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Early Warning of Urban Residential Development Considering Sustainability Factors

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Abstract

It has never been an outdated topic to discuss how to construct and improve the residential urban area in the process of territorial development. The challenges and problems of creating a residential urban area are always associated with the issues of human beings, relations and activities among human, the district surrounding, etc. For instance, the creation of urban areas for human beings may be harmful to the environment and cause more population pressure problems. Hence, the creation of residential urban area does not only bring advantages, but is also connected to problems. To manage it carefully it is necessary to consider sustainable development, which stresses that environment should not be separated from development. Diverse approaches have been used for measuring the sustainability, as it reflects relationship between human beings and the systems of environment. Based on the approaches, sustainability assessment is utilized to assess the overall improvement of sustainable development. In the context of the sustainability assessment, the purpose of this article is to integrate two diverse approaches, including the systems of environmental indicator and the analysis for early warning. This paper also aims to offer a tool that helps the decision maker to measure whether the development of residential urban areas are sustainable and healthy or not, and prevent problems in advance so that urban areas develop healthily and quickly. Hence, this paper analyzes how to create proper early warning indicators and appropriate approaches and modeling that can be utilized for the analysis. To provide sufficient evidence to this article, a real case is discussed in this paper that is connected to the evolution of a residential urban area in China.

Keywords: *urban areas, sustainability, residential development, early warning.*

1. Background

Sustainability is often defined as a necessary for both human beings and the Earth to develop sustainably and healthily. It considers diverse aspects of the development of territory, containing population, economic development and environment quality, and so on [1]. The sustainable development assessment has been used by a lot of countries or international organizations to assess the environment through the usage of specific indicators [2,3,4]. Referring to the information that were collected from the other urban areas, the indicators help to provide information about the status of the system and it also can be used to predict the future trends for the systems [5,6,7]. In this case, it is significant for most of the developing countries, in which the development of the urban areas develop too quick and it is necessary to use the tool to foresee the future sustainability.

In the context of the sustainability assessment, the purpose of this article is to integrate two diverse approaches, including the systems of environmental indicator and the analysis for early warning. This paper also aims to offer a tool that helps the decision maker to

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measure whether the development of residential urban areas are sustainable and healthy or not, and prevent problems in advance so that urban areas develop healthily and quickly.

Following the introduction, there are six sections in this paper: 1) the sustainability indicator system is illustrated in the first section as it is useful for measuring the development of residential urban areas; 2) the Early Warning Systems (EWS) theory is presented in the second section; 3) this section mainly introduces the research methodology, which exhibits how to integrate the indicators approach and EWS; 4) a real case is discussed here through the usage of the methodology; 5) results and findings are discussed and analyzed in this section; 6) a conclusion is made in the final section.

2. Basic Concepts

2.1 Sustainability Indicator System

An indicator is regarded as a parameter, which can be used to assess the environmental status and offer information for the features of the issue in a global form [8]. Many indicator systems are suitable for assessing the sustainable development, and they have been set up by four major organizations. Three of them are often used by the international or European organizations that are specialized in the assessment of sustainable development while the fourth one is mainly used by a Chinese organization.

- Economic Cooperation and Development (OECD) has been studying on the system of environmental indicators for around 27 years. Their work mainly concentrates on the usage of indicators for decision making for countries or international environment problems. Moreover, the methods are also utilized to develop indicators for assessing eco-systems [8].
- The European System of Social Indicators (EUSI) is an international organization as it is a cross-boundaries project in Europe, which was established at the end of 1990s and aims to monitor and assess welfare phenomenon and social status in Europe [9]. The work of the organization mainly focuses on sustainability of welfare development, related to social exclusion, quality of life, social cohesion, etc.
- The United Nations Commission on Sustainable Development (UNCSD) has created several indicators that can be used for sustainability assessment. The approaches set by the organization are very helpful and timely forum, which are available for countries, international organizations and diverse stakeholders. The indicators developed by the organization have played an important part in the world, since it helps countries make decision that is related to the issues of sustainable development, and are applied by a lot of countries as their national indicators are based on the approaches [10].
- The Chinese Urban Development Centre (CUDC) has developed an approach that can assess sustainable development for residential urban areas [11]. The approach is related to an indicator system, which provides information for strategic context, mission, purpose and decision for the sustainable development in China.

Though there are different problems that happened in the residential urban areas, the above indicator systems can be used to address diverse issues. For instance, the indicator system created by the CUDC can be used to assess environmental quality problems, which is very useful for decision making and predict the future environment. In conclusion, the sustainability indicator systems mentioned above can be used to assess the following aspects: environment, economy, housing and society, related major indicators are chosen from the four indicator systems. As Table 1 shows, it provides a clear representation for the indicators that are suitable for assessing and measuring the sustainable development for the residential urban areas.

2.2 The Early Warning Systems (EWS)

The theory of EWS is defined as specific models that can be applied to examine the disadvantages of an indicator system, and to inform decision makers timely information and accurate signal about the events so that specific measures can be taken and decision makers can react timely for the problems.

Abundant research data may not be found from EWS, as it only specializes in economy [12,13,14] and real estate market [15]. Moreover, their work is also related t many other fields, such as natural disasters [16,17], energy [18], project management [19], etc. Their research in diverse fields has helped improve the system and the warning theory, which is good for application in reality.

Table 1. Evaluating Indicators for Urban Residential Development

	Housing	Economy	Environment	Society
OECD		• Growth and structure of GDP; • Private and public consumption expenditure; • Pollution abatement and control expenditure; • Water treatment and noise abatement expenditure; • Official Development Assistance.	• Urban air emissions; • Population exposure to air pollution and noise; • Ambient water conditions in urban areas; • Green spaces.	• Population growth & density; • Structure of energy supply; • Road traffic volumes; • Stock of road vehicles
UNCSD		• GDP per capita; • Intensity of energy use, total and with reference to the different economic activities.	• Ambient concentration of air pollution in urban areas; • Share of renewable energy sources in total energy use; • Generation of waste; • Waste treatment and disposal.	• Proportion of population living below national poverty level; • Proportion of urban population living in slums; • Life expectancy at birth; • Population growth rate; • Dependency rate
EUSI	• Relative size of dwelling stock; • Room and living space per person; • Availability of housing services; • Dwellings in deficient state of repair.	• Percentage of owners; • Households living in one-family houses; • Income related inequality; • Burden of housing costs; • Average rent.	• Noise pollution; • Air pollution; • Accessibility of green space; • Built up land per inhabitant; • Crime in residential areas; • Environment-friendly energy sources for heating; • Energy consumption for space heating; • Energy loss per building; • Insulation of housing stock.	• Shortage of space; • High burden of housing costs; • Satisfaction with housing situation; • Subjective safety in the residential area, • Satisfaction with neighborhood; • Overcrowded dwellings; • Lack of basic amenities
CUDC	• Living space per capita.	• Urban economic aggregate; • GDP per capita; • Amount of residential investment; • Exploitation of real estate; Average wages; • Urban housing price.	• Urban land areas; • Average water resource per capita; • Water supply per capita; • Water consumption per capita; • Electricity consumption per capita; • Public green urban areas per capita; • Green coverage ratio;	• Dependency rate; • Natural population growth rate; • Urban infrastructures;

As it is shown in figure 1, the procedure of the system is divided into 6 aspects, which define the objective of the foundation of the system, exhibit the quantitative and qualitative research of the indicator systems and present the method that predicts future danger. To achieve the prediction for future, the organization has been developed with the application of mathematics and software, which includes MATLAB, regression analysis, etc.

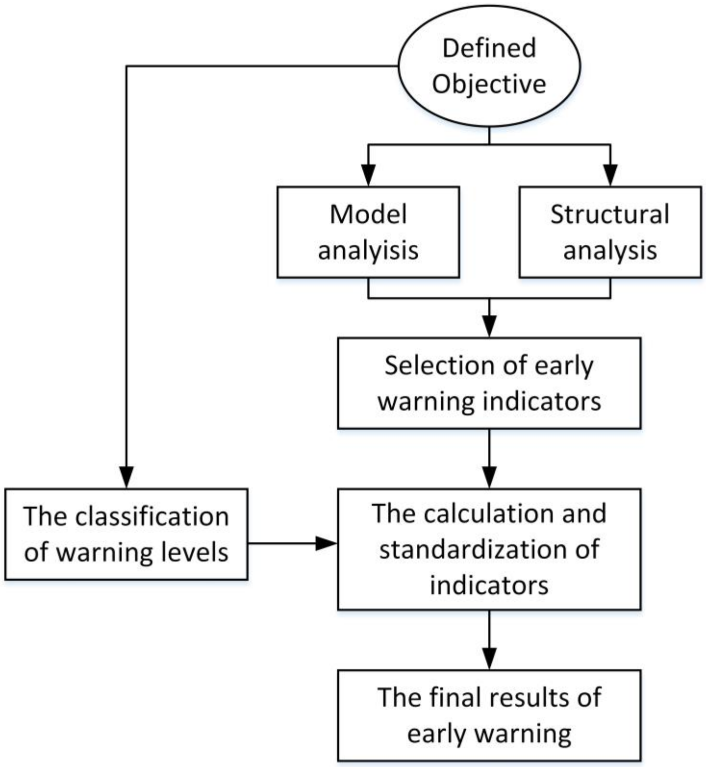

Figure 1. The Early Warning System Procedure

4. The Integration of Sustainability Indicators and Early Warning Systems

Based on the theory of EWS, the assessing model is supposed to contain two major parts: assessment and prediction. The two parts are basic and functional: evaluation provides historical data while the prediction part offers estimate values. Hence, the two function parts provide diverse data according to the EWS model. On one hand, the historical data, also regarded as previous indicators, collects the information according to the requirement of the historical data from yearbooks, social and economic reports, surrounding observations, etc. On the other hand, the estimate values, also defined as future indicators, can estimate the information two years. For instance, a predicted indicator can provide values that go up or go down regularly most of the time, such as GDP. These indicators can predict exact values from the development goals of the nation, the regional development planning, and the information of the global economic organizations. Besides the above two kinds of indicators, the other types of indicators are irregular, since it is regarded as predicted indicators that are unstable, such as indicator for yearly assessment of the urban air emission and the yearly indicator for assessing the living space. The regression analysis approach should be used so that the values of the unstable indicators can be estimated.

To have the sustainability assessment indicators systematized in a EWS, it is a method to think about the work of Driving Forces-Pressure-State-Impact-Response (DPSIR). The framework of DPSIR was originally developed by the Organization of Economic Co-operation [3] and Development (OECD) and has been popular with most of the decision makers for managing the environment [20], which helps the integration of environment indicator and social-economic indicator.

Five steps can be set to integrate DPSIR indicators and a EWS:

Step1. Indicator Selection

The DPSIR indicator can demonstrate the relationship within the interactions of the system in residential urban areas. It is concluded below:

• The motivation of changes in the process of development is driven by the human activities, which are reasons that cause pressure during the period of development in the urban areas;

- The pressures can be direct stresses that have impact on environment, society and economy, as it is from the human activities;
- The real status of the residential urban areas is reflected by the State;
- Influence is caused by the assessment of the surrounding effects because of the human activities in the residential urban areas;
- Specific actions can be taken to reduce pressure and enhance the evolution according to the administrative measures.

The DPSIR presents availability, reliability, usability and sensitivity, which reflect the processes underlying society and economy. And the data and framework of the system have been utilized as the criteria to create the indicator system for this work. There are different types of indicators for the indicator system, containing economic, housing, social and environmental indicators. In table 1, it shows some sustainability assessment indicators, which possess similar functions. An indicator system that is integrated and concise can be selected to deal with the EWS. In Table 2, it exhibits that there are 23 indicators that are chosen for applying the EWS with sustainability assessment in residential urban areas basing on the framework and data of the DPSIR.

Therefore, the whole system can be defined as diverse layers: classifications of DPSIR framework, thematic areas and indictors. The structure of the system is demonstrated in Figure 2.

Table 2. Early Warning Indicators for Urban Residential Development

Thematic Area	Indicator	DPSIR Category
Housing	• Relative size of dwelling stock;	S
	• Living space per capita;	S
	• Availability of flushing toilet, bath/shower and central heating;	S
	• Dwellings in deficient state of repair	S
Economy	• GDP;	D
	• Average urban housing price;	P
	• Average rent price.	P
	• Exploitation and investment of real estate;	R
	• Environmental pollution abatement and control expenditure;	R
	• Official Development Assistance.	R
Environment	• Crime in residential area;	P
	• Built up land per inhabitant;	P
	• Urban air emissions (SOx,NOx,VOC);	I
	• Ambient water conditions in urban areas;	I
	• Generation of waste;	I
	• Green coverage ratio;	I
	• Share of renewable energy sources in total energy use.	R

Society	• Natural population growth rate; • Urban infrastructure; • Dependency rate; • Road traffic volumes. • Proportion of population living below national poverty level; • Stock of road vehicles.	D D P P S S

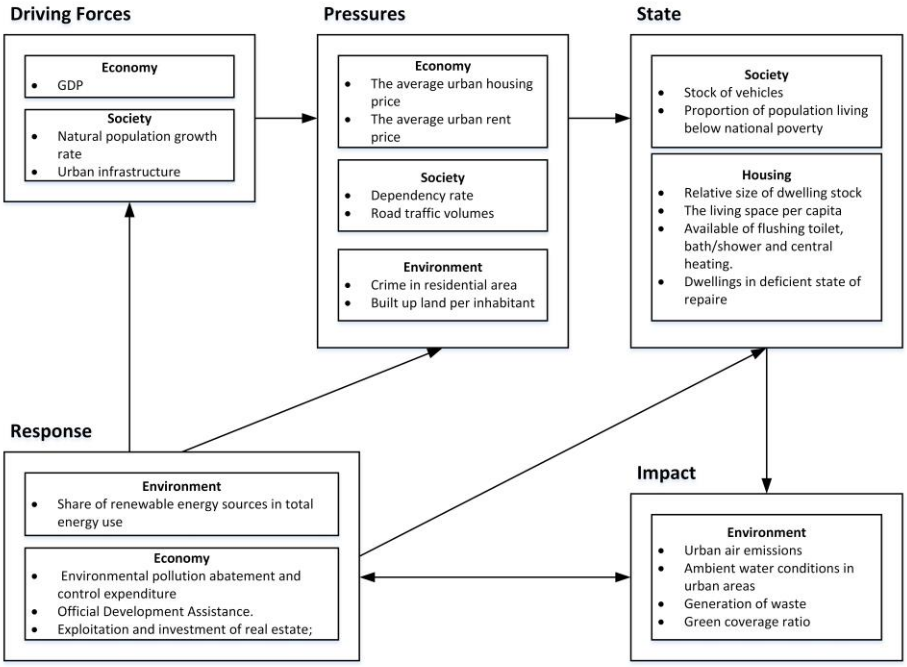

Figure 2. The Structure of DPSIR Framework for Early Warning Indicators

Step2. The Determination of the weight of indicators

The Multicriteria Analysis (MCA) method is adopted to identify the weight of each indicator. Firstly, the Analytic Hierarchy Process (AHP) [21] is applied to real practices as to analyze the weight of each indicator based on the professional comments of the experts as well as the sustainability evaluation of residential areas in cities. Then, the judgment matrixes are generated for further researches. For instance, Table 3 illustrates the matrix comparing the degree to which various DPSIR categories are important to the sustainability assessment of residential urban areas. By this process repeating several times throughout the system, a weight result that is relatively stable will be obtained. Table 4 stands for the structure of the system, where the values in the square brackets represent the weight of indicators in the whole system.

Table 3. Pairwise Comparison Matrix for DPSIR Category Assessment

	D	P	S	I	R	Weight
D	1	2	3	3	1/2	0.25
P	1/2	1	2	2	1/3	0.15
S	1/3	1/2	1	1	1/5	0.08
I	1/3	1/2	1	1	1/5	0.08
R	2	3	5	5	1	0.44

Table 4. The Early Warning Indicator System in the DPSIR Framework

System	DPSIR	Thematic areas	Indicators

	categories		
Sustainable development of urban residential areas[1]	Driving forces [0.25]	Economy [0.66]	1: GDP [1]
		Society [0.34]	2: Natural population growth rate [0.5] 3: Urban infrastructures [0.5]
	Pressure [0.15]	Environment [0.33]	4: Crime in residential areas [0.34] 5: Built up land per inhabitant [0.66]
		Society [0.33]	6: Dependency ratio [0.5] 7: Road traffic volumes [0.5]
		Economy [0.34]	8: Average urban housing price [0.75] 9: Average rent price [0.25]
	State [0.08]	Housing [0.75]	10: Relative size of dwelling stock [0.24] 11: Availability of flushing toilet, bath/shower and central heating [0.13] 12: Living space per capita [0.53] 13: Dwellings in deficient state of repair [0.1]
		Society [0.25]	14: Stock of road vehicles [0.25] 15: Proportion of population living below national poverty [0.75]
	Impact [0.08]	Environment [1]	16: Urban air emissions [0.28] 17: Generation of waste [0.28] 18: Ambient water conditions in urban areas [0.28] 19: Green coverage ratio [0.16]
	Responses [0.44]	Environment [0.34]	20: Share of renewable energy sources in total energy use [1]
		Economy [0.66]	21: Environmental pollution abatement and control expenditure [0.4] 22: Official Development Assistance [0.2] 23: Exploitation and investment of real estate [0.4]

Step3. The Standardization of the Indicator Value

The sustainability of residential urban areas is influenced by the chosen indicators in both positive way and the negative way. In another words, the chosen indicators push and block the sustainability of the areas. Therefore, as to put both positive and negative values of the indicators into consideration, the calculation of the standard value of each indicator must follow the equation (1) below:

Positive indicator:

$$x_i = 0.5 + \frac{x - \overline{x}}{s^2}$$

Negative indicator:

$$x_i = 0.5 - \frac{x - \overline{x}}{s^2}$$

(1)

In the equation above, x represents the actual value of the indicator i in each part of the considered period, xi represents the standard value of the indicator i in the temporal period under analysis, $\overline{x}$ represents the average value of and s represents the standard deviation of the indicator i in the period.

Step4. The Calculation of the Results

After Step 2 and Step 3, the value of the subsystems layer with reference to the DPSIR categories can be obtained by using equation (2) below:

$$Y_k = \sum_{j=1}^{n} \sigma_j \left(\sum_{i=1}^{m} w_i x_i\right)$$

(2)

In the equation above, Y_k represents the value of the subsystem layer with reference to the category k under the DPISR framework, accordingly n represents the number of the thematic areas under Y_k, and σj represents the weight of thematic area j that corresponds to Y_k. Furthermore, w_i represents the weight and xi represents the standard value of indicator i, and m represents the number of indicators under thematic area j. The final result of the sustainability degree of the indicator system can be obtained by weighted summing the five subsystems k, as indicated in the equation (3) as below:

$$Z = \sum_{k=1}^{5} \mu_k Y_k$$

(3)

In the equation above, Z represents the final result of sustainability of the indicator system, Y_k represents the value, and μ_k represents the weight of category k of the DPSIR framework. From the equation, it can be seen that Z is a composite index that derives from the value of the State, Pressure, Driving Forces, Impact and Response categories, and its value is included in the (0, 1) domain.

Step5. The Early warning results

Following Step 4, a set of values of the composite index Z and of the five subsystems in the different years under analysis can be obtained, as shown in Table 5 in which n represents the single year in the considered period.

It can be seen that when Z has a very low value, it will be difficult to carry on a sustainable development in the urban areas, due to some indicators like urban infrastructures or GDP implying a poor performance. Nonetheless, the previous consideration does not imply that the value of Z is positively related to the sustainability level of the indicator system. On the basis of the warning level in environmental impact assessment classification [22], the sustainability level of residential urban areas can be classified with the use of a five-grade classification (Table 6). In the determination process of the threshold values for Z, the special characteristics of sustainability in different areas must be put into consideration. In this research, the Nanjing city has been selected as the case in China. Therefore, the threshold values (Table 6) is determined on the basis on a related study on the city's housing development [23].

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Table 5. Sustainability Level in the Considered Period (year 1 ~ year n+2)

	Historical data				Estimate value	
	1	2	…	n	n+1	n+2
Driving forces	Y_{D1}	Y_{D2}	…	Y_{Dn}	Y_{Dn+1}	Y_{Dn+2}
Pressure	Y_{P1}	Y_{P2}	…	Y_{Pn}	Y_{Pn+1}	Y_{Pn+2}
State	Y_{S1}	Y_{S2}	…	Y_{Sn}	Y_{Sn+1}	Y_{Sn+2}
Impact	Y_{I1}	Y_{I2}	…	Y_{In}	Y_{In+1}	Y_{In+2}
Response	Y_{R1}	Y_{R2}	…	Y_{Rn}	Y_{Rn+1}	Y_{Rn+2}
Z	Z_1	Z_2	…	Z_n	Z_{n+1}	Z_{n+2}

Table 6. Warning Level in Five-grade Classification

Grade	Value	Qualitative evaluation	Warning district	
Ⅰ	$Z>0.86$	Develop excessively	Yellow light	Warning
Ⅱ	$0.72<Z\leq 0.86$	Develop quickly	Green light	No warning
Ⅲ	$0.48<Z\leq 0.72$	Develop steadily		
Ⅳ	$0.34<Z\leq 0.48$	Bear pressure	Yellow light	Warning
Ⅴ	$Z\leq 0.34$	Bear great pressure	Red light	

Put another way:

•Z has the smallest value in grade V, indicating that the residential urban areas are under great pressure for sustainability. In this case, the sustainable development of the areas encounter great barriers in all aspects. The warning of this grade is indicated with a red light.
•Z has a relatively smaller value in grade IV compared to grade III and II. At this point, the residential urban areas can overcome the obstacle to obtain sustainable development. This condition can be improved with adoption of effective actions to obtain economic, social, and environmental development. This grade of warning is indicated with a yellow light.
•Z has a medium value in grade II and III, indicating that the urban areas are experiencing a medium (grade III) or higher (grade II) rate of development. In this case, Z implies an ideal sustainability level, and both of the grades are indicated with a green light that stands for no warning.
•Z has an excessively large value in grade I, indicating that the residential urban areas are experiencing a very rapid economic, social and environmental development. For instance, the heavy emphasis on the environment of the areas would cause the residents' actual demands to be overlooked, especially in developing countries in which the residents need higher income more urgently than eco-friendly environment. This grade of warning is indicated with a yellow light.

5. The Application of the Model to the Case of Nanjing City

The Nanjing city under analysis is the selected case in this research. Nanjing is the capital of Jiangsu province in China. Over the recent years, Nanjing has been expanding very fast in term of both residential urban areas and population. In 2001, the residential urban areas were only 2599 km2, while in 2008 this figure had grown to 4723 km2. Moreover, the city's population has also been changing very rapidly over the same period. In 2001, its population was only 3,71 million, but this figure grew to 5.41 million by the end of 2008. The EWS model has been utilized to assess the sustainability level of the city's residential areas with 23 indicators obtained over a decade from 2006 to 2015. A brief explanation of the 23 indicators is illustrated in Table 7.

Table 7. Description of Early Warning Indicators

	Indicators	Description	Unit of measure
1	GDP	GDP stands for Gross domestic product and it reflects the sum of private consumptions, gross investments, government spending and exports, while the imports are subtracted.	Billion
2	Natural population growth rate	This represents the births and deaths in the population of a country or city. It does not take into account migration.	‰
3	Urban infrastructures	This represents the investments in urban infrastructures in a year.	Billion
4	Crime in residential area	This is indicated by the number of criminal registered cases per unit of 10000 people per year.	n/y
5	Built up land per inhabitant	This is indicated by the business-land area issued to the public by the municipal government.	million/m^2
6	Dependency ratio	This represents an age-population ratio who are usually not in the labor force who registered at an employment agency and those who are usually in the labor force.	%
7	Road traffic volumes	This aims at measuring the urban traffic condition and it is represented by the number of public transportation vehicles per unit of 10000 people.	n/10000 p
8	Average urban	This is the ratio of housing prices and the basic	%

	housing price	price in 2001.	
9	Average rent price	This is indicated by the price index of housing rent. It considers the rent in 2001 as a basic price.	%
10	Relative size of dwelling stock	This is indicated by the floor area completed in one year.	million/m^2
11	Availability of flushing toilet, bath/shower and central heating	This varies from a 0-1 point scale where the value 0 stands for unavailability and the value 1 stands for total availability.	n.
12	Living space per capita	This reflects the average level of housing per capita.	m^2
13	Dwellings in deficient state of repair	This indicates the households or units relocated due to building demolition.	n.
14	Stock of road vehicles	This is represented by the quantity of possessed family cars per 100 urban households.	n. /100 p
15	Proportion of population living below national poverty level	This represents the ratio of the population living below the national poverty and the full city town population. Low-income families are urban residents whose average family income is lower than the minimum living standard of NanJing city.	%
16	Urban air emissions	This considers the Air Pollution Index (API). The index has 5 grades, where: grade I (API< 50): the air quality is excellent; Grade II (50<API<100): the air quality is good; Grade III (100<API<200): light air pollution exists; Grade IV (200<API<300): medium air pollution exists; Grade V (API> 300): heavy air pollution exists. Here the indicator is obtained from the number of days in which the pollution index attains Grade I and Grade II in a year.	d/y
17	Generation of waste	This reflects the domestic waste in a whole year.	million ton
18	Ambient water conditions in urban areas	This indicates the total urban domestic water consumption volume.	million m^3
19	Green coverage ratio	This represents the ratio between the green areas in the city and the overall urban area.	%
20	Share of renewable energy sources in the total energy use	This indicates the energy consumption (standard coal) for every ten thousand Chinese yuan (CNY) worth of the gross domestic product (GDP). This is an index on the energy utilization efficiency to reflect the consumption level and the saving energy and reducing consumption conditions.	million m^2
21	Environmental pollution abatement and control expenditure	This indicates the complete investment concerning pollution-control projects.	million
22	Official Development Assistance	This represents the budgetary outlays from local finance for environment protection.	million
23	Exploitation and investment of real estate	This indicates the amount of investment in real estate development.	billion

The values under analysis are divided into the historical values obtained from the year 2006 to 2013 and the future values obtained from the year 2014 to 2015. The historical values are collected from the governmental reports, while the future values are forecast with the use of regression analysis (For the values for the indicators 1, 5, 14, 16 and 20 in the years 2014 and 2015, refer to Nanjing's development plan). The values of all the indicators under analysis over the decade are illustrated in the Table 8, where the values obtained through the regression analysis are highlighted with a border.

Following the methodology explained in the Section 4, the sustainability level of the overall system and of the subsystems can be calculated respectively based on the indicator values shown in Table 8 in each year over the decade (Table 9).

Table 8. Indicator Values of the Early Warning System

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
I1	121.85	138.51	169.08	206.72	224.11	277.38	328.37	377.5	416.59	480
I2	1.6	0.7	0.08	2.29	2.34	2.18	2.84	2.51	3.29	3.71
I3	2.98	3.14	4.3	5.13	6.33	7.66	7.32	10.63	11.65	13.42
I4	70	77	71	68	95	90	70	74	69	61
I5	0.27	1.65	5.7	2.27	4.69	5.5	6.85	3.7	4	2.7
I6	3.59	4.13	4.18	4.03	3.35	3.33	3.3	3.16	2.65	2.25
I7	10.85	9.84	10	9.63	11.4	13.8	14.2	15	17	20
I8	100	114.6	125.8	145.1	156.4	163.1	173.9	194.1	202	213.2
I9	100	99.4	103.8	109	109	109.4	111.4	125.3	127.2	133.7
I10	3.09	3.75	3.36	5.6	5.65	6.71	5.79	8.91	9.26	10.41
I11	1	1	1	1	1	1	1	1	1	1
I12	19	20.1	21.11	21.61	24.3	25.21	26.08	32.21	34.29	38.07
I13	13057	20032	21308	13500	15000	15000	16000	25000	24381	27965
I14	0.09	0.3	1.6	2	4.88	6.38	6.63	13	13.3	17.3
I15	0.95	1.6	1.99	2.12	2.4	2	2	2	1.48	0.98
I16	247	215	297	295	304	305	312	322	320	330
I17	1.33	1.00	1.52	1.66	1.69	1.62	1.62	1.66	1.59	1.5
I18	149.42	242.77	138.62	144.17	154.09	415.29	398.14	409.17	565.3	689.41
I19	40	42.9	43.51	44.46	44.94	45.49	45.92	46.5	46.05	45.67
I20	1.8	1.5	1.43	1.37	1.36	1.31	1.25	1.18	1.15	1.09
I21	176.39	133.12	162.6	233.03	205.93	527.12	585.91	836.8	1100.4	1406.3
I22	73	129	114	200	200	216	527	385	548	653
I23	11.1	13.76	18.38	29.29	29.61	35.12	44.6	50.82	58.23	66.17

Table 9. Sustainability Level of the Subsystems and of the Overall System

Year	Subsystem (B)					Subsystem (A)	
	Driving forces	Pressures	State	Impact	Response	Sustainable development of urban residential asreas	
2006	0.09	0.05	0.05	0.05	0.14	0.38	Yellow
2007	0.09	0.04	0.03	0.1	0.14	0.4	Yellow
2008	0.09	0.08	0.02	0.03	0.14	0.36	Yellow
2009	0.12	0.05	0.03	0.03	0.15	0.38	Yellow
2010	0.13	0.06	0.03	0.03	0.16	0.41	Yellow
2011	0.12	0.09	0.04	0.03	0.2	0.48	Yellow
2012	0.14	0.1	0.03	0.03	0.25	0.55	Green
2013	0.15	0.08	0.04	0.04	0.32	0.63	Green
2014	0.16	0.11	0.06	0.04	0.35	0.72	Green
2015	0.16	0.12	0.08	0.04	0.4	0.76	Green

Figure 3 shows the line chart of five subsystems while Figure 4 shows the line chart of the sustainable development situation of residential urban areas in the city of Nanjing for the period 2006-2015.

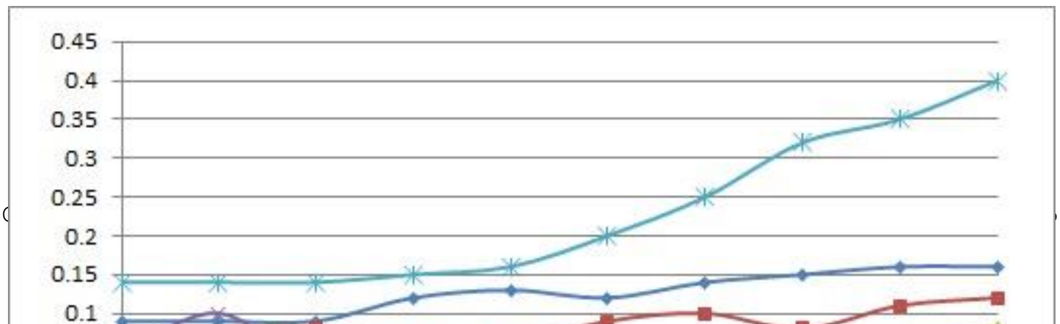

Figure 3. Line Chart of the Five Subsystems

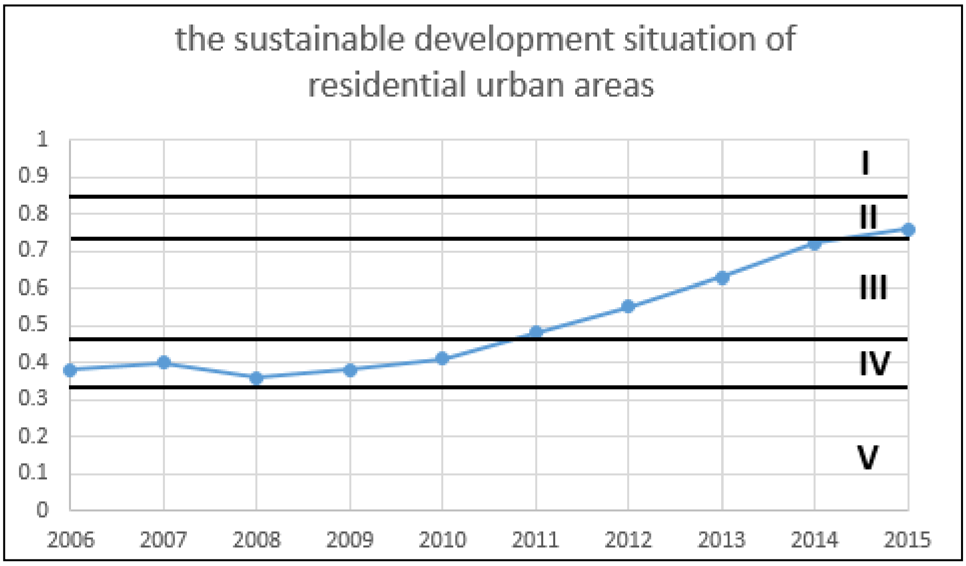

Figure 4. Line Chart of the Sustainable Development Situation

Through the application of the DPSIR/EWS model to Nanjing's residential urban areas, the trend in the Nanjing city's sustainable development from 2006 to 2015 can be obtained.

With the five subsystems (Figure 3) under consideration, it can be seen that the categories of Impact and State develop smoothly over the period. Comparatively, the categories of Pressure, Driving Forces and Response experience significant variations during the development process. Against its usual performances, the category of Impact experiences a significant development in 2007 due to the variation of I18 (the water conditions in the residential urban areas). During the period, the categories of Response and Driving Forces increased constantly, as a result from the rising values of indicators. For instance, the increased Exploitation and Investment of Real Estate resulted in the increased values in the category of Response, and the increased GDP resulted in the increased value in the category of Driving Forces. Commonly, the category of Pressures increases in a fluctuant state during the period under consideration. Based on the application of the DPSIR/EWS model to the overall system under analysis (Figure 4), the sustainability of Nanjing's residential urban areas has an optimal performance (indicated by green light) during the latter period of the decade, i.e. from the year 2012 to 2015. It can be seen that the poor performance in the former period has been driven by the rising trend of the categories of Response and Driving Forces towards high sustainability.

These results indicate that the model can reflect the facts in the real world, providing a practical instrument representing multiple aspects of an issue.

6. Conclusion

This article has focused on explaining how to use the assessment tool combining Early Warning Systems (EWS) and the DPSIR indicators to evaluate the sustainable development of residential urban areas. This model has been applied to the case of the Nanjing city in China. According to the case study, Nanjing's residential areas have kept a good historical record of sustainability, and will obtain the highest sustainable level of record by 2015. According to this research, the model that combines EWS and DPSIR can effectively represent the trend in sustainability of residential urban areas. In the real practices, the model can be used as a useful tool for decision makers. With the adoption of the EWS/DPSIR model, the sustainability of residential urban area can be obtained through monitoring and measuring various factors of the overall system. Moreover, this tool is flexible in all kinds of contexts.

Nonetheless, this study can be expanded and the research result can be validated in the following three ways. Firstly, this research focused on merely core indicators. In further researches, more indicators derived from policies can be added. Secondly, further researches may optimize the data collection and the early warning model in this study. Thirdly, future researchers may improve the determination of the weights of different factors of this model. As to achieve it, they should not be limited to professional advice, but also take the public perception into account by using questionnaire surveys and focus groups.

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