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Letter to the Editor

Communications on emergy indices of regional water ecological-economic system

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Emergy evaluation perspective of water has been used as an effective tool for water resource management and sustainable utilization (Buenfil, 2001; Kang and Park, 2002; Chen et al., 2009, 2011; Lv and Wu, 2009; Pulselli et al., 2011). Lv and Wu (2009) proposed a theoretical framework and methodology of water ecological-economic system (WEES) assessment based on emergy synthesis. They also developed five indices, water emergy ratio (WER), water emergy utilization ratio (WEUR), water emergy self-support ratio (WESR), water emergy density (WED), and water resources population carrying capacity (WPC). However, the formulations and implications of these indices could be discussed as follows.

1. Water emergy ratio (WER)

WER is the ratio of the emergy of water resources to the total emergy by Lv and Wu (2009).

$$\mathrm{WER} = \frac{\mathrm{WR}}{U} \tag{1}$$

where WR is the total emergy of water, defined as the sum of surface and groundwater within system; U is the total emergy of system, which is the vector sum of inputs and export, formulated as $U = R$ (renewable local resources) + N(non-renewable local resources) + IMP(purchased inputs) − EXP(export resources).

Lv and Wu (2009) stated that WER was a measure of the sustainability of WEES: the higher the value, the higher the ability of the system to make use of the local available water resources. However, WR in Eq. (1) reflects the emergy of available water within the system. The water diverted from outside rivers could be a sustainable source for many riverside cities. The numerator in Eq. (1) would be reasonable if it included the reliable source of outside river water. Nevertheless, since WR is a theoretic value for local water development at the current standard of technology and U is an actual value of the total emergy use in a given year, the ratio of WR and U might not indicate the sustainability of WEES well. Thus, we proposed another indicator similar to WER, water emergy input ratio (WIR) estimated by Eq. (2).

$$\mathrm{WIR} = \frac{\mathrm{WC}}{U} \tag{2}$$

where WC is the emergy of consumed water at the current standard of living. WIR indicates the contribution of water resources to the real wealth of the economy (Chen et al., 2009).

2. Water emergy self-support ratio (WESR)

Lv and Wu (2009) developed WESR estimated by Eq. (3).

$$\mathrm{WESR} = \frac{\mathrm{WL}}{\mathrm{WC}} \tag{3}$$

where WL is the emergy of local water consumed. They also described that system with higher ratio would depend more on local water resources and have more potential to raise productivity. However, WESR is a measure of the “relative” self sufficiency of the region for water use. The emergy of water from home or outside is mainly determined by its quantity (m^3) and transformity (sej/J). WESR only indicates the “relative” dependence of the region on local water and the emergy-based contribution of local water to the total water use, but might not indicate the “potential to raise productivity”.

3. Water emergy density (WED)

Lv and Wu (2009) developed WED, the total water consumption emergy divided by the area. They also stated, “The higher the WED, the higher the development of a system. The system consumes less water emergy per unit area with relatively low economic development level”. However, this index is connected with other important factors, such as the quantity, transformity and efficiency of different water use, the distribution density of water use sectors, and the size of land area. It is only a “relative” symbol of economic development in its initial stage. A developed and big region with high saving technologies might have a lower WED. Yet, WED could be a comparative index among different regions, indicating the different contributions of water resources to regional economy. We also proposed two similar indices, total water abundance (WA) and local water abundance (LWA):

$$\mathrm{WA} = \frac{\mathrm{AW}}{\mathrm{area}} \tag{4}$$

$$\mathrm{LWA} = \frac{\mathrm{ALW}}{\mathrm{area}} \tag{5}$$

where AW is the emergy of available water from home and outside at the current standard of technology, ALW is the emergy of available water only from home. These two indices reveal the water abundances and water development technology levels for different regions.

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4. Water resources population carrying capacity (WPC)

Lv and Wu (2009) proposed the index of water resources population carrying capacity (WPC), calculated by Eq. (6).

$$\mathrm{WPC} = 8 \times \frac{\mathrm{WR}}{(U/P)} = 8 \times \left(\frac{\mathrm{WR}}{U}\right) \times P \tag{6}$$

where P is the population. However, they simply used the definition of the renewable and developed carrying capacity of a region at the current standard of living by Odum (1996). The renewable carrying capacity is estimated by multiplying the fraction of renewable use by the present population of the region. The developed carrying capacity is also estimated by multiplying the value of renewable carrying capacity by "8". The number of "8" is an average ratio of purchased to renewable emergy in developed countries from past studies (Odum, 1996). The renewable water is a part of the total renewable resources and the non-renewable groundwater (deep aquifers) is also a part of the total non-renewable resources. There is no evidence of "8" indicating the relationship among different water emergy and other resources emergy. Thus, the ratio of 8 directly used in Eq. (6) might be inappropriate. Furthermore, WPC does also not consider the case of the regions that have reliable outside water source. This index could be revised by considering the relationship between the emergy of available water and that of consumed water at the current standard of technology and living. The formulas can be summarized as follows:

$$\mathrm{WPC} = \left(\frac{\mathrm{AW}}{\mathrm{WC}}\right) \times P \tag{7}$$

$$\mathrm{LWPC} = \left(\frac{\mathrm{ALW}}{\mathrm{WC}}\right) \times P \tag{8}$$

where AW is the emergy of available water from home and outside at the current standard of technology; WC, the emergy of consumed water at the current standard of living; LWPC, local water resources population carrying capacity; ALW, the emergy of available water from home at the current standard of technology.

In addition, the calculation of water transformities and the identification of system boundary are preconditions for emergy analysis of WEES. More concerns and interpretations about them should be reported in the study. Moreover, other indicators can be developed for better understanding the sustainability of WEES, such as: water emergy use per person (the total water emergy use divided by the population), water abundance per capita, the ratios of waste water emergy to U, WR and WC. Further studies should be conducted to evaluate the sustainability of WEES based on emergy theory. More additional emergy evaluations of water should also be completed to provide adequate guidelines for policy decisions about optimum eco-efficiency alternatives of water development and utilization (Chen et al., 2011).

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