Environmental sustainability control by water resources carrying capacity concept: application significance in Indonesia

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Abstract. This paper reviews the use of Water Resources carrying capacity concept to control environmental sustainability with the particular note for the case in Indonesia. Carrying capacity is a capability measure of an environment or an area to support human and the other lives as well as their activities in a sustainable manner. Recurrently water-related hazards and environmental problems indicate that the environments are exploited over its carrying capacity. Environmental carrying capacity (ECC) assessment includes Land and Water Carrying Capacity analysis of an area, suggested to always refer to the dimension of the related watershed as an incorporated hydrologic unit on the basis of resources availability estimation. Many countries use this measure to forecast the future sustainability of regional development based on water availability. Direct water Resource Carrying Capacity (WRCC) assessment involves population number determination together with their activities could be supported by available water, whereas indirect WRCC assessment comprises the analysis of supply-demand balance status of water. Water resource limits primarily environmental carrying capacity rather than the land resource since land capability constraints are easier. WRCC is a crucial factor known to control land and water resource utilization, particularly in a growing densely populated area. Even though capability of water resources is relatively perpetual, the utilization pattern of these resources may change by socio-economic and cultural technology level of the users, because of which WRCC should be evaluated periodically to maintain usage sustainability of water resource and environment.

1. Introduction

Water-related environmental hazards in Indonesia increasingly happen in both frequency and intensity. Most of Indonesian region is influenced by humid tropical climate, characterized by abundant rainfall that ought to provide abundant water resources. Many places in Indonesia particularly in the densely populated regions, actually suffer water scarcity during a dry season, and are ironically struck by floods and landslides during rainy season. This worsening conditions indicate that land and water resources are exploited in an inappropriate manner that exceed their carrying capacity (CC).

The root of the causes is attributed to population growth and urbanization which lead to the expansion of settlement and infrastructure area. However, rural area is not completely abandoned and even more intensely exploited such as intensive agriculture, plantations particularly oil palm, raw pulp industry plantations, etc. Since the annual availability of water and its monthly fluctuation are locally almost unchanged, misuse and overexploitation of these resources often overshoot. Besides that, economic improvement increases the number of middle-class society who gains better income that changes their life style using more technology and consuming more resources including energy and water. Increasing water consumption in a growing urban will diminish water availability and produce more wastes that
could also contaminate water body or source. Population growth requires more land that leads to land use/land cover change that may alter further local hydrologic regime and weather dynamics [1]. Influence of extreme climate events caused by global climate change is also considered as another deterioration factor.

Insufficient of local resource to supply water demand [2] and increasing wastes concentration in water body [3] indicate that water exploitation is beyond water resources carrying capacity (WRCC), whereas land resources overexploitations are indicated by frequent floods, landslides and high the water turbidity of water stream in a rainy season.

The actual trends of population growth and urbanization as well as regional developments are almost unavoidable, but to prevent environmental deterioration and hazards, instead of having development benefit, the exploitation of land and water resource should not exceed the CC limit of sustainable utilization and should be able to recycle the wastes. The threshold is demanding to determine since it encompasses inter-correlated natural and societal factors. The constraint is only disclosed when utilization is overshoot that the negative impacts of overexploitation appear. It is perhaps the explanation why only the worst impacted countries perform the CC studies. However, the efforts to avoid or to rehabilitate the negative impact of land and water resources overexploitation will be very challenging to achieve without considering this CC Limits. The CC studies are as the basis for environmental or regional planning and management conducted mostly in arid regions such as Algeria [4] or that are worse impacted by overpopulation, such as USA, Indonesia, and particularly China.

2. Methods and Parameters
CC originated from ecology concept, refers to the maximum number of individuals that can be supported within an area of an environment without decreasing the ability to maintain future generations [5]. Since resources in an environment of an area are limited, every living creature has to adapt to this limitation by population number control and way of living adjustments. Among living things, human being has an extraordinary capability to cope and overcome the restraint. By this capability human population growth on earth far exceeds the other living even despoil resource allocation of another existence. Human population proceed to have very rapid growth and does not show any deceleration since its first presence. This phenomenon caused an anxiety of many environmental scientists of the last centuries, that increasing human demand on resources may attain the amount that could not be fulfilled anymore by nature [2]. In fact, until today when human population is about 7 billion, most of human life still goes on even though some densely populated countries or regions suffer environmental related crises or hazards.

Nowadays, CC is a term commonly used in the constraint of human environmental development. Therefore, CC value involves not only the quantity of supporting resources but also the capacity to carry human activities and natural activities. In human ecology, CC is a threshold value of the availability of the resources that can sustainably support the economy and environmental developments of an area (6). At the beginning regional CC measured environmental carrying capacity (ECC) that considered many interrelated ecological factors, but in the latest development, CC assessment method is simplified by taking only few of the most significant factors. Indonesian Ministry of Environment developed ECC measure based on Water and Land [7], whereas CC studies in arid countries such as China and Algeria were built only on water resources [4], [8]. In India, CC study is relatively limited and typically carried out for a distinct theme such as WRCC of New Delhi City [9] or agricultural CC. However, water is always a part of the important consideration in every CC study. In several mentioned countries above, the report of WRCC study is in very short supply, except CC studies for classic ecological purposes.

3. Assessment practices and results
The use of CC concept to solve the environmental problems of human overpopulation took place not earlier than about 40 years ago. It was in 1976 in the USA when Florida City officials and residents were concerned with hurricane evacuation, and had to prepare 30,000 residential units and settled on 7,800 units to house an evacuated population that should be sustainable in the long run [10]. In the
1980’s the neighboring state, Atlanta: one of the most populous regions in the USA, was instructed to create a carrying capacity analysis model (CCAM). The CCAM generates information based on 6 modules covering human activity and ecosystems: socioeconomic, population, fiscal, human (water and traffic) infrastructures, terrestrial and marine environment. In fact, this is a comprehensive environmental impact assessment model that could guide the city to avoid future conservational problems.

In China, CC studies were initiated in around 1984 in the western part of the country, aimed to assess the capability of water resources of the region in supporting the economic development of arid area [11]. In the period of 1995-2000, these studies were continued in other provinces and many cities spreading out all over the country. After 2000, the WRCC studies in China cover larger area and include surface and groundwater resources evaluation by a single comprehensive assessment method.

Set pair analyses [12] were used to assess WRCC of Sanjiang Plain in RDC which used several interactive indicators as input parameters. The evaluation results are visually expressed on a map by GIS representing spatial distributional of water resources carrying capacity. To extract the information of many WRCC influencing factors, spatio temporal approach is adopted to evaluate the development feasibility and environmental sustainability by also considering climate change in North Shelterbelt of China [13]. The analyses were concerned with the socio-economics data including technological factors, and ecological factors consisting of rainfall and land conditions. The model shows that although spatial variation could better reveal, it lacks of a study of future WRCC. To minimize the gap between WRCC and Water Ecological Footprint (WEF) index measurement results in multiscale (city, watershed, and basin) analysis and differs pressure index was applied [14]. This break is caused by a fluidity of water transfer by river system, recycling and conservancy services. The method also forecasted the tendency of WEF to correct the existing static error.

Temporal change information is important for the past experiences-based evaluation and to measure the extent of effort that should be prepared to face the coming situation progress. Simple forecasting could be carried out by looking at population growth rate as the prompt factor of future water demand increase thus will decrease WRCC. Since many other socio-economic factors influence water consumption behavior of a region, technology input could increase water availability. In fact, future change of WRCC is the result of all influencing factors interaction, which requires more comprehensive forecasting model to have a better precision of assessment result.

The most comprehensive study in China is the application of P-S-R framework analysis to formulate causal indicator system coupled by VFuzzyPR and AHP to see the variability of WRCC by Successive Dynamic assessment for all the country [15]. The method brings about not only accurately understanding of the change of WRCC but also the mutual growth both socio-economic and sustainability. Socio-economic development will strengthen environmental requirements and raise the conservation inspiration of human; even though development will consume water and produce pollution.

In Indonesia, CC is officially used as the basic to regulate spatial distribution of development and established as Indonesian spatial planning law. CC determination is based on three denomination: (1) Supply (availability) and demand ratio of Water in one area, (2) Supply and demand ratio of land in one area, and (Land Capability approach). CC determination guideline was enacted as a Ministerial Regulation by Minister of Environment [5].

One of the environmental carrying capacity studies of Yogyakarta Urban Area [16] takes the assumption that all water runoff could be utilized and all the land is suitable for settlement or infrastructure construction, except 30% of the total area which should be allocated for open space according to spatial planning law. The results show that WRCC will be accomplished 100 years earlier (in 2161) comparing to that of Land Resource CC (LRCC, in 2262) with the current magnitude of utilization and growth rate trends of population and economic activity.

The preliminary result of current WRCC status study covering a larger area and detailed spatio-temporal variation has been carried out in Bandung Basin using the data of 2012 (Figure 1). Assuming that only 20% of total base flow is usable for human activities out of ecological need. The result shows that total human water use amount almost exceeds an ideal amount of proportional utilization between
human activities and environmental conservation necessity. The significant distribution gap between availability and utilization exist both spatially and temporally: water deficit in a densely populated area particularly during a dry season. Therefore, in the near coming years, water scarcity problem could be overcome by minimizing these gap distributions.

All WRCC assessment results give the illustration on the level of how critical the water use or water needs to its resources is; therefore, the policy maker could prepare a strategy to maintain the sustainability of future water utilization by considering the current tendency.

Figure 1. WRCC status distribution for 2012 and examples of monthly supply-utilization balance of some sub districts in Bandung Basin.

4. The importance of WRCC assessment in Indonesia
Responding to the emerging of recurrent water-related hazards in a densely populated area, alert handling should deal with the main problems to bring a thorough solution that generates newly sustainable custom of resource utilization. Water resource is quantitatively abundant in most part of Indonesian territory, but in the point of view of quality, many regions possess poor water quality such as acidic water in peat land province and brackish water in a coastal area. Similar ironic condition of abundant but deprived quality of water could also be shaped in overpopulated urban caused by high production of pollutant. Therefore, future WRCC assessment in humid tropic country should take water quality deterioration into consideration besides quantity depletion.

In the humid tropic like Indonesia, water-related problem is not derived only from water resource misuse or overexploitation, but could also come from inappropriate land use in the watershed that may cause an increase of water flow destructive power after rainfall and aggravate water scarcity during the dry season. Therefore, WRCC status deterioration is not solely caused by augmenting water consumption but also by enlarging and intensifying of land utilization leading to discharge amplitude
amplification between rainy and dry season. This phenomenon, besides conveying water-related hazards, also alter continuity of water availability that aggravates water scarcity in prolonged dry season.

The land capability norm for land use regulation exists in Indonesia, but it concerns only with utilization for the agriculture sector, whereas for other purposes, such as building and other infrastructure, there is no practically limitation as long as technically and economically feasible. Indonesian government put into effect Regulation on Spatial Planning to control spatial arrangement of land use. Law no. 26/2007 regulates that outside the city spatial arrangement should concern regional carrying and bearing capacities, while in the city at least 30% of the total area must be allocated for open space. By the existing spatial regulations, an uncontrolled congregation of a population and their activity in a preferential area is still possible to occur. In the mountainous area, for example, freshen temperature, unpolluted air, and beautiful scenery attract people to come and live, where areal WRCC status overshoot is possibly set off. The only way to inhibit exceeding utilization is to recognize WRCC measure below which water utilization amount should be maintained in the region. Since both water availability and water demand changes, WRCC should be evaluated periodically to adjust land and water utilization control. For that purpose, it is necessary to determine the practical WRCC assessment method that could be used as a consistent tool for continuous evaluation.

5. Conclusions
The use of WRCC measure to forecast and control sustainable environment and water use in a developing region has been reviewed. WRCC is an essential measure known to control land and water resource utilization, particularly in a growing densely populated area. WRCC, as well as ECC, is a dynamic value. Even though capability of Water resources is relatively perpetual, the utilization pattern of these resources may change by socio-economic and cultural technology level of the users, because of which WRCC should be evaluated periodically to maintain sustainable use of water resource and environment. In a humid tropic climate such as in Indonesia, attempts to avoid water quality deterioration and intensified land use are of great importance while assessing WRCC.

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