

Analysis of the Concept of Environmental Carrying Capacity

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Abstract From the concept of carrying capacity proposed in the early 20th century to as an important tool for describing development constraints in the 21st century, many scholars have conducted extensive and detailed research on carrying capacity at different levels, but the carrying capacity system has not yet formed a unified theoretical and methodological system. By summarizing and analyzing the existing literature, based on the viewpoints of Mr. Gao Jixi and Mr. Zeng Weihua, the relationship between different mainstream carrying capacities is analyzed, and finally a system for summarizing the elements of different carrying capacities is provided, which to some extent serves as a reference for scholars who have just come into contact with the concept of carrying capacity. It is thought that: ① the research on ecological carrying capacity covers the scope of cities, and the research at the urban level complements the neglected and insufficient areas of ecological research. ② The main difference among ecological carrying capacity, urban comprehensive carrying capacity and resource environment carrying capacity lies in the different research scopes. In the mainstream view, environmental carrying capacity and resource carrying capacity are summarized under the framework of different research scopes. Water environment carrying capacity, land resource carrying capacity and other single factor carrying capacity are special in-depth studies of environment and resource carrying capacity. ③ Ecological carrying capacity at the ecological level includes environmental carrying capacity and resource carrying capacity. At the urban level, urban ecology is equivalent to urban environment to a certain extent, and resources can be classified into urban environmental carrying capacity as an environmental element.

Keywords Environmental carrying capacity, Ecological carrying capacity, Resource carrying capacity

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In the 1970s, IUCN/UNEP/WWF used the term sustainable development for the first time in the *World Conservation Outline*. The concept of sustainable development is to meet the needs of contemporary people without compromising the needs of future generations, and it is recognized by governments and scientists from various countries at that time. Subsequently, scientists from various disciplines conducted research on the concept, significance, and application of sustainable development from different perspectives.

Environmental carrying capacity is a scientific method, which is introduced by engineering and widely used to solve the contradictions in sustainable development. However, there are still problems in the current carrying capacity system, and further improvement is needed. Therefore, the carrying capacity of different elements is analyzed and summarized to provide reference and theoretical support for future generations to further explore sustainable development.

1 Research status of environmental carrying capacity

1.1 Foreign research

At first, carrying capacity was regarded as a term in engineering geology, which described the structural stability and load resistance of the foundation. This concept was widely used in various construction projects at that time.

Environmental carrying capacity originally studied environmental capacity, which refers to the maximum population or biomass that can be maintained by an ecosystem or region under specific environmental conditions. The cognitive process of environmental capacity can be traced back to 1798. Malthus first proposed the relationship between biology and the natural environment in his book *An Essay on the Principle of Population*^[1]. With the development of related research, Park and Burgess accurately proposed the concept of carrying capacity in 1921 and applied it to environmental science. In 1953, Odum combined the concept of carrying capacity with the logarithmic growth equation in his book *Principles of Ecology* and gave the concept of carrying capacity a more precise mathematical form. Meadows once again mentioned the concept of environmental capacity in his book *Limits to Growth* published in 1972, pointing out that carrying capacity is the limit, and any population growth beyond its carrying capacity is unsustainable^[2]. Afterwards, UNESCO officially proposed the concept of “resource carrying capacity” in 1980 (Table 1).

With the continuous development and expansion of human activities, environmental issues are receiving increasing attention. Environmental carrying capacity is also born. Scholars from all over the world have gradually carried out environmental analysis on water,

land, atmosphere and other elements, and put forward research on carrying capacity of various elements plus environment and resources.

1.2 Domestic research

In 1991, the Center for Environmental Science of Peking University put forward the concept of environmental carrying capacity, and pointed out in the report that environmental carrying capacity refers to the threshold that a region's environment can withstand the impact of human activities on it in a specific time period, state or condition. In this definition, “a certain state or condition” refers to the prerequisite that there will be no changes that are detrimental to human survival in the actual or predetermined environmental structure^[3]. This definition provides a foundation for conducting in-depth research on environmental capacity and provides strong theoretical support for environmental protection and sustainable development. With the development of time, different scholars have improved the concept of environmental carrying capacity from different perspectives, and conducted in-depth or shallow research on environmental carrying capacity according to different elements and different regions. Seen from Table 2, the scholars of environmental carrying capacity in different periods had different views on the concept based on different disciplines and research needs, and it has not been unified up to now.

2 Differentiation and analysis of environmental carrying capacity

Because carrying capacity is a multi-disciplinary concept, mixing the concepts of carrying capacity in various disciplines and fields can cause conceptual confusion. In this paper, different concepts of carrying capacity from the perspective of elements are differentiated and analyzed. Based on the viewpoints of Mr. Gao Jixi and Mr. Zeng Weihua, a summary diagram of carrying capacity elements is constructed (Fig.1).

Firstly, the relationship between different elements of carrying capacity is analyzed from several common usages, such as ecological carrying capacity and sustainable development, ecological carrying capacity and urban comprehensive carrying capacity, environmental carrying capacity and ecological carrying capacity, environmental carrying capacity and resource carrying capacity, environmental carrying capacity and resource carrying capacity.

2.1 Existing problems and counter-measures of environmental carrying capacity

When studying environmental carrying capacity, it will encounter many different concepts of carrying capacity, such as water resources carrying capacity, land carrying capacity, earth carrying capacity, resources carrying capacity, ecological carrying capacity, ecological environment carrying capacity, etc. These concepts all involve carrying capacity. When deeply understanding these concepts, it will find that there is often confusion and ambiguity between them. For example, it often confuses the concepts of resource environment carrying capacity and environmental carrying capacity in the study of resource environment carrying capacity. In addition, different carrying capacities also use different measurement and evaluation methods, such as ecological footprint, energy footprint, route method, area method, state space method, bucket theory, NPP method, supply and

demand balance method, a series of methods from *An Essay on the Principle of Population* and comprehensive index evaluation method. The numerous concepts and research methods make the study of carrying capacity very difficult.

At the same time, because carrying capacity is a concept introduced by engineering, as long as there is a relationship between bearing and being carried, a research model for its carrying capacity can be constructed, such as forest carrying capacity in parallel with environmental carrying capacity^[12-13], ocean carrying capacity^[14-15], atmospheric carrying capacity^[16-17], space carrying capacity^[18-19], green space carrying capacity^[20-21], traffic carrying capacity^[22-23]. The research methods for each type of carrying capacity vary greatly, and the usage methods are also different. It seems that these carrying capacities are greatly separated from each other and cannot form a system.

As early as 2006, Zhang Baocheng mentioned in the *Review of Research on Natural Resource Carrying Capacity* that there are many

Table 1 Development history of carrying capacity

| Time | Concept advancement |
|-----------|---|
| 1798 | In his book <i>An Essay on the Principle of Population</i> , Malthus, a British scholar, discussed the relationship between living things (population) and natural environment (food), and believed that living things have a trend of unlimited growth, while natural factors are limited, and the growth of living things must be restricted by natural factors |
| 1838 | Verhulst put forward the famous logistic equation according to Malthus' basic theory, which became the earliest mathematical expression of the concept of carrying capacity |
| 1920-1921 | American demographers Pearl and Reed put forward again and gradually became an important method for ecology to describe the relationship between biology and environment. In 1921, Parker and Burgess put forward the concept of ecological carrying capacity in the <i>Journal of Human Ecology</i> , namely "the maximum limit of the number of individuals under a specific environmental condition (mainly referring to the combination of living space, nutrients, sunlight and other ecological factors)" |
| 1953 | In his book <i>Principles of Ecology</i> , Odum linked the concept of carrying capacity with the theoretical maximum constant of the logistic curve (namely the constant K of the logistic equation), thus providing a more accurate mathematical expression for the concept of carrying capacity |
| 1968 | B. Malisz proposed the theory and method of Ultimate Environmental Threshold (UET) |
| 1972 | <i>The Limits to Growth</i> is essentially a re-mention of environmental capacity. The book points out that carrying capacity is the limit, and any population growth beyond its carrying capacity is unsustainable |

Table 2 Domestic concept of environmental carrying capacity^[4-11]

| Time | Author | Opinion | Level |
|------|----------------------|--|---|
| 1993 | Zhang Huiqin et al. | It is believed that environmental carrying capacity refers to the capacity of the environment to contain pollutants, which is also known as environmental capacity | - |
| 1996 | Peng Zaide et al. | It is believed that environmental carrying capacity refers to the threshold value of the support capacity of a certain regional environment to human social and economic activities in a certain period of time and under the standard environmental state | Socio economic/environmental structure |
| 1996 | Gao Jixi | It is believed that environmental carrying capacity refers to the amount of pollutants that can be borne by the environmental subsystem, as well as the economic scale and corresponding population that can be supported under the conditions of certain living standards and environmental quality requirements and not exceeding the elastic limit of the ecosystem | Economic scale and population, living standards and quality of life, environmental capacity |
| 1998 | Hong Yang, Ye Wenhui | In essence, environmental carrying capacity refers to the threshold value of the support capacity of the environment of a certain period, a certain environmental state, and a certain region for human social and economic activities | - |
| 2010 | An Ping | The ability of a regional environmental system to withstand various human socio-economic activities during a certain period and within a certain regional scope, while maintaining the structure of the regional environmental system without qualitative changes and the function of the regional environment without turning towards a malignant direction | Capacity level/threshold level/capability level |
| 2014 | Zeng Weihua | The threshold at which the environmental system can withstand human activities, provided that the structure of the environmental system does not undergo qualitative changes and the environmental function is not damaged, within a certain period and range, as well as under certain natural environmental conditions | Natural level, social level |
| 2017 | Bu Jianwei | It refers to the ability of a regional environmental system to withstand various human social and economic activities within a certain period of time and a certain region, while maintaining the structure of the regional environmental system without qualitative changes and the function of the regional environment without turning malignant | - |
| 2021 | Bao Keyu | The ability of a regional environmental system to withstand the impact of human economic and social activities, including the ability to supply resources required for regional development and the ability to absorb pollutants | - |

concepts about resource environment carrying capacity at home and abroad, but they are not unified^[24]. The complex definition of carrying capacity is even enough to confuse scholars specializing in studying carrying capacity. In the research on urban carrying capacity and water resource carrying capacity, Liu Xiaoli et al.^[25-27] have expressed that there is still no systematic and scientific theoretical system for carrying capacity to date. In the near future, Ding Xiaoping et al.^[28-29] clearly pointed out that the carrying capacity has not yet formed a complete system. Gao Xihong et al.^[30] also showed that the concept and connotation of carrying capacity have not yet reached a consensus, and the indicator system needs to be improved urgently, and the quantitative methods are not yet mature.

This also indicates that current research on carrying capacity is carried out without a complete system, which is prone to deviation, repetition, and even problems in the evaluation of the same problem. Although scholars believe that there is a lack of a complete system for carrying capacity, this precisely indicates that in their minds, carrying capacity is not isolated and unrelated, but rather there is an undiscovered system that can connect existing and potential carrying capacity.

In response to the above issues, the authors found that the unclear concept of carrying capacity mainly stems from unclear elements. There are many professional terms in carrying capacity research that have not been analyzed, which leads to exposure to many concepts when conducting carrying capacity research. Due to the incomplete system of carrying capacity and the unclear relationship between various carrying capacities, scholars need to understand various concepts, which has led to their exposure to a large number of homogeneous concepts, increasing the difficulty of carrying capacity research. To address this issue, differentiation will be made based on the research elements of bearing capacity, and attempts will be made to classify the research elements of carrying capacity based on the theories of authoritative scholars.

2.2 Ecological carrying capacity and sustainable development

Gao Jixi defines ecological carrying capacity as the self-sustaining and self-regulation capacity of an ecosystem, the supply capacity of resource and environmental subsystems, the intensity of their sustainable socio-economic activities, and the population sensitivity with a certain standard of living^[7]. He believes that ecological carrying capacity can be divided into three aspects: ecological-environmental carrying capacity, ecological-resource carrying capacity and ecological elasticity^[7].

In the book *Protecting the Earth—Sustainable Survival Strategy*, sustainable development is defined as “improving the quality of human life without exceeding the capacity to maintain ecosystem carrying”.

To some extent, carrying capacity and sustainable development are two aspects of the same event, as they both address issues of resources, environment, population, and development. Although they have different perspectives, both emphasize the protection of natural resources and the environment to achieve the goal of sustainable development. The core issue of sustainable development is to balance the relationship between population growth, resource utilization, environmental protection, and economic development. This needs to take into account the needs of future generations and ensure that current development does not endanger future viability. The core issue of carrying capacity lies in determining the actual carrying capacity of natural resources and the environment, as well as determining the speed of population and socio-economic development based on these capacities. This can be seen as starting from the “bottom of the foot” and it determines the speed of development by considering natural conditions. Although the two methods have different perspectives, their core goal is to achieve sustainable development. To achieve this goal, it is necessary to think from a higher perspective and consider the limitations of natural resources and the environment, in order to protect the earth's home while achieving human development. So, sustainable development is the goal, and people are the link, and carrying capacity is the cornerstone of sustainable development.

Overall, achieving sustainable development requires ensuring ecosystem integrity, sustainable resource supply, and long-term environmental carrying capacity. The core of sustainable carrying capacity lies in maintaining the sustainable carrying capacity of the ecosystem, including the sustained carrying of single resources and environmental elements. Therefore, in order to avoid irreversible damage to the ecosystem, human activities must be limited within the elastic range of the ecosystem to ensure its sustainability. In summary, human activities should not exceed the carrying capacity limits of ecosystems^[7].

2.3 Single element carrying capacity and multi-element carrying capacity

The evaluation of urban carrying capacity can be divided into two types based on different carrying elements: single element carrying capacity evaluation and multi element carrying capacity evaluation^[26,31]. The evaluation of single element carrying capacity mainly focuses on empirical analysis and quantitative evaluation of single elements such as water resources, land resources, environmental resources, mineral resources, geological and cultural factors in cities, and proposes corresponding countermeasures and suggestions. The evaluation of multi-element carrying capacity comprehensively evaluates the carrying capacity of cities (land) from the perspective of multiple elements. By constructing an evaluation index system, empirical analysis and quantitative evaluation are conducted, and countermeasures to improve urban carrying capacity are proposed.

From the perspective of elements, a single element will not appear in the paper alone. Single element carrying capacity such as water carrying capacity and land carrying capacity will generally be used together with multi-element carrying capacity such as resources and environment, such as water environment carrying capacity, water resources carrying capacity, land carrying capacity, land resources carrying capacity, etc. And from the perspective of research content, the emphasis on single factor carrying capacity is stronger, which is a specialized in-depth study of the environment and resources. The interpretation of the two in this paper is that each has its own focus. The research on multi-element carrying capacity is more comprehensive, while the research on single element carrying capacity is more specific and targeted. Both studies have value.

2.4 Ecological carrying capacity and urban comprehensive carrying capacity

The study of urban comprehensive carrying capacity can be traced back to Wei Houkai's explanation of urban regional carrying capacity^[32]. Against the backdrop of the continuous expansion of urban scale, research on carrying capacity is gradually shifting towards the city level. Afterwards, there has been increasing research on the urban comprehensive carrying capacity^[33-34], and there have also been numerous studies on the comprehensive carrying capacity of urban agglomerations^[35-36].

In 2013, Shi Yishao et al. demonstrated that the carrying capacity at the urban level is not a false proposition, and that carrying capacity is a practical concept under the constraints of spatio-temporal conditions, resource endowment, and environmental capacity. It refers to the threshold of the population and activity intensity that

can be borne under specific time and spatial conditions, considering the limitations of resource endowment and environmental capacity. In the field of urban planning and sustainable development, studying the comprehensive carrying capacity of cities is particularly important. Urban comprehensive carrying capacity refers to the threshold of the population and the scale and intensity of human activities that urban land resources can accommodate under certain economic, social, and technological conditions, as well as specific resource and environment constraints. This concept emphasizes the constraints of resources and environment, closely linking urban development with sustainable development. Therefore, understanding the concept and threshold of urban comprehensive carrying capacity is of great significance for urban planning, land use, and environmental protection.

From the perspective of research scope, the research scope of ecological carrying capacity is more extensive, and the research generally acts on the level of the ecological environment, such as the Heihe River ecological basin studied by Gao Jixi and the Yangtze River Economic Belt urban agglomeration studied by Li Huan. They generally focus on ecology, with a focus on energy flow interaction, ecological consumption,

ecological support, and the self cycling ability of its ecology. However, the scope of urban (comprehensive) carrying capacity research is relatively small, and the research generally acts on the urban level, such as the carrying capacity of three cities in Beijing, Tianjin and Hebei studied by Wang Zhenpo and Li Qingwen, and the carrying capacity of national central city studied by Liu Rongzeng. The main research subjects are generally people living in cities and their living environment, and the focus is whether cities can develop in a coordinated way.

2.5 Environmental carrying capacity and ecological carrying capacity

Zeng Weihua^[8] defined environmental carrying capacity as “the threshold value that the environmental system can withstand human activities in a certain period, within a certain range, and under certain natural environment conditions, without qualitative changes in the structure of the environmental system and damage to the environmental function”.

Environmental carrying capacity belongs to ecological carrying capacity. Gao Jixi also put environmental carrying capacity into the ecological carrying capacity, and defined the ecological–environmental carrying capacity as “the amount of pollutants that the environmental subsystem can absorb under the con-

dition of not exceeding the elastic limit of the ecosystem under certain living standards and environmental quality requirements, as well as the supported economic scale and corresponding population”^[7]. The difference from Zeng Weihua’s environmental carrying capacity is that Gao Jixi’s environmental carrying capacity is more inclined to the self circulation aspect of the environment, while Zeng Weihua’s environmental carrying capacity includes the social environmental aspect (environmental functions include not only the natural aspect, but also the social aspect).

In addition, Zeng Weihua believes that the object of ecological carrying capacity is specific to the entire biological community, and carrying capacity using ecology as the theme word is desirable, but the applicable conditions and carrying capacity are different. Although the environment is targeted at the subject, the human oriented environment is in the ecology whether natural level or social level, and ecological carrying capacity should also include environmental carrying capacity^[8].

The authors believe that the relationship between environmental carrying capacity and ecological carrying capacity is related to the subject of environmental selection. If the subject of environmental selection is biology or ecological environment, then its relationship with ecological carrying capacity is that ecological carrying capacity includes environmental carrying capacity, and what is studied is the problem of ecological hierarchy. If the environmental subject is a human environment, although it is also in an inclusive relationship with ecological carrying capacity, the relationship will be far away, and the level of research is city or smaller. In other words, if the study area is at the ecological level, then the ecological carrying capacity includes environmental carrying capacity. If the study area is at the city level, environmental carrying capacity is the ecological carrying capacity of the city.

2.6 Environmental carrying capacity and resource carrying capacity

UNESCO proposed the concept of “resource carrying capacity” in the 1980s. The resource carrying capacity of a country or region refers to the number of people who can sustain support within a foreseeable period of time, utilizing the region’s energy and other natural resources, as well as intellectual and technological conditions, while ensuring material living conditions that comply with its social and cultural norms.

Mr. Zeng Weihua pointed out that the concept of environmental carrying capacity is

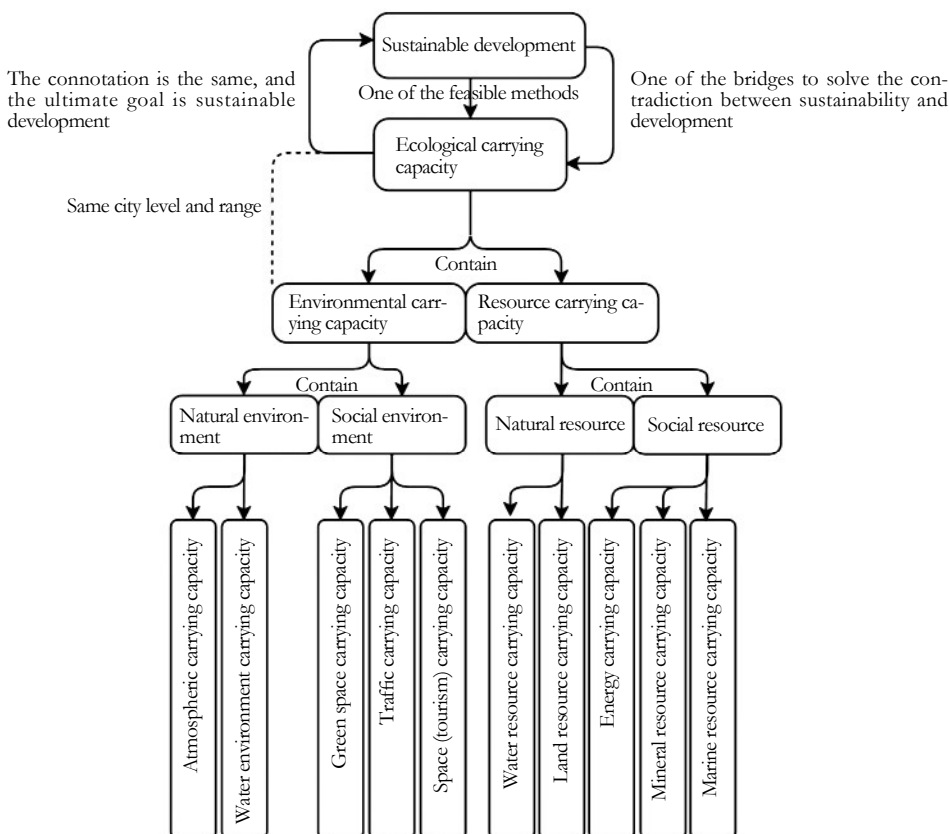


Fig.1 Summary of carrying capacity elements

different from that of resource carrying capacity, and their use scope is also different^[8]. Resource carrying capacity is usually used for single factor research, such as water resource carrying capacity, land carrying capacity, etc., while environmental carrying capacity is usually used to study the comprehensive impact of all environmental factors in the region. Therefore, the study of environmental carrying capacity needs to consider a broader range of factors to comprehensively assess whether a region is sustainable. When considering environmental carrying capacity, it is necessary to take into account the impact of various natural and human factors, including land use, water resources, atmosphere and climate, ecosystem and socio-economic aspects. Therefore, when conducting research on a region, it is necessary to distinguish their differences in order to more accurately assess the sustainability of the region.

The author believes that the two are integrated at the ecological level, and the resource elements of the environment cannot cover all resources. For example, oil is not so much an environmental resource as a resource in the ecology. At the macro level, ecology includes both. The environment, resources, and the ecological elasticity formed by their interaction together constitute the ecological carrying capacity. At the city level, the two are inclusive, and the environmental carrying capacity includes the resource carrying capacity. The environmental carrying capacity at the city level is equivalent to the ecological carrying capacity, and naturally includes the resource carrying capacity.

2.7 Environmental carrying capacity and resources environment carrying capacity

The resource environment carrying capacity refers to the ability of the regional resource and environment system to withstand various social and economic activities of human beings in a certain period of time and within a certain region under the condition that the regional resource structure meets the needs of sustainable development and the regional environmental function still has the ability to maintain its steady effect.

The term 'resource environment' appears frequently in various literature and is often used in parallel, without distinguishing their relationship or difference. Some scholars believe that resource includes the environment, while others believe that the environment includes resource, resulting in unclear expression of the two words. Resource environment carrying

capacity is a concept of comprehensive carrying capacity including resources and environmental elements.

From the definition of resource, resource element is a collective term for various material elements such as material resources, financial resources, and human resources possessed by a country or a certain region, and all objective entities that can be developed and utilized by humans. The definition of resource is formed in the process of modern industrialization and urbanization, and is influenced by political, economic, and cultural factors. In the classification of resources, natural resources and social resources are two basic concepts, covering both material and intangible fields. Natural resources include sunlight, air, water, land, forests, grasslands, animals, minerals, etc. These resources are endowed by nature to humans, and humans can use them to meet their own needs. And social resources include human resources, information resources, and various material wealth created through labor. Human resources refer to the intelligence and technology created by humans in the fields of economy, culture, technology, etc., while information resources refer to the knowledge and technology accumulated by humans in science, technology, and information dissemination.

Environmental factors refer to all external factors (namely objects) that surround and influence something (namely subject)^[9]. Environment is a relative concept that can only be defined and understood when it is related to a specific subject. The environment may include natural environments such as climate, terrain, hydrology, etc., as well as social environments such as politics, economy, culture, etc. In addition, the environment can also be a multi-level concept, from micro to macro, and from local to global.

For human subjects, resources refer to the relatively concentrated material resources that humans can utilize in production and life, and are the source of human production and life materials. For the environment, resources are a type of environmental element, and the two cannot be considered as a parallel relationship, but rather an inclusive relationship. For the environment of human subjects, resource is a part of their environmental elements. For urban areas, the environment of resource environment carrying capacity can include resources.

3 Conclusions

The above analysis is based on the multi-element carrying capacity, among which

environmental carrying capacity and resource carrying capacity are also multi-element carrying capacity, including natural environment and social environment, natural resources and social resources, respectively.

At the research level, most of the existing research on the carrying capacity of ecological non engineering categories focuses on the ecological and urban levels, and the research of ecological level covers the urban level, while the research of urban level complements the shortcomings of the ecological level. For example, pure ecological research does not consider the impact of human economy, while research of urban level complements this to make research of ecological level more comprehensive and draw more accurate conclusions.

From the perspective of elements, the main difference among ecological carrying capacity, urban comprehensive carrying capacity and resource environment carrying capacity lies in the different research scopes. The mainstream view will summarize environmental carrying capacity and resource carrying capacity under the framework of different research scopes. At the ecological level, Mr. Gao Jixi divided the ecological carrying capacity into environmental carrying capacity and resource carrying capacity, discriminated its relationship with sustainable development, and bounded up resources environment carrying capacity. Mr. Zeng Weihua characterized the environment at the urban level as an environment with human as the object, and further restricted the resource environment carrying capacity in the planning document by taking resource as a kind of environmental information. It can be concluded that resource environment carrying capacity at the ecological level can be understood as ecological carrying capacity, and resource environment carrying capacity at the urban level can be understood as environmental carrying capacity.

Single elements such as water carrying capacity or land carrying capacity are not differentiated because most of the single elements belong to multi-element carrying capacity and are deeply studied. If divided by the research level and the discipline, they can be classified into multi elements, such as the urban level water environment carrying capacity of the environmental discipline, and the ecological level land resource carrying capacity of the planning discipline.

Based on the theories of Mr. Gao Jixi and Mr. Zeng Weihua, as well as the research of numerous scholars, the authors summarize the elements of carrying capacity in Fig.1.

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