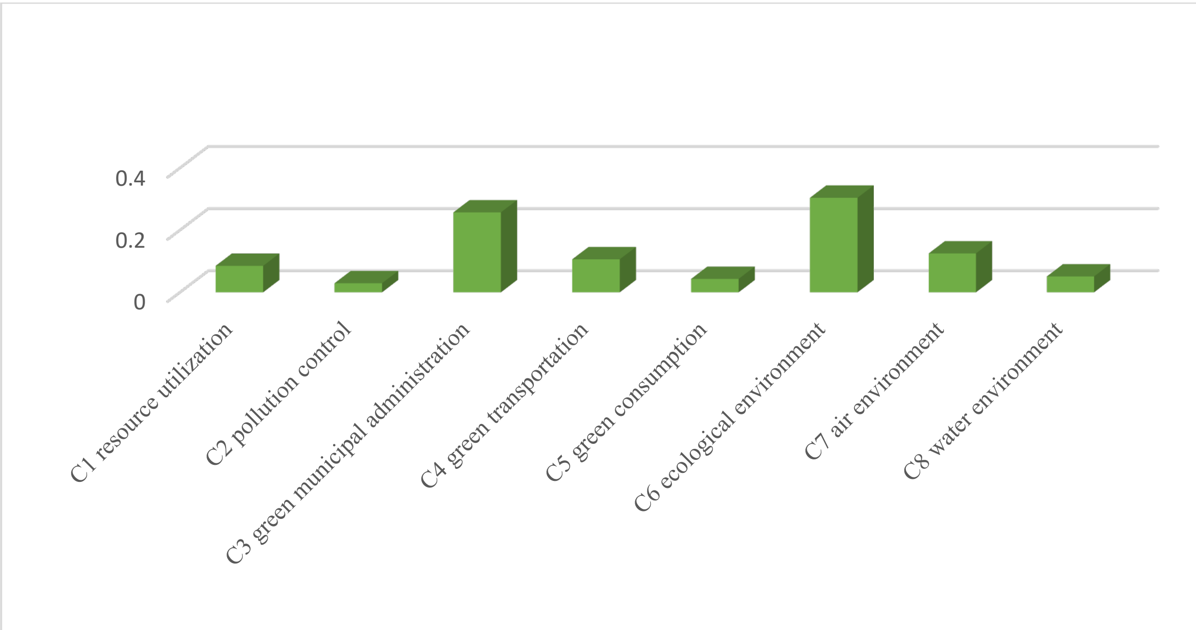

Fig. 6. Weights of the evaluation factors for sustainable development level of G.C.

5. Conclusions

This study put the research emphasis on determining the evaluation indexes and designing the criterion of G.C. sustainable development. The geometric mean and the consistency were calculated from analyzing the questionnaire of the experts. The result shows that the weight of environmental quality was largest (0.480), which exceeded the weights of the other two dimensions. The environmental quality should be considered in G.C. construction. Among various indexes, geological environment and green municipal administration had the greatest weights (0.304 and 0.257), which suggests that the ecological environment should be protected and planned in the construction of the G.C. to maintain integrity. Meanwhile, green municipal administration needs to bring vitality to city development. The weights of ecological environment and green transportation were 0.125 and 0.106, respectively. This suggests that air quality should also be considered in G.C. construction. Only a clean and acceptable air quality is attractive for the development of industries such as tourism and culture. The result suggests the government tries not to gain economic benefits at the cost of natural and human profits from overdevelopment. We simply set up a G.C. evaluation system, hoping to provide experience for the future G.C. construction.

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