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An improved method for evaluating ecological suitability of hydropower development by considering water footprint and transportation connectivity in Tibet, China

Guannan Cui, Xuan Wang, Linyu Xu, Jin Zhang and Bing Yu

ABSTRACT

Ecological suitability evaluation for hydropower development is effective in locating the most suitable area for construction and emphasizes a clear direction for water resources governance. In this paper, water footprints and transportation connectivity were introduced to improve the existing ecological suitability evaluation application for hydropower development by revising the defects of the traditional indicator system. The following conclusions were reached. (1) Tibet was in a state of water use surplus; the prospect of further hydropower development is positive. (2) Chamdo, Lhasa and Nyingchi excelled in water use efficiency, and Ali was placed last. Nakchu was slightly superior to Ali, but it lagged behind the southern regions. Lhasa, Chamdo, Nyingchi, Xigaze and Shannan were suitable for hydropower development, which could further meet local needs and benefit other regions of China. (3) The evaluation results were in accordance with the actual eco-environmental conditions of the built hydropower projects, indicating that current hydropower development planning was basically reasonable.

Key words | ecological suitability evaluation, hydropower development, transportation connectivity, water footprint, water resources utilization

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INTRODUCTION

Energy drives human life and is extremely crucial for continued human development. With the increase in human population, urbanization and modernization, the growth in global energy demand is projected to rise sharply over the coming years (Asif & Muneer 2007). Hydroelectric power plays an essential role in many regions of the world and is generated in more than 150 countries, especially in developing countries (Kaygusuz 2004). Furthermore, hydropower's role as a clean renewable energy source will continue to be supported (Bartle 2002). However, hydropower development will have some impact on the eco-environment, such as interrupted river flow, biodiversity losses, soil erosion, and water pollution and shortages (Liu & Diamond 2005). Although efforts were made to face the problems of uncertainty and complexity in energy management and non-point source water pollution control (Cai *et al.* 2009; Tan *et al.* 2011), it is necessary to identify whether ecological and environmental conditions are suitable for regional hydropower development prior to the construction of a hydropower project by evaluating the region's ecological suitability.

The suitability evaluation is a comprehensive evaluation of land use through hydrology, geography, topography, geology, biology and cultural characteristics, among other characteristics, to determine the land's suitability for a particular purpose. Currently, it has been developed for a wide range of research areas, including the suitability evaluation of land use for farming, forestry, herbs and urban expansion (Kalogiroua 2002; Sicat *et al.* 2005). However, few studies have been conducted on ecological suitability evaluations for hydropower development. In addition, neither the efficiency and economic value of water resources use nor the transportation network, which can reflect dynamic connectivity information for the entire region, has been taken into account in previous indicator systems. Therefore, a specialized indicator system should be developed to focus on water resource utility and transportation connectivity for ecological suitability evaluation of hydropower development.

As water issues continue to emerge, the evaluation of water resource utilization has become a focus of water resource research. The related conventional evaluation

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methods include fuzzy comprehensive evaluation methods (Chen *et al.* 2013), AHP (the analytical hierarchy process (García *et al.* 2014)), and so on. However, the water resource system is complicated by demographic, economic, environmental and natural constraints. The evaluation method based on the water footprint considers human activities from a consumer's point of view; thus, relationships between water use and human consumption patterns are established (Simonovic 2002). Petrescu *et al.* (2010) proposed that a water footprint could be used as an effective tool to analyze water consumption patterns. In addition, transportation connectivity among regions is an important foundation for achieving water resource complementarity and scheduling management. Connectivity is a concept first used in landscape ecology to describe the interaction and the interconnection of sub-landscape units (Merriam 1984). Then it was increasingly accepted in spatial planning that emerged from the biological conservation field. It was of significance not only to spatially establish integrated biological conservation infrastructure to reduce the threats posed by habitat fragmentation for biodiversity, but also to emphasize administrative cooperation and participation for harmonizing the conflict between conservation and utilization (Biemans & Snethlage 2008). To underline the importance of relations among the sub-regions, this indicator was introduced in the system. Therefore, evaluation based on water footprint and transportation connectivity would enable a new perspective on the socio-economic area of the water problem.

Based on water footprint and transportation network theories, the traditional indicator system was updated for a hydropower development suitability evaluation. This study entails the following tasks. (1) Assess the water footprint from the aspects of structure, benefits, ecology, security and sustainability for the entire region. (2) Calculate water resource utilization and transportation connectivity for seven sub-regions to enrich the database and analyze the structure and benefit indicators. (3) Conduct an ecological suitability evaluation for hydropower development with a consideration of the water footprint and transportation connectivity, and intuitively display the evaluation results using geographic information system (GIS) techniques. Obviously, taking water footprint and transportation connectivity into consideration in the evaluation process could give an in-depth and comprehensive view for grasping ecological suitability status, and also provide important support for enacting hydropower development planning.

STUDY AREA

The Tibet Autonomous Region (Figure 1) is one of the five autonomous regions of China; it is located at latitude 26° 50′ to 36° 53′ and longitude 78° 25′ to 99° 06′, which is southwest of the Qinghai-Tibet Plateau. The entire region covers 1.27 million km^2 and has a population of 2.81 million. Seven sub-regions are present: the capital Lhasa, Chamdo, Nyingchi, Shannan, Xigaze, Nakchu and Ali. The Tibet Autonomous Region is called the 'Roof of the World' because it has an average altitude of 4,000 metres above sea level. An uneven seasonal distribution of

Figure 1 | The administrative map of the Tibet Autonomous Region, China.

precipitation occurs, which results in distinct dry and rainy seasons. The average annual rainfall amount is 400 mm.

Tibet is rich in water resources with 1.53×10^5 m^3 per capita. The water reserves amount to 2.01 million kilowatts, which account for 30% of the total water resources (the highest in the country). Of the more than 500 kilowatts of technological resources, hydropower produces 110 million kilowatts, which accounts for nearly 20% of the country's output. However, the actual water resources development rate in Tibet is less than 1% at present. The uneven geographical and seasonal distributions of water resources can engineer water shortages to an extent. This situation causes the abundant resources to restrict socioeconomic development. Therefore, the scientific development of water resources is desirable to address the restriction and reduce the ecological harm caused by fossil energy.

METHODOLOGY

The indicators of traditional suitability evaluation systems of hydropower development were selected based on previous research (Lathrop & Bognar 1998; Marull *et al.* 2007). Transportation connectivity and water footprint were added into the system to increase the rationality of the evaluation results. Depending on AHP, the suitability evaluation was conducted and regionalization was displayed with the aid of GIS mapping.

Calculating the water footprint and transportation connectivity

Water footprint could be calculated by green and blue water, while combined with grey water (Thaler *et al.* 2012). And a nation's water footprint could also be subcategorized into two components: the internal and external water footprint (Vanham 2013). The latter method was chosen from the aspect of obtaining data. Detailed equations could be referenced in the research of Chapagain & Hoekstra (2004). As to transportation connectivity, some relevant parameters such as corridor number and node number of the transportation network were used for calculation (Wang 2010). The data involved in the calculations were obtained from the Tibet Statistical Yearbook (2012), National Bureau of Statistics of China and China Water Resources Bulletin (2012). Information about land use was extracted from the GIS map attribute table.

Construction of an indicator system for evaluating the ecological suitability of hydropower development

In this research, the main ecological impact factors that affect hydropower development and construction were selected as the key indicators by expert judgment (Table 1). Additionally, the ecologically sensitive area was considered a limiting factor to ensure the healthy development of ecological protection zones. AHP was used to determine the weight of each indicator. Single indicator suitability scores were divided into four categories; the assignments were 100, 75, 50, and 25. For a comprehensive evaluation, the determination of suitability was achieved by a weighted sum based on different factors. The results were displayed in GIS by overlaying each factor layer.

The traditional indicator system for the evaluation of ecological suitability included environmental, ecological and social sub-systems. The three indicators involved in the social sub-system considered human activities and economic aspects (Table 1). To further emphasize water use efficiency and correlations among the various regions, the indicator system was improved by using more comprehensive views of water resource utility and transportation connectivity. The three benefit indicators of water footprint reflected the social and economic views of different regions and the water use efficiency. Furthermore, γ index, being defined as a ratio of corridor number to node number in the transportation network and commonly used in urban green ecological network planning (Wang 2010) was introduced to reflect the connectivity among the regions and the response sensitivity during emergencies.

RESULTS AND DISCUSSION

Water footprint and transportation connectivity indicator analyses

The ecological water footprint was calculated, and this accounted for the greatest amount (93.86%) due to the very large rivers and lakes in the region. The agricultural water footprint ranked second (5.53%). Domestic and industrial water comprised only very small amounts (0.36% and 0.26%). Contributing to the foreign water trade, the internal water footprint was 563.32×10^8 m^3, and the external water footprint was 0.096×10^8 m^3. By summarizing the two findings, the total water footprint amounted to 563.42×10^8 m^3. Compared with the total water resources of $4{,}593 \times 10^8$ m^3, Tibet was in a state of water use surplus.

Table 1 | Traditional and improved indicator systems for evaluating ecological suitability of hydropower development

Target layer	Criterion layer	Indicator layer 1	Indicator layer 2	Level	Classification	Weight
Suitability level A	Environmental sub-system B1	Topography C1	Elevation D1(m)	1	≤ 3000	0.1163
				2	(3000,3500]	
				3	(3500,4000]	
				4	> 4000	
			Landform D2	1	Valley area	0.093
				2	Gorge area	
				3	Lake basin	
				4	Mountain	
		Environmental quality C2	Surface water quality D3	1	Better than III	0.0621
				2	III-IV	
				3	IV-V	
				4	Worse than V	
		Land use C3	Land cover type D4	1	River	0.281
				2	Others	
	Ecological sub-system B2	Climate C4	Annual mean temperature D5 (°C)	1	≥ 15	0.061
				2	[7,15)	
				3	[0,7)	
				4	< 0	
			Annual mean precipitation D6 (mm)	1	≥ 500	0.0683
				2	[350,500)	
				3	[200,350)	
				4	< 200	
		Ecological quality C5	Ecological environment indicator D7	1	≥ 60	0.0894
				2	[45,60)	
				3	[30,45)	
				4	< 30	
	Traditional indicator system					
	Social sub-system B3	Intensive degree C6	Population intensity D8 (cap/km^2)	1	≤ 1	0.0812
				2	(1,5]	
				3	(5,10]	
				4	> 10	
		Economic level C7	GDP growth rate D9 (%)	1	≥ 16	0.0739
				2	[13,16)	
				3	[10,13)	
				4	< 10	
			GDP per capita D10 (10^4 yuan RMB/cap)	1	≥ 3.5	0.0739
				2	[2.5,3.5)	
				3	[1.5,2.5)	
				4	< 1.5	
	Improved indicator system					
	Social sub-system B3	Water resource utilization C6*	Water footprint per capita D8* (m^3/cap)	1	≤ 5000	0.061
				2	(5000,12000]	
				3	(12000,20000]	
				4	> 20000	
			Water footprint per unit area D9* (m^3/km^2)	1	≤ 20000	0.061
				2	(20000,44000]	
				3	(44000,60000]	
				4	> 60000	
			Economic value of water footprint D10* (yuan RMB/10^{4}t)	1	≥ 20000	0.061
				2	[11000,20000)	
				3	[5000,11000)	
				4	< 5000	
		Transportation connectivity C7*	γ Index D11*	1	≥ 0.5	0.0459
				2	[0.45, 0.5)	
				3	[0.4, 0.45)	
				4	<0.4	

Note: the asterisks indicate additional indicators in the improved indicator system.

Table 2 shows indicators of the Tibet region from structural, benefit, ecological security and sustainability aspects. The water self-sufficiency (WSS) of the Tibet region in 2010 was 99.98%, which exceeded the WSS of the world (84%) and China (93.6%) (Hoekstra & Chapagain 2007). The self-sufficiency of the Tibet region was rather high; the area did not need external help with water resources. This finding was attributed to the following: the Tibet region had abundant water resources to meet citizens' needs; meanwhile, the inconvenient transportation situation restricted foreign trade in water.

The economic value per 10^4 t water footprint was smaller than the average value in China. The corresponding value for the indicator in China was 20.68×10^4 yuan RMB/10^4 t. Compared to the Chinese water footprint per capita of 1.48×10^3 m^3/cap, that of Tibet did not reach the general level. However, the water footprint per unit area was better than the national standard (20.04×10^4 m^3/km^2). Generally, the efficiency of water use in Tibet was not satisfied, unlike the national mean level. In the national economy, water resources had not played an efficient role, which contributed to the scale of city development, industrial layout and other factors. Regarding the external benefit indicators, the water footprint net trade volume was positive. Thus, the Tibet region played a role in water resource output in the virtual water trade. In contrast, the contribution rate of water resources was smaller than 1, which illustrated that Tibet did not significantly contribute to relieving the pressure of water resources in other areas (Qi *et al*. 2011).

The ecological security indicators revealed that the stress level in Tibet was much lower than that in well-developed cities. The region was not worried about facing excessive development. Water scarcity and water pressure were approximately the same due to the small amount of virtual water exports to other countries and regions. Overall, the region was in an ecologically safe condition from the water utility aspect. The regional water footprint expansion range was less than the available water resource expansion range. Under the circumstances, a smaller water sustainability index (WSI) resulted in a more sustainable region. According to the judgment process of regional water resource sustainability, Tibet had a sustainable outlook regarding water utility. The prospect of further hydropower development would be positive.

Figure 2 clearly displays the water use conditions as explained by the three indicators associated with the water footprints of the seven sub-regions. Chamdo performed the best at water footprint per capita with 2.29×10^3 m^3/cap. Nyingchi and Lhasa followed with 5.34×10^3 m^3/cap and 6.77×10^3 m^3/cap, respectively. Regarding the economic value, the top three sub-regions were Nyingchi, Lhasa and Chamdo, which created 72.1, 56.8 and 54.9 thousand Yuan per 10^4 t water footprint. Geographically, southeastern Tibet used water resources fairly effectively. All of the indicators referred to previously had similar trends in which Ali did not behave positively. The water footprint per unit area demonstrated a quite different rule compared to the others. Nyingchi and Chamdo maintained satisfied

Table 2 | Indicator system of evaluating regional water resource utilization based on the water footprint method

Indicators		**Calculation**	**Value**
Structural indicators	Water import dependency WD (%)	(EWFP/WFP) ×100%	0.02
	WSS (%)	(IWFP/WFP) ×100%	99.98
Benefit indicators	Internal benefit indicators		
	Water footprint per capita (m^3/cap)	WFP/TP	2.0×10^4
	Water footprint per unit area (m^3/km^2)	WFP/A	4.44×10^4
	Economic value per 10^4t water footprint (yuan/10^4 t)	GDP/WFP	1.07×10^4
	External benefit indicators		
	Water footprint net trade volume (10^8 m^3)	VWE_{dom}-EWFP	1.04
	Contribution rate of water resources (%)	(VWE_{dom}-EWFP)/ WA	0.02
Ecological security indicators	Water scarcity WS (%)	(WFP/WA) ×100%	12.27
	Water pressure WP (%)	(IWFP + VWE_{dom}) /WA	12.29
Sustainable performance indicators	Water footprint rate of change WFPR (%)	(WFP_2-WFP_1)/WFP_1	12.61
	Water availability rate of change WAR (%)	(WA_2- WA_1)/WA_1	13.99
	Water sustainability index WSI (%)	|WFPR|/|WAR|	0.90

WFP is a national or regional water footprint; IWFP is the internal water footprint; EWFP is the external water footprint; TP is total population; A is area of nation or region; VWE_{dom} is the virtual water exported to other countries in relation to the export of domestically produced products; WA is water resources available; WA_2 and WA_1 are water resources available in the evaluation year and the year before, respectively; WFP_2 and WFP_1 are water footprints in the evaluation year and the year before, respectively.

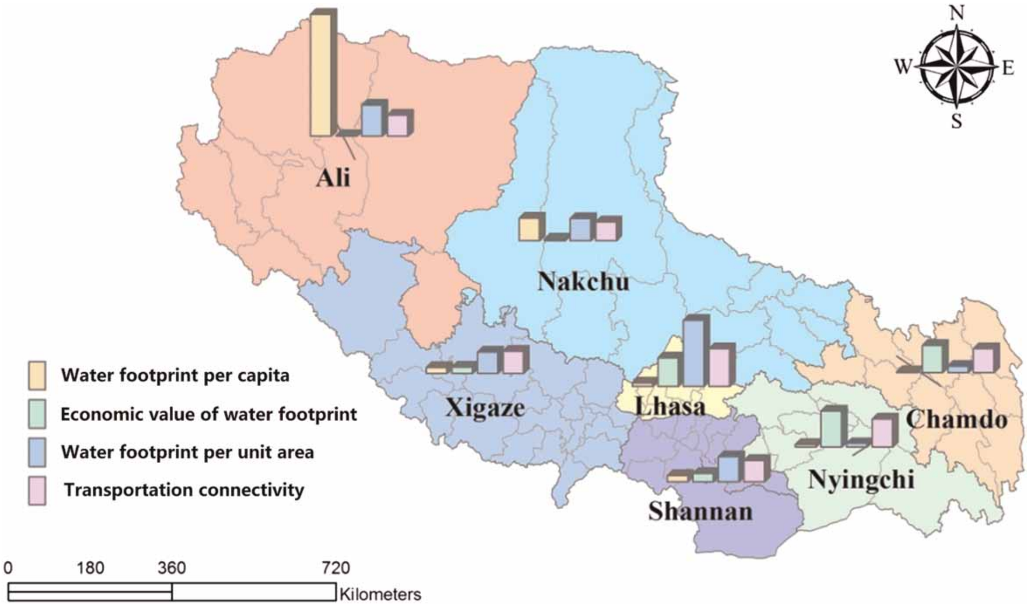

Figure 2 | Water footprint benefit indicators and transportation connectivity indicator of seven sub-regions.

positions with 73 and 124 m^3/km^2, whereas Lhasa used 1.32×10^3 m^3 water per km^2 land area. This result was even worse than that of Ali. The large water demand and the smallest land coverage might contribute to this finding. As to transportation connectivity, Lhasa and Nyingchi stood as transport hubs with high connectivity levels (0.75 and 0.56, respectively). Chamdo and Xigaze followed behind (with connectivity less than 0.5); Shannan and Ali had constraints with transportation situations while Nakchu was worst in the transportation ranking. In summary, the indicators revealed that the southeastern region of the study area performed better than the rest of the area. Ali experienced problems in water use efficiency due to severe environmental conditions and human activities without vitality. Compared with Ali, Nakchu performed slightly better, but lagged behind the southern regions. Generally, Chamdo, Lhasa and Nyingchi excelled in this aspect.

Results of the evaluation of ecological suitability for hydropower development in Tibet

Based on the two different indicator systems, the comprehensive evaluation results are shown in Figure 3. Except for the ecologically sensitive areas, Lhasa was the most appropriate region for hydropower development; Xigaze, Shannan and Nyingchi were suitable, whereas Nakchu was less suitable. Ali had the worst development conditions in both systems. The main discrepancy between the two indicator systems was the suitability level of Chamdo. The actual distribution of hydropower construction (of 17 typical hydropower stations) was as follows: eight in Chamdo (one is a large power plant, which refers to the installed capacity being more than 10^5 KW); five in Nyingchi (two are large power plants); two large power plants in Lhasa; one hydropower station in Ali; one hydropower station in Xigaze.

Combined with the actual eco-environmental conditions in Tibet, the traditional evaluation results were not reasonable for Chamdo. Chamdo facilitated hydropower development in many ways. It had ample water resources and had an essential location to connect to external regions. The convenient position could offer electric power transmission for the sake of realizing the precious water resource value of Tibet. The altered social sub-system in the improved indicators reflected the true state of water use efficiency and the transportation network function more evidently. The evaluation results indicated that current hydropower development planning was basically reasonable.

During the 'Eleventh Five-Year' planning period (2006–2010) in China, water conservation work experienced remarkable achievements in Tibet. According to the evaluation results, the decision makers could fairly draw up a plan. Ali and Nakchu should build hydropower stations to ensure citizens' basic needs. The huge potential of the other areas could be extracted for 100% electricity availability for rural residences. Furthermore, it would inspire

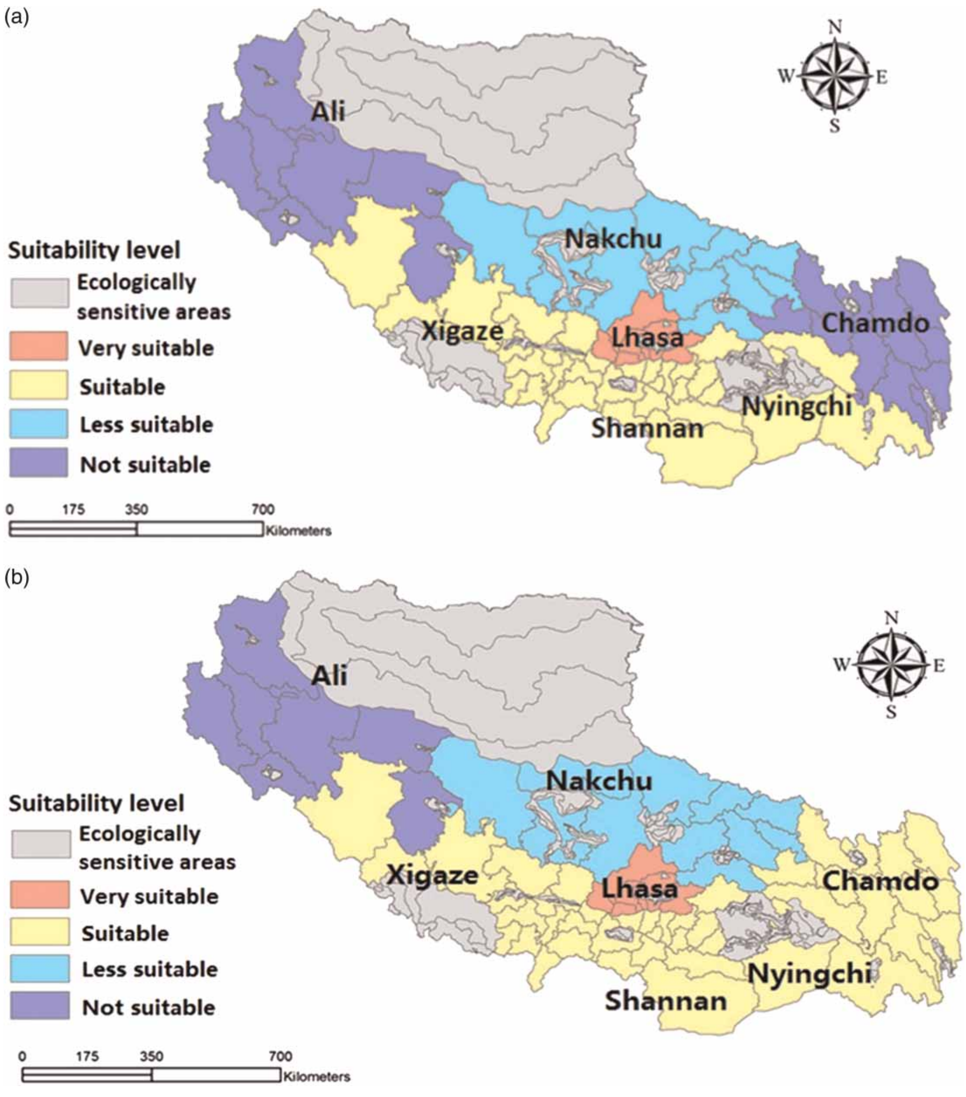

Figure 3 | Evaluation of ecological suitability for hydropower development with the traditional (a) and improved (b) indicator systems in Tibet.

efforts to address irrigation water shortages, drought mitigation and flood control. The Brahmaputra River and its two tributaries (i.e., Lhasa River and Nyangqu River) are the key river basins for the 'Twelfth Five-Year' planning period (2011–2015). The watershed situated in Lhasa, Xigaze and Shannan was in accordance with the evaluation results. Tibetan water conservancy development in the future could not only further meet native needs, but it could also benefit other regions in China. In summary, the new evaluation indicator system had a more precise outcome that strongly supported hydropower development planning, and could be applied to evaluate the ecological suitability of hydropower development in other locations and to revise the defects of the traditional indicator system.

CONCLUSIONS

This research conducted an evaluation of ecological suitability for hydropower development through an improved indicator system that considered the water footprint and transportation connectivity in Tibet. The results indicated the following:

(1) Tibet was in a state of water use surplus. Meanwhile, the region was in an ecologically safe condition in its water utility aspect and had positive prospects for sustainable hydropower development.
(2) Chamdo, Lhasa and Nyingchi excelled in water use efficiency; Ali was the least efficient. Nakchu

performed slightly better than Ali, but it lagged behind the southern regions. The water use indicators that evaluated the ecological suitability of hydropower development suggested that Lhasa, Chamdo, Nyingchi, Xigaze and Shannan were suitable for hydropower development. In this case, the needs of the local population would be met while other regions in China would also benefit.

The evaluation indicator system was improved by considering more comprehensive views of water use conditions and the network connectivity among regions to reflect a long-term socioeconomic effect resulting from hydropower development. Through the evaluation, it is within the government's control whether hydropower constructions are in the sustainable range. This improved system was of practical significance and could be applied to other scenarios of hydropower development planning. If the data were collected in a time series, then the research could provide more information on temporal trends. Combined with the spatial distribution, the method could provide comprehensive suggestions for water resource management.

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REFERENCES

Asif, M. & Muneer, T. 2007 Energy supply, its demand and security issues for developed and emerging economies. *Renewable and Sustainable Energy Reviews* **11** (7), 1388–1413.

Bartle, A. 2002 Hydropower potential and development activities. *Energy Policy* **30**, 1231–1239.

Biemans, M. & Snethlage, M. 2008 *SPEN – Interactions between Policy Concerning Spatial Planning and Ecological Networks in Europe: Country Study for the Netherlands*. European Centre for Nature Conservation, The Netherlands.

Cai, Y. P., Huang, G. H., Yang, Z. F. & Tan, Q. 2009 Identification of optimal strategies for energy management systems planning under multiple uncertainties *Applied Energy* **86** (4), 480–495.

Chapagain, A. K. & Hoekstra, A. Y. 2004 *Water Footprints of Nations*. Value of Water Research Report Series: No. 16. UNESCO-IHE, Delft, The Netherlands.

Chen, H. W., Fan, M. Y., Huang, J. W., Zhang, X., Liu, H. J. & Fu, S. D. 2013 Comprehensive evaluation on exploitation and utilization of water resources based on improved fuzzy pattern recognition model. *Applied Mechanics and Materials* **361–363**, 1036–1041.

China Water Resources Bulletin 2012 The Ministry of Water Resources of the People's Republic of China. (In Chinese.)

García, J. L., Alvarado, A., Blanco, J., Jiménez, E., Maldonado, A. A. & Cortés, G. 2014 Multi-attribute evaluation and selection of sites for agricultural product warehouses based on an Analytic Hierarchy Process. *Computers and Electronics in Agriculture* **100**, 60–69.

Hoekstra, A. Y. & Chapagain, A. K. 2007 Water footprints of nations: water use by people as a function of their consumption pattern. *Water Resources Management* **21** (1), 35–48.

Kalogiroua, S. A. 2002 Expert systems and GIS: an application of land suitability evaluation. *Computers Environment and Urban Systems* **26** (2/3), 89–112.

Kaygusuz, K. 2004 Hydropower and the world's energy future. *Energy Sources* **26**, 215–224.

Lathrop Jr., R. G. & Bognar, J. A. 1998 Applying GIS and landscape ecological principles to evaluate land conservation alternatives. *Landscape and Urban Planning* **41**, 27–41.

Liu, J. G. & Diamond, J. 2005 China's environment in a globalizing world. *Nature* **435**, 1179–1186.

Marull, J., Pino, J., Mallarach, J. M. & Cordobilla, M. J. 2007 A land suitability index for strategic environmental assessment in metropolitan areas. *Landscape and Urban Planning* **81**, 200–212.

Merriam, G. 1984 Connectivity: a fundamental ecological characteristic of landscape pattern. In: *Proceedings of the First International Seminar on Methodology in Landscape Ecological Research and Planning*, J. Brandt & P. Agger (eds), International Association for Landscape Ecology, Roskilde University, Roskilde, Denmark, pp. 5–15.

Petrescu, D. C., Bran, F. & Petrescu-Mag, R. M. 2010 The water footprint and its impact on sustainable water consumption. *Metalurgia International* **15**, 81–86.

Qi, R., Geng, Y. & Zhu, Q. H. 2011 Evaluation of regional water resources utilization based on water footprint method. *Journal of Natural Resources* **26** (3), 486–495. (In Chinese.)

Sicat, S. R., Carranza, E. J. M. & Nidumolu, U. B. 2005 Fuzzy modeling of farmers' knowledge for land suitability classification. *Agricultural Systems* **83**, 49–75.

Simonovic, S. P. 2002 World water dynamics: global modeling of water resources. *Journal of Environmental Management* **66**, 249–267.

Tan, Q., Huang, G. H. & Cai, Y. P. 2011 Radial interval chance-constrained programming for agricultural non-point source water pollution control under uncertainty. *Agricultural Water Management* **98** (10), 1595–1606.

Thaler, S., Zessner, M., Bertran De Lis, F., Kreuzinger, N. & Fehringer, R. 2012 Considerations on methodological challenges for water footprint calculations. *Water Science and Technology* **65** (7), 1258–1264.

Tibet Statistical Yearbook 2012 China Statistics Press, Beijing, China. (In Chinese.)

Vanham, D. 2013 The water footprint of Austria for different diets. *Water Science and Technology* **67** (4), 824–830.

Wang, M. Z. 2010 *The Study of Urban Green Space Ecological Network Based on Connectivity*. MS Thesis, Beijing Forestry University. (In Chinese.)

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