

## Ecological assessment of cities—procedure and a case study

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**Abstract**— This paper discusses the scientific background and content of the ecological assessment of cities, and takes Boda, a new town in Xinjiang province, China, as a case study.

**Keywords:** ecological assessment; urban ecosystem; ecological countermeasure.

### INTRODUCTION

The city is a multi-function complex containing political, socio-economical and cultural activities of human beings. The process of urbanization to date exhibits more and more anti-nature features. These, on one hand, increase the human being's ability for surviving; but on another hand, damage in different degrees of normal relationships between man and its surrounding nature and between components (the biotic and/or abiotic) of the nature. In other words, urbanization damages in different degrees the inherent harmony of the nature. So-called "urban evils" which people have widely been aware of are just the results of the damage of natural harmony, and those can also be viewed as the revenge of the nature against the anti-nature behavior of urbanization. In this sense, urbanization is also harmful to human's own survival. It is therefore absolutely necessary to scientifically evaluate the structure and function of cities (especially of new towns and the cities needing to renew) and suggest reasonable countermeasure in order to overcome existing and possible urban evils, improve urban functions, and develop the harmony between man and the nature.

There are three of assessment of cities: socio-economical assessment; environmental assessment, and ecological assessment.

The socio-economical assessment of cities focuses only on the human's own benefit, and pays a simple attention to the socioeconomic function of cities.

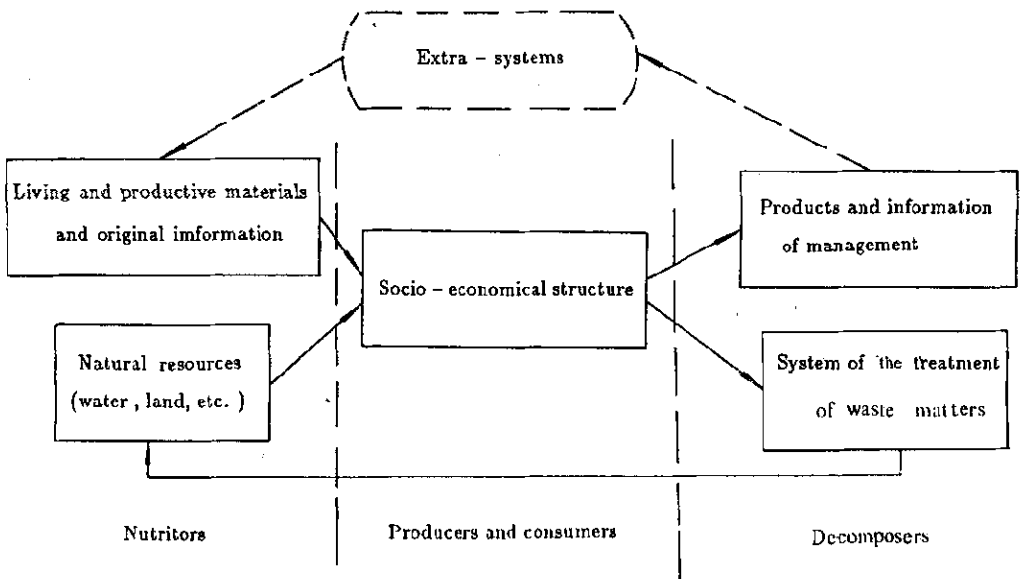
The environmental assessment of cities pays attention to the protection of environmental quality of cities during economical development. Since the 1960s, the economical development of cities has given rise to severe environmental pollution. Thus, the environmental assessment

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of cities is becoming a necessary supplement to the socio-economical assessment. This environmental assessment usually focuses on the living environment of human beings. It can be viewed as a narrow-sense environmental assessment, and the countermeasures it suggests represent a passive defence against environmental pollution.

The ecological assessment of cities represents a new kinds of view to physical, socio-economical and environmental issues of cities. The urban ecosystem concept and the studies of ecological aspects of cities (UNESCO/MAB, 1971; Bradshaw, 1984; UNESCO/MAB, 1984) make man a leap in the cognition of cities. People start to treat urban issues from the standpoint of "natural human being". This means that human beings, like other natural species, act as the components of ecosystem. They interact not only with themselves but also with the biotic and abiotic nature. Thus the urban ecosystem concept can offer a proper framework to understand those interactions related to human beings. An urban ecosystem can be described in Fig.1



**Fig. 1** Structure of urban ecosystems

From Fig.1, the materials, original information and natural resources for living and producing activities of cities can be regarded as the "nutritors" of urban ecosystems; human beings can be regarded as the "consumers" of the "nutritors", and the "producers" which behave a certain degree of autotrophical function; and those components which are in charge of the treatment of waste materials discharged from the consumptive and productive activities of

human beings can be regarded as the "decomposers". Those "decomposers" are usually composed of the part of natural environment and some man-made systems. Compared to natural ecosystems, urban ecosystems are more open, since each urban ecosystem has a lot of exchange of materials, energy and information with system outside it. This also means that the urban ecosystem has an external feedback besides an internal feedback.

On the basis of the analyses of relationships between components of a city and between the city and its extrasystems, we can understand that the economical development and environmental pollution of cities are two aspects contradicting with each other. If the economical development is considered the thing which human beings subjectively seek, the environment pollution is yet the objective result which human beings have to suffer. In essence, the environmental pollution results from the fact that human beings' activities go against the natural law and break out the balance between "nutritors" and "consumers", and a deficient decomposition arises between "producers" and "consumers" and "decomposers". This is the scientific background on which the ecological assessment of cities emerges as a new approach to evaluate urban structure and function. The methodological points of the ecological assessment of cities are:

(1) to investigate the relationships of three component parts (natural resources, socio-economical structure and environment) of an urban ecosystem and the relationships between this urban ecosystem and its neighbor systems.

(2) to set up the criteria of ecological assessment. This means that a high-quality urban system should strengthen, not weaken the harmony of the nature.

(3) to suggest ecological countermeasures relevant to particular issues of cities according to ecological principles.

It is very clear that the ecological assessment of cities not only contains a consideration of the demands of economical development and environmental protection, but it is a synthetic at a higher level and in a wider scale. Based on the analysis of urban ecosystem, it can offer a necessary direction of the socio-economical development and the environmental protection of an city. The direction will be beneficial not only to the city itself but also to its neighbor ecosystems, and prevent the damage of the whole ecological quality of cities as seeking a one-side benefit.

## PROCEDURE OF ECOLOGICAL ASSESSMENT OF CITIES

The procedure of ecological assessment of cities can be shown in Fig. 2. This procedure of ecological assessment can be explained in details as follows.

1. *The central issue of ecological assessment of cities is how to recognize and treat the contradiction between the structure and function of urban ecosystems.*

The urban function is the goal of urban planning. The implementation of urban function

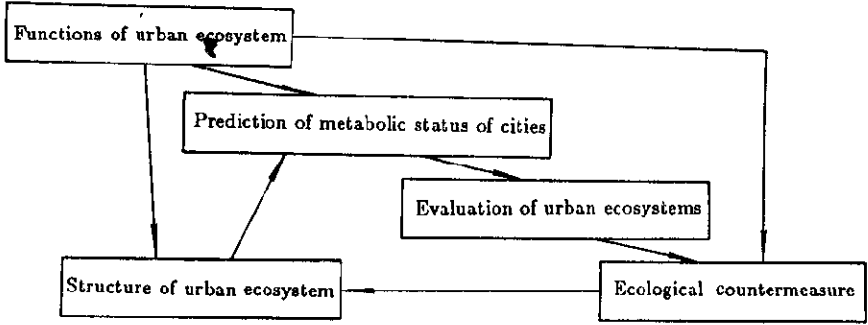


Fig. 2 Procedure of the ecological assessment of cities

must be dependent on a particular and proper urban structure. Otherwise, every city is built on the basis of original ecosystem (a natural ecosystem or an original urban ecosystem) which can be called the background ecosystem: there are always some special function and structure of planned city which are different from original one. Thus four sorts of contradiction between the structure and function of ecosystem can be shown as Fig. 3.

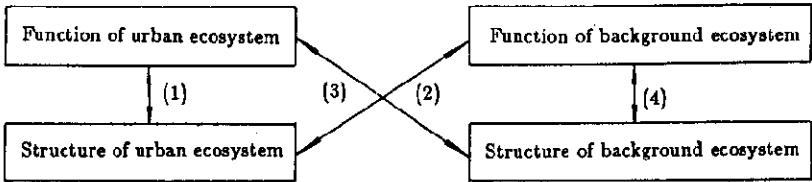


Fig. 3 Contradiction between the function and structure of urban ecosystems

These are:

(1) the contradiction between each function of urban ecosystem and its corresponding structure which the function needs.

(2) the contradiction between the structure of an urban ecosystem and the function of its background ecosystem.

(3) the contradiction between the function of an urban ecosystem and the structure of its background ecosystem

(4) the contradiction between the structure and function within the background ecosystem.

These four sorts of contradiction are related to the harmony of urban ecosystems. (1) and (2) are more important, since (1) is related to the inherent harmony of the structure and function of an urban ecosystem and (2) is related to the harmony of the urban ecosystem and its external environment. These two kinds of harmony can respectively be viewed as the internal

harmony and external harmony. They are two of the most important issues of the ecological assessment of cities. (3) and (4) are also related to the internal and external harmony, but they take a main part during the stage of urban site-selecting, not during the stage of urban planning. The ecological assessment of cities should focus on the internal and external harmony of urban ecosystems on the basis of the analysis of the contradiction between the structure and function of urban ecosystems.

## *2. Description of the metabolic status of urban ecosystems*

The metabolic status of an urban ecosystem presents its dynamic behavior, particularly reveals the contradiction between structure and function. The description of the metabolic status of urban ecosystem provides a data basis for the ecological assessment. This description is based on historical data, always a prediction of new or renewed cities. It can proceed by two steps:

### (1) The selection of principal state variables (PSV) of urban ecosystems

The metabolic status of urban ecosystems can be presented by input-output relationships of materials, energy and information. These relationships lead to an analysis of two kinds of benefit, namely socio-economical benefit and ecological-environmental benefit. Furthermore, the input-output relationships can be described by state variables of the urban ecosystem, and those variables which are of more importance to the kinds of benefit can be termed principal state variables (PSV). In fact, the metabolic status of an urban ecosystem can briefly be described by a few PSV. Those PSV can be chosen qualitatively or semi-quantitatively.

### (2) prediction of the metabolic status of urban ecosystems

The first is to set up the relationships between the chosen PSV, and show as far as possible the relationships on diagrams. Those relationships and diagrams should reflect the structure and function of an urban ecosystem, and present its principal socio-economical benefit and ecological-environmental benefit. The second is, based on the relationships and diagrams, to simulate and predict the metabolic status of urban ecosystems. This prediction is quantitative or semi-quantitative.

## *3. Evaluation of the quality of urban ecosystems*

The quality of urban ecosystems contains three aspects: the harmony between the structure and function of the urban ecosystem; the harmony between the urban ecosystem and its natural ecosystem; and the harmony between the urban ecosystem and its neighbor human ecosystems. This harmony here exhibits two meanings, that is to say, ecosystems should be of a high socio-economical benefit, a high-quality environment and self-sustaining capacity as much as possible.

## *4. Ecological countermeasures*

The ecological countermeasures are perhaps the most creative part of the ecological assessment of cities. These ecological countermeasures, based on the ecological principles and focusing on the whole urban ecosystem, will be obviously different from simple socio-economical and environmental countermeasures.

## THE CASE STUDY—THE ECOLOGICAL ASSESSMENT OF BODA CITY

Boda—originally a piece of wasteland—is chosen as the logistics and management base of oil industry of Xinjiang Province. The overall plan of Boda (Architectural Designing of Boda City, 1986) has been finished, and Boda is being in construction. Now we make an ecological assessment of Boda on the basis of its overall planning.

### 1. Background ecosystems

The background ecosystems of Boda are a native ecosystem and a neighbor human ecosystem of Fukang County.

#### (1) Native ecosystem

The native ecosystem (Environmental Protection Institute of Xinjiang Autonomous Region, 1986) is a wild grassland at the northern foot of Tianshan Mountain. Its vegetation is dominated by artemisia; its geographical and meteorological conditions are not very good; and the diversity of natural species is rather poor. The structure of the native ecosystem is very simple, and its productive power is low.

What is worth paying attention to is the fact that the precipitation, sunshine time and solar radiation during the period from May to September are about 60% of annual amount. This period is the golden time for the development of productive potency of the native ecosystem.

Water resource in Boda region is very deficient, but a vast wild land as land resource is very rich.

#### (2) Fukang County

Fukang neighboring to Boda is an agriculture-featured county. Some problems such as the provision of food, the distribution of natural resources, possible environmental pollution and so on will arise between Boda and Fukang.

### 2. Structure and function of planned Boda City

In terms of the overall plan of Boda, the basic functions of Boda can be shown in Fig. 4, and its structure serving for those functions can be shown in Fig. 5.

The conclusions on the relationships of functions and structure of Boda can be made as follows:

(1) The function of living and management takes the first position of Boda; the function of service for industrial production, such as storage, transport, repair and so on takes the second position.

(2) The functions of living and management are consistent to the need of high-quality environment, but the function of service for industrial production may damage the environment. It is obvious that the contradiction between the function of living and management and the function of service for industrial production exists. The key to settle this contradiction is to ensure the function of living and management; and develop the function of serving for industrial production as much as possible and without any damage of the function of living and management.

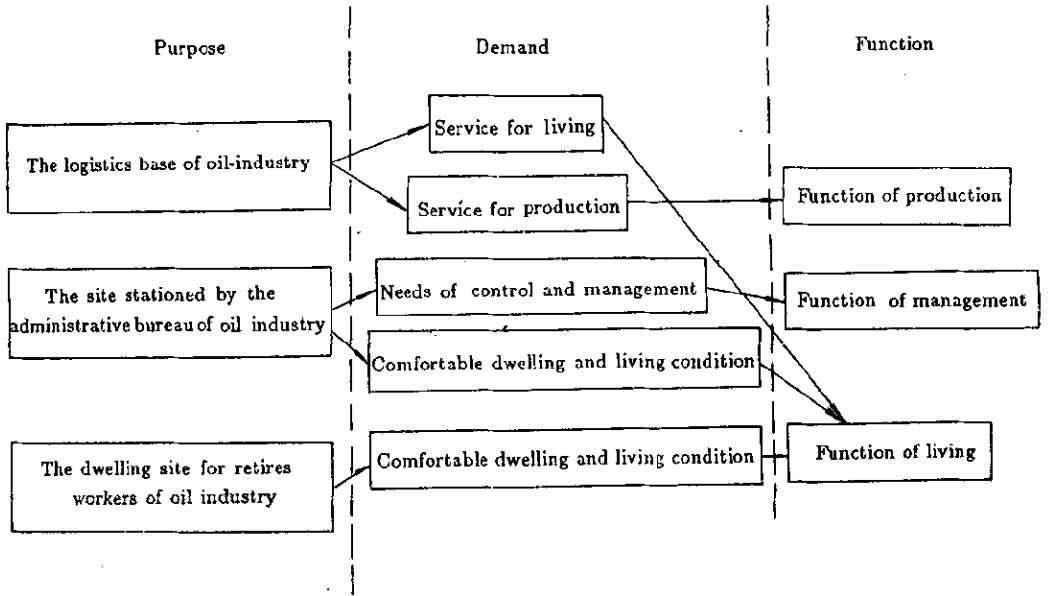


Fig. 4 Analysis of the functions of Boda urban ecosystem

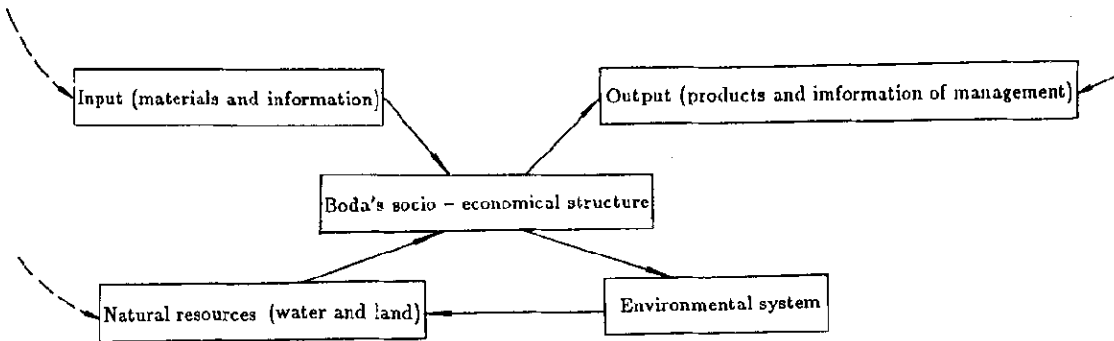


Fig. 5 Structure of Boda urban ecosystem

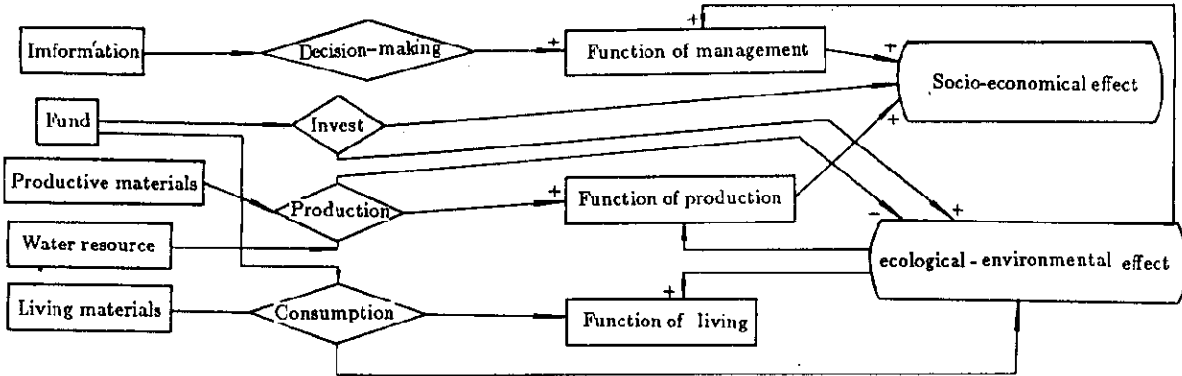
(3) The harmonic relationship between Boda and its background ecosystems should carefully be considered, because the issues such as distribution of water resource and provision of living materials are concerned with both of them.

3. Prediction of metabolic status of Boda

(1) PSV of Boda urban ecosystem

The interactions of state variables of Boda urban ecosystem can be shown in Fig. 6. An

qualitative evaluation of the economical and environmental effects of the interactions can also be shown in Table 1.



**Fig. 6** Relationship of the PSV of Boda urban ecosystem

**Table 1** Assessment of environmental and economical effects of PSV of Boda urban ecosystem

Input		Output		
Item	Amount	Item	Amount	
Productive materials	Big	Products and waste matters	Big	
Living materials	Big	Waste matters	Big	
Original information	Big	New information	Big	
Water resource	Big	Waste water	Big	
Income	Big	Expense	Big	
Function	Economical	Environmental effect		
Production	Indirect	water	Air	Soil
Living		Big	Big	Big
Manage	Indirect	Big	Big	Big
Living and productive activities	Big	Big		

According to Table 1, the PSV chosen are:

a. Living material.

It reflects the first function of Boda—living and dwelling.

b. Income

It reflects the economical strength of oil industry, as well as determine the possibility of high-quality living and environmental conditions.

c. Water resource



It, as a main natural resource, affects not only each aspect of Boda but also the relationships between Boda and its neighbors systems.

#### d. Environmental quality

It reflects the overall effect of all human activities on environment.

Other state variables such as productive material and information are not PSV, since productive materials reflect the second function of Boda, and the effects of productive materials and information can indirectly be shown by the PSV of income and the environmental quality.

### (2) Prediction of PSV

Since Boda is still in construction, there is no enough data of its PSV. And since the structure of Boda urban ecosystem is simple, we need not make a complicated modelling but adopt a "reference-comparison" approach to it. Here the "reference" means that the data needed in the discussion of Boda can refer to other cities, and the "comparison" means that the prediction of the development of Boda can be compared to another similar city. Thus the metabolic status of Boda can be drawn as follows:

#### a. Consumption of living materials in Boda

The living standard of Boda during the 90s can be referred to the standard of Beijing-Tianjin-Tangshan region in the 2000(Chinese Research Academy of Environmental Sciences, 1985). Thus the consumption of living material in Boda can be estimated as shown in Table 2.

Table 2 Prediction of the living standards of Boda

Item	Grain	Food oil	Vege- table	Meat	Egg	Milk	Fruit	Fish	Total amount
Recent (10kt)	0.7	0.025	0.64	0.14	0.088	0.175	0.263	0.044	2.05
Future (10kt)	2.0	0.07	1.83	0.4	0.175	0.5	0.75	0.125	5.85
Per person (kg)	200	7	182.5	40	17.5	50	75.5	12.5	584.5

From Table 2, the level of food consumption will be up to 50 yuan (Chinese monetary unit) per person-month. Oil workers can financially bear this expense. But it also means that there are a total amount of 60000 t/a materials which Boda has to import from its neighbor areas.

#### b. The financial condition of Boda

The income of Boda as an logistics and management base is backed by its oil industry. Thus its financial status can refer to that of Kelamayi (Environmental Monitoring Center of Kelamayi City, 1985), another oil-industry city in Xinjiang, which is shown in Table 3.

**Table 3** Output value of Kelamayi (1983)

Item	Industry		Agriculture		Total		Total benefit
	Output value	Value per person	Output value	Value per person	Output value	Value per person	
Amount of money (10 <sup>4</sup> yuan)	94379	1.04	333	0.1	94712	1.0	24932

Kelamayi faces a worse natural condition than Boda, but an abundant income of oil industry has been keeping a health development of urban function of Kelamayi. It can be reasonably supposed that Boda can also do so in the same way.

c. The water-resource condition of Boda

In terms of the overall plan of Boda (Architectural Designing Institute of Xinjiang Autonomous Region, 1986), the water-use plan can be shown in Table 4.

**Table 4** Planned amount of water use of Boda

Item	Boda	
	Recent	Future
Total amount, 10 <sup>4</sup> t/a	539.8	1226
Industry, 10 <sup>4</sup> t/a	182.5	273.8
Agriculture and plantation, 10 <sup>4</sup> t/a	81.1	273.8
Living activity, 10 <sup>4</sup> t/a	232.1	788.4
Amount per person, L/a	130	180

Following three points are, then, very clear. Firstly, the level of water use per person exceeds that of Kelamayi. This means that Boda has a more comfortable living and working condition. Secondly, the amount of water for domestic use in Boda will be about 80% of the total water-use amount; but the amount of water for industrial use in Kelamayi is about 70% of its total water-use amount. This implies that the waste water is dominated by domestic sewage in Boda but by industrial sewage in Kelamayi. Since domestic sewage is much more easily treated than industrial sewage, this offers Boda an advantageous condition of water re-use. And thirdly, Boda, like Kelamayi, faces a rather expensive cost of water exploitation. The price

of water will be about 0.72 yuan/m<sup>3</sup>. Since Boda lacks productive industries, the economical benefit of water use in Boda is lower than in Kelamayi.

d. The pollutant load of Boda's environment

A prediction of the environmental pollutants of Boda and a comparison of environmental quality of Boda to Kelamayi's can be shown in Table 5.

**Table 5** Comparison of environmental quality between Boda and Kelamayi

	Item	Boda		Kelamayi
		Recent	Future	status
Sewage	BOD (kg/d)	900	3000	2500
	SS (kg/d)	900-1200	3000-5000	2705
	Total amount (m <sup>3</sup> /d)	6500	19500	10000
Solid waste (10 <sup>4</sup> t/a)		1.3	3.6	5.3
Air pollutant	SO <sub>2</sub>	Not exceed the standard	Not exceed the standard	Not exceed the standard
	NO <sub>x</sub>	Not exceed the standard	Not exceed the standard	Not exceed the standard
	Dust fall	Not exceed the standard	Not exceed the standard	Exceed 5.97 times of the standard
	Solid particle	Note exceed the standard	Not exceed the standard	Exceed 0.83 times of the standard
Green space	Total amount (mu)	2000	3200	97.5
	Per person (m <sup>2</sup> )	38.1	21.4	0.87
Acoustic environment		Good	Good	General

According to Table 5, each aspect of environmental quality of Boda is better than Kelamayi's. Especially the green area per person of Boda is 25 times as much as Kelamayi's. All these obviously show that Boda has a much better dwelling condition.

#### 4. *Ecological evaluation of quality of planned Boda*

The conclusions can be made as follows:

(1) Planned Boda is acceptable. This is because:

a. Boda can provide all functions as needed by a logistics and management base of oil industry. In terms of Table 2, 3, 4 and 5, the living condition and environmental quality of Boda is obviously better than Kelamayi's.

b. Since backed by a strong oil industry, Boda City can stably and continuously run.

(2) the comprehensive benefit of Boda urban ecosystem needs to further improve. This is because:

a. In terms of the overall plan of Boda, the beneficial natural conditions such as the vast wasteland and those good-climate seasons are not appropriately used. The total living materials of Boda have to be provided by external systems. It itself does not exhibit any self-sustaining ability.

b. In terms of the overall plan of Boda, the environmental quality of Boda is simply dependent on engineering measure to treat pollutants; and Boda ecosystem itself lacks a strong decomposition ability. This means that the cost of environmental protection arise.

c. The economical benefit of water in Boda is rather low.

d. The relationships between Boda and its background (natural and man-made) ecosystems are not enough considered. The overdue needs of living materials and water resource by Boda may damage the development of the background or neighbor ecosystems.

#### 5. *Ecological countermeasures*

It can be suggested that the way to improve comprehensive benefit is to harmonize the interrelationships of Boda ecosystem and the interrelationships between Boda and its neighbor ecosystems, and to improve the self-sustaining ability of Boda.

(1) The starting point of ecological countermeasures is how to utilize water resource

Water resource takes a big part of the development of Boda urban ecosystem. Sewage is the main environmental pollutant in Boda. The treatment of sewage is directly involved to water quality as well as environmental quality of Boda. Water is also such a resource which Boda, Fukang and the native ecosystem commonly share, and the distribution of water resource will be involved to the development of Boda's and Fukang's economies and to the conservation of the native ecosystem.

But since the planned water-use system of Boda is so simple as that: fresh water-utilized for producing and living activities-waste water-treated by engineering measures-discharge of treated water. It is difficult to get a high economical and ecological benefit.

(2) Favorable conditions of water utilization in Boda

a. A large amount of waste water

According to Boda planning, the amount of water use will be  $1226 \times 10^4 \text{t/a}$ , and the amount of water-used discharge will be  $843 \times 10^4 \text{t/a}$ , after the 1990. Suppose that total amount of

discharge were used to irrigation, the irrigated area would be 17000mu (Chinese area unit. 15mu=1ha). Thus this area is 5 times of planned green area. It is obvious that Boda is of great potency to develop agriculture.

b. 80% of waste water of Boda is domestic sewage.

Since a lot of evidences show that is easily treated, and after treating, it can be reused for terrestrial and aquatic agriculture, it is possible to develop a way to renew the waste water of Boda.

c. A vast uncultivated land surrounding Boda

This land provides not only a site for the treatment of sewage, but also a rich land resource for the development of agriculture.

d.A strong oil-industry income

If this fund is invested to the resourcization of used water and the development of poor native ecosystem, it will get a long-term benefit. This is a correct way more effectively to use the oil-industry fund.

(3) An integrated planning of water use in Boda:the ecological farm characterized by resourcization of waste water

This ecological farm can be drwan in Fig. 7.

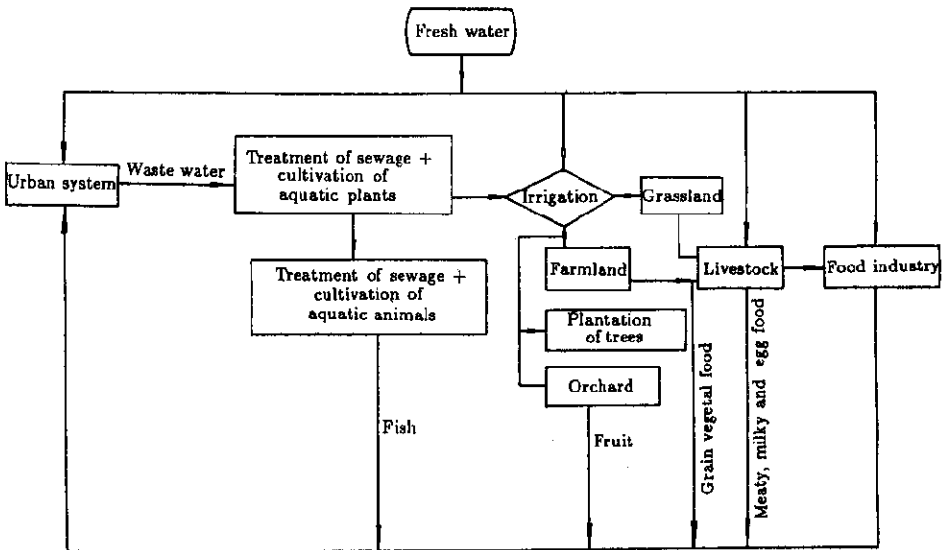


Fig. 7 Production flowchart of Boda's ecological farm

The ecological farm shown in Fig. 7 focuses on the multi-level treatment and multi-level use of water. A combination of the treatment and application of waste water not only saves the cost of treatment of sewage but also improves the economical benefit of water. The economy of

this ecological farm will be dependent on three factors: its structure, the efficiency of irrigation and the output value per person.

(4) A assessment of comprehensive benefit of the ecological farm

The comprehensive benefit of the ecological farm can be evaluated by a comparison to the originally planned water-use system. The assessment is shown in Table 6.

**Table 6** Assessment of comprehensive benefit of Boda ecological farm compared to the overall planning of Boda

Item	The overall plan of Boda	Ecological countermeasures
Tape of use of water	Fresh water ... waste water ... treated water ... irrigation of tree and grass	Multi-level treatment and multi-level use of waste water
Environmental benefit	Water quality improved; Area of plantation: 20m <sup>2</sup> /person	Water quality improved; Area of plantation 78 m <sup>2</sup> /person
Ecological benefit		Save water resource; Can use and develop the vast wasteland
Economical benefit	Cost of treatment of sewage will be $4 \times 10^5$ yuan/a	Economical benefit of water use arise; Provide Boda a lot of agricultural products; Increase the income of Boda about $10^6$ yuan/a*.
Social benefit		Increase the opportunity of employment; Be beneficial to the cooperation of the region of Boda-Fukang.

\* denotes that the computation of the increasing income refers to the output value per mu of Shihezi City (Environmental Monitoring Centre of Shihezi City, 1985)

### SUMMARY

This paper views urban issues in terms of the principles of urban ecosystem theory, and suggests that an ecological assessment of new or renewed cities is necessary to guarantee a complete, high effective and stable urban function.

This paper proposes a procedure of ecological assessment of cities.

The paper takes Boda city as a case study to show how this procedure proceeds.

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