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"A Review on: Multi-Scales Analysis of Water Resources Carrying Capacity based on Ecological Footprints"

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***Abstract*— Sustainable groundwater development has absolutely fundamental importance for universal access for safe drinking water and is yet poorly understood. The problem of water resource caused by the imbalance between supply and demand. Water resources carrying capacity is a basic measurement of water resource security that plays an important role in recognizing and basically water resource security system. Water footprint focuses on the consumption and trade of the water resource and has been seldom in assessing the latter sustainability due to the water supply. In addition both the ecological and water footprint has static status in accessing the result and explanting the present and past status of water resource. Therefore, making the use of ecological and water footprint appropriately for resource management & maintain the balance between the available water resource and consumption.**

***Keywords*— Carrying capacity, Ecological footprint, Water resource, Water demand and supply.**

I. Introduction

Water resource carrying capacity is a basic measurement of water resources security that plays a very important role in recognizing and building water resources security system. The concept of 'carrying capacity' originates from ecology and is expanded to the study of natural resources and environment to describe the ability of the eco-environment or natural resources to sustain soci-economic activities (Feng Shangyou 2000). 'Water Rsources Carrying Capacity' (WRCC) is defined as 'the scale of economy and population that the local water resources can sustain in a region, provided with necessary requirements of eco-environment protection and a given level of technology and socio-economic development at a certain historical stage'. WRCC research has received increasing attention over the past two decades in China and has become an important approach to measure water security in order to achieve sustainable development, particularly in the areas that face serious water scarcity (Xia Jun et al. 2002).

The water footprint shows the extent of water use in relation to consumption of people. The water footprint of a country is defined as the volume of water needed for the production of the goods and services consumed by the inhabitants of the country. The internal water footprint is the volume of water used in other countries to produce goods and services imported and consumed by the inhabitants of the country (A.Y. Hokestra et al., 2006). The Ecological Footprint is a resource accounting tool that measures how much bioproductive land and sea is available on earth, and how much of this area is appropriated for human use. The Ecological Footprint, human demand and bio-capacity, ecosystem supply, are both measured in units of global hectares, a hectare normalized to the average productivity of all bio-productive hectares on earth (Justin Kitzes et al., 2007). Within this context, important agreements have been proposed in order to promote a global governance of water use. The concepts of water footprint and virtual water trade were proposed in the 90s and since there, an increasing number of studies have focused on quantifying these parameters. The water footprint, originally proposed by (Hoekstra and Hung, 2002), in analogy of the ecological footprint (Rees, 1992), originates from the concept of virtual water proposed by (Allan, 1994). The water footprint of a country accounts for the water used for domestic purposes to produce goods and services domestically and abroad. In a similar way, the virtual water trade, refers to the water used in the products that are traded between different countries (Hoekstra and Hung, 2002; Zimmer and Renault, 2003).

Due to issues of non-universality and unilateralism, the quantifiable method for modeling (Zhang et al, 2010; Liu and Borthwick, 2011) and system dynamics (Haraldsson and Rannveig olafsdottir, 2006; Feng et al., 2008), an improvement in Malthus population model (Irmi Seidl and Clem Tisdell, 1990), has become a widely debated topic. However, this changed when the ecological footprint method was proposed (Rees, 1992et al., 1996).

The ecological footprint method has been used in assessing the carrying capacity of resource (Wacknagel et al., 2011). The method has also been used to study the complexities of varying ecological environments, technologies, and consumption patterns (Hubacek et al., 2009; Sutton et al., 2011). However, the ecological footprint is difficult to calculate based on water resource carrying capacity due to variations in fluidity form the land resource (i.e., the regular transfer of the resource via river system, water recycling, and operations of water conservancy facilities). Therefore, there is a gap between reality and the carrying capacity results of the ecological footprint method as measured by the quantifiable method, which include the average yield for freshwater, yield factor for freshwater, and equivalence factor for freshwater (Huang et al., 2008). This gap exists in many water resource carrying capacity assessments conducted for regional research, especially in metropolitan areas. Hoekstra (2003) proposed a method, and analogue of the ecological footprint, which focused on water volume requirement of water trading. This concept become known as “embedded water” or “virtual water”, and later called “water footprint” (Hoekstra, 2009). However, the use of water footprint in assessing water resource carrying capacity is questioned. In fact, water footprint focusing on the consumption and the trade of the water resource has been seldom applied in assessing the latter’s sustainability due to its inability to demonstrate the capacity of the water resource supply (Stoeglehner, 2011). Additionally, both the ecological and water footprints use static status in assessing the result and explanting the past and current status of the water resource, making the use of ecological and water footprints inappropriate for resource management and planning.

II. Water Resource Ecological Footprint

Compared with works on the land resources in Benin, Bhutan, Costa Rica, the Netherland (Van Vuuren and Smeets, 2000), Italy (Cerutti, 2011), New Zealand (Buckenl land Ball, 1998), and so on the use of ecological footprint in water resource assessment is more difficult. Huang et al. (2008), converted the ecological footprint model to calculate the WEF by identifying the capacity of water production per unit area. They presented three sub-accounts in the regional WEF (Huang et al., 2008).

Currently, we follow the conventional ecological footprint method to calculate the WEF and assess the carrying capacity in our multi-scale framework. The WEFs of different sub- accounts are given below:

1. Household Water Ecological Footprint
2. Productive Water Ecological Footprint
3. Ecological Water Ecological Footprint
4. Total Water Ecological Footprint

III. Multi-Scale Water Resource Ecological Footprint

After constructing the WEF multi-scale framework and employing the hydrological and population data, we were able to quantify the WEF for each sector in city scale and the assessment in multi-scale. The volume of the water resource required to satisfy the need and the sustainability level of the water resource in the region were also identified. Three different scales of water resource carrying capacity are given below:

A. City scale

Water ecological footprint accounts for five sectors in the city scale. Agriculture irrigation is considered as the highest water-consumptive sector in most cities, consuming more than 50% of the total footprint. Water intensity in the industry and household sectors are also very high, whereas the absolute amount of WEF is relatively low due to low consumption. The secondary sectors, forest, and the environment, require relatively low water resources.

B. Watershed scale

The second scale, namely, the watershed scale, is required for accurate results. In this scale, the fluidity of the resource between the tributaries was examined for use in the basic scale.

Both the carrying capacity and ecological footprint have to be calculated in the watershed scale to narrow the gap in the city scales. This means that the residual water from the city in the upstream cam be distributed to the cities in the same watershed by the river system.

C. Basin scale

The basic assessment is the city scale. In this scale calculation of water ecological footprint and ecological carrying capacity of every city is to be made and then analyzed the results for the water resource sustainability by using the traditional ecological footprint method.

However, these cities are not isolated in the region and the also the water resources are not static in the river system.

Taking into account the fluidity of the water resource between the tributaries, the sustainability assessment of the water resource in the basin scale was calculated based on the watershed scale and the city using the proposed Water Ecological Footprint .The aim is to assess the tendency of the ecological footprint, under the hypothesis that the consumption forms of the water resource are unchanged (i.e., the WEF per capita is constant), (Shuo Wang, et al., 2012).

IV. HISTORICAL BACKGROUND

Many scholars have focused on the ecological status of the regional water resource. Only a few works have conducted quantitative analyses of the tendency of the ecological footprint, in which the researcher focuses on the variations caused by spatial structure (Yue et al., 2006) and other social reasons, such as consumption and management (Jorenson, 2003). The multiplicity method is used in forecasting the ecological footprint similar with the afore mentioned analysis. Jin et al., (2009) adopted the system dynamics to forecast the ecological footprint based on the view that consumption and the economy are the drivers of ecological footprint variation. Jia et al., (2010) regarded the ecological footprint as the static indicator that an autocorrelation can be forecasted using the static method such as ARIMA.

A number of studies have been oriented to quantify the water footprint of countries or the water embodied in specific products (Hoekstra and Hung, 2002; Chapagain and Hoekstra, 2003; Chapagain and Orr, 2009; Chapagain et al., 2006; Hoekstra et al., 2002, 2005; Zimmer et al., 2003; Oki et al., 2004; Hubacek et al. 2009), very few attempts have been focused on the global water use (Hoekstra et al., 2007; Hoekstra et al., 2002) and only recently a high spatial resolution estimation of the water globally used and traded has been provided by (Hoekstra and Mekonnen, 2012). However, till date no studies have analyzed the evolution of the water footprint of nations and of the flows of virtual water across. Xu Youpeng, (1993), taking the Hetian river basin as an example, explores the method of comprehensive evaluation of water resource carrying capacity and sets up an evaluation model by applying the fuzzy comprehensive evaluation method. The water resource carrying capacity in the Hetian river basin is evaluated by a model.

It provides a decision-making basis for water resource development in the basin. Fu Xiang et al., (1999), aiming at the subjective random problem of the Fuzzy Comprehensive Evaluation Method in the comprehensive evaluation, of the regional water resource carrying capacity, regional irrigation rate, utilization rate of water resource, exploitation degree of water resource, water supply module, water requirement module, per capita water requirement quantity all environment water use rate was analyzed.

Hoekstra (2003), proposed a method, and analogue of the ecological footprint, which focused on water volume requirement of water trading. This concept become known as “embedded water” or “virtual water,” and later called “water footprint”. Michael Kiparsky et al., (2003), has worked on demand management, especially in face of population increase is critical to mitigate loss of water supply. More water efficient methods in agricultural, industrial and urban water have been effective in the past in this capacity (Owens-Viani et al. 1999), and should be further developed and implemented. As the economic and environmental costs of new water-supply options have risen, so has interest in exploring ways of improving the efficiency of both allocation and use of water resources. Improvements in the efficiency of end users and sophisticated management of water demands are increasingly being considered as major tools for meeting future water needs, particularly in water scarce regions where extensive infrastructure already exists (Postel et al., 1997).

Chagapain A.K. et al., (2006), describe the consumption of a cotton product is connected to a chain of impacts on the water resources in the countries where cotton is grown and processed. To assess the ‘water footprint’ of worldwide cotton consumption, identifying both the location and the character of the impacts. Zhang et al., (2006), describes that resources and environmental have been hot issues for scholars with the advent of energy crisis. The notion of resource carrying capacity provides a new research stream. This article surveys the definitions and quantitative methods for water carrying capacity. K.Chapagain et al., (2008), explains that as water resources point of view one might expect a positive relationship between water scarcity and water import dependency, particularly in the ranges of high water scarcity. Water scarcity is defined here as the country’s water footprint – the total water volume needed to produce the goods and services consumed by the people in the country –divided by the country’s total renewable water resources (Chapagain and Hoekstra 2004).

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Water import dependency is defined as the ratio of the external water footprint of a country to its total water footprint. The external water footprint of a country refers to the use of water resources in other countries to produce commodities imported into and consumed within the country. The relation between water scarcity and water import dependency is not as straightforward as one would expect, although indeed a number of countries – e.g. Kuwait, Qatar, Saudi Arabia, Bahrain, Jordan, Israel, Oman and Lebanon combine very high water scarcity with very high water import dependency. The water footprints of these countries have largely been externalized. The water scarcity and use of external water resources for some selected countries are discussed.

Feng, L. H. et al., (2008), made a risk assessment model for water shortage using a risk analysis method based on the information diffusion theory. The application of this model is demonstrated in the city of Yiwu in Zhejiang Province, china. Based on the analytical results from a small sample, this study indicates that the present model is more stable and effective than the traditional model. However, if the present water supply level is maintained but does not increase in the near future, Yiwu's water supply will be unable to satisfy requirements even under this scheme. In this case, the carrying capacity of water resources in the region can only be effectively improved by promoting more efficient use of water and water conservation schemes, as well as strengthening long-term investment in environmental protection. Hokestra A.Y., (2008), the water footprint concept introduced in 2002 is a analogue of the ecological footprint concept originating from the 1999s. Whereas the Ecological Footprint (EF) denotes the bio productive area (hectares) needed to sustain a population the Water Footprint (WF) represents the freshwater volume (cubic meters per year) required. In elaborating the Water Footprint concept into a well-defined quantifiable indicator, a number of methodological issues have been addressed, with many similarities to the methodological concerns in Water Footprint analysis.

As per CDRI publication (2008), Governance has become a key consideration in the international literature on water governance and development. For example, The United Nations' World Water Development Report (2003) states that the water crisis is mainly a crisis of governance. The 1992 Dublin-Rio Statement acknowledges that water is massive in volume but "finite" in nature.

The volume of water available is limited, and increasing use, fuelled by rapidly increasing population and economic growth, thus creates scarcity in relation to demand.

Hang et al., (2008), says, the ecological footprint is difficult to calculate based on water resource carrying capacity due to variations in fluidity form the land resource (i.e., the regular transfer of the resource via river system, water recycling, and operations of water conservancy facilities). Therefore, there is a gap between reality and the carrying capacity results of the ecological footprint method as measured by the quantifiable method, which include the average yield for freshwater, yield factor for freshwater, and equivalence factor for freshwater. Yizhong, Z., (2008) describes that water resources carrying capacity study is intended to assess the scale of economy and population that local water resources can sustain in a certain region. Taking Zhangye in China as a case, an integrated and dynamic WRCC assessment model based on scenario analysis is established to conduct a comprehensive study of such issues as water resources development, land use, virtual water trade and socio-economic development. The study indicates that provided the 'water re-allocation' scheme and the necessary environment protection measures are implemented, Water resources of Zhangye can support continuing economic development with an annual average GDP growth rate around 7%, with its population continuing to enjoy a 'fairly comfortable' living standard according to agricultural products consumption criteria from 2000-2020 if the industrial structure adjustment and water-saving technology improvements could be achieved.

A water footprint measures the total consumed by a nation, business or individual by calculating the total water used during the production of goods and services, (A. K. Chapagain., 2009). Er. Mukesh Chauhan, (2009), described the requirement of water for drinking, industry and municipal purposes have accordingly increased manifold. Being situated on flat Malwa plateau and at the edge of vindhya mountain ranges from where most of rivers of the region originate, Indore is at disadvantage for not having good reservoir sites and rivers with adequate water resources in its reasonable proximity. This dependence will further increase in future. Lihong,M., et. Al., (2009), explores the method of comprehensive evaluation of water resources carrying capacity and sets up an evaluation model applying the fuzzy comprehensive evaluation method.

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Based on the data of nature, society, economics and water resources of the Tarim River Basin in 2002, and evaluated the water resources carrying capacity of the basin by means of the model.

Xilian Wang, Youpeng, Xu., (2010), made multiple-factor evaluation on the carrying capacity through comprehensive judgment matrix on the basis of evaluating each factor affecting the carrying capacity of water resource by using fuzzy comprehensive estimation. He also built a set of index system and calculation method which is suitable for estimating the carrying capacity of oasis water resources. Liu and Borthwick, (2011), describe' the issues of non-universality and unilateralism, the quantifiable method for modeling. Stoeglehner, (2011) use static status in assessing the result and explanting the past and current status of the water resource, making the use of ecological and water footprints for resource management and planning.

Ecological footprint analysis (EFA) has been used since the early 1990s as a measure of sustainability for geographical regions, products, and activities. EFA is used as a measure of land and water ecosystems needed to provide the resources for a given population and process the waste that it produces in a globalized metric (global hectares), generally on an annual basis (Klein-Banai, C., Theis, T. L., 2011). The index system of water ecological carrying capacity (WECC) is constructed based on Pressure-State-Response model. In light with the calculation of water ecological carrying capacity in different years, the development tendency of WECC in Liaoning Province is analyzed. It concludes that WECC of Liaoning is lower than that of national average. It is thought that the shortage of water resources is the limitation of the water environment in Liaoning. Finally, some effective suggestions to improve the WRCC of Liaoning are proposed (Ling, X., et. al., 2011). Shou Wang, et al., (2012) made a Multi-Scale assessment framework for evaluating water resource sustainability based on the Ecological Pressure Index (EPI) is introduced. In the study he corrected the two faults in the water resource ecological carrying capacity after comparing the traditional ecological footprint and the water footprint.

Navalpotro, J. A. et al.,(2013) develop a general perspective, conforms a primary urban network which highlights the urban region of Madrid, which has generated an extremely important economic and social space along with a demographic polarization in the centre of the country.

With this fact they have add its diverse geographical features that create a complex reality in water supply. Where the analysis of water consumption becomes especially relevant, due to the importance of this resource for the social, economic and environmental development of the region.

Sustainable groundwater development is absolutely fundamental for universal access to safe drinking water and yet this is poorly understood. Groundwater is a finite resource that in some countries is under serious threat from pollution causing permanent aquifer damage while in others over-abstraction is resulting in reduced water availability (Furey S. G., et al., 2012). Water resource development has taken place all over the world. Protecting the surface water resources from wastewater pollution plays a vital role for the development. The disposal of wastewater into the surface water bodies leads to serious problems and affects the people in health aspects (Alaguraja P., et al., 2010).

V. Conclusion

There is a tremendous amount of pressure in protecting the water resources available in the country. The water footprint of a country is the total volume of freshwater used to produce goods and services demanded by the inhabitant of the country. The large scale consumptive use of water is in household activities, irrigation purposes, forest, industry and environment for their management. So, fulfilling the demand of water use we have to make a spatial scale analysis in order to main the balance between available water resources and Ecological Footprint, such as domestic water ecological footprint, agriculture WEF, industrial WEF, service WEF, water ecological footprint, water resource and population. The basic conclusion of this study is to solve the problem of imbalance between water resources and ecological footprint.

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