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A framework of indicator system for zoning of agricultural water and land resources utilization: A case study of Bayan Nur, Inner Mongolia

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ABSTRACT

A major problem in food security, especially in developing countries, is the issue of the effective and sustainable utilization of agricultural water and land resources (AWLR). The system, however, is complicated by the interaction between humans and nature. There is a critical need to understand geographical differentiation and regional characteristics for the purpose of formulating management measures and altering development planning to fit the local conditions. This action requires establishing a set of indicators to conduct agricultural water and land resources utilization (AWLRU) zoning. This paper presents a general framework for the design and application of zoning indicators, integrating four dimensions of the AWLRU system: natural, technological, socio-economic and ecological. The supply–demand (SD) theory with the DPSIR (Driver–Pressure–State–Impact–Response) model was identified as an analytical framework by examining both the existing frameworks, and the desirable characteristics of indicators of AWLRU zoning. Five attributes or layers within the AWLRU system were defined, by which interdependent and interaction relations between nature and humans were revealed. Bayan Nur of Inner Mongolia was selected as the location for the case study. The results indicate obvious regional characteristics of AWLRU distributed along the Yellow River. The spatial pattern of AWLRU zoning was consistent with the condition of water resources and the characteristics of land use. Divisions were drawn clearly from the upper reaches to the lower reaches of the Yellow River. The results also indicate that water supply and the available land resources played a major role in the process of agricultural production that they determined the degree and direction of water and land resources utilization, and the types of agricultural production. The case study demonstrates the practicality and reasonability of the proposed framework and provides a reference for reasonable formulation and management of AWLR.

1. Introduction

Food security has an important place on the sustainability development agenda. Especially under the background of population growth, economic development and climate change, food production systems have been given more attention by scientists (Allouche, 2011; Gerbens-Leenes and Nonhebel, 2004; Hanjra and Qureshi, 2010; Tiwari and Joshi, 2012). An important method to address the issue of food security is to explore "double high" agricultural paths, i.e. to enhance resource use efficiency with increasing crop yields per unit area of land (Shen et al., 2013). Water and land resources (WLR) are two of the most vital resources in food production systems. As stated by Berhanu et al. (2013), water is at the center of all efforts to address food security, nutrition security, poverty reduction, economic growth and human health. Land is the most fundamental carrier of human society and agricultural production. However, the shortage of total WLR and their spatial mismatch pose a serious threat to food production and misuse of WLR exacerbates the issue. Brown, head of the U.S. World Observation Research Institute, brought forward "food threat of China" twice (Brown, 1995; Brown and Halweil, 1998), the focus of which is just on issues of cultivated land and water resource shortages in China. For these and other reasons, effective and sustainable utilization of AWLR is critical to promote increased food production.

Abbreviations: WLR, Water and land resources; AWLR, Agricultural water and land resources; AWLRU, Agricultural water and land resources utilization; SD, Supply–demand; DPSIR, The Driver–Pressure–State–Impact–Response framework; MESMIS for its acronym in Spanish, The Framework for Assessing the Sustainability of Natural Resource Management Systems; FESLM, The International Framework for Evaluating Sustainable Land Management; SAFE, the Sustainability Assessment of Farming and the Environment framework.

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Natural resources are an important component of the environment and are strongly dependent on the corresponding circumstances (Feng et al., 2013). As a result, the AWLRU system can be influenced by a number of factors due to the complex circumstances. Meanwhile, these factors often vary over space (Tu, 2011). A geographically differentiated analysis is thus necessary for AWLRU zoning. Specific indicators can help to understand and to interpret a complex system by a set of procedures, such as synthesizing data, showing the current state, demonstrating the achievement or failure of objectives, and communicating the current status to users for management decisions (Bockstaller et al., 1997; Mitchell et al., 1995). A set of indicator values can provide a representative picture and describe the components or processes of the system studied in all of its relevant aspects (natural, economic, social and ecological) (Huang et al., 1998). However, an "indicator explosion" has occurred for the last two decades with the development of numerous indicator-based methods. It is a source of confusion because of the fact that many methods are not evaluated for their scientific relevance and feasibility (Riley, 2001a, 2001b). A framework can be utile in organizing indicators and large quantities of data used for developing an indicator system (Smith and McDonald, 1998).

Two types of frameworks can be distinguished: system-based frameworks and content-based disciplinary frameworks (Agyemang et al., 2007; Bell, 2012; López-Ridaura et al., 2002; Smyth and Dumanski, 1993; Van Cauwenbergh et al., 2007). The existing frameworks, however, have certain limitations especially when they are applied to agricultural production systems. System-based frameworks (e.g. MESMIS and FESLM) provide a good thinking structure for indicator derivation based on general attributes of the system (such as productivity, stability, and resilience), but the lack of specific content for the different attributes requires an extensive knowledge of the system under investigation to formulate indicators. Furthermore, due to the highly complex nature of systemic indicators, these indicators remain qualitative rather than quantitative parameters. Content-based frameworks (such as SAFE) facilitate the translation of functions into specific objectives and quantitative parameters, yet the lack of a holistic approach in most frameworks for agriculture does not allow for the evaluation of the system as a whole (Van Cauwenbergh et al., 2007). In addition, most of these frameworks were applied to evaluate the sustainability with problem-based characteristics. The indicator system was established to place an emphasis on sustainability or unsustainability of a system and on evaluation strategies. Currently, there is no guidance available as to a general framework to reflect the state of natural resources utilization or to identify the current status within different areas. Therefore, one cannot establish zoning-oriented indicator sets, especially for information regarding the zoning of integrated AWLRU.

The purpose of this paper is to develop a new analytical framework system to meet the needs described above. We first examined desirable characteristics for indicators aimed at the utilization and management of AWLR in different regional conditions in Section 2. This examination was conducted by reviewing the previous literature and discussing with experts to consider candidate indicators and to organize them into a useful framework. The SD theory combined with the DPSIR model was given special attention to select different sets and dimensions of possible indicators. The attributes and criteria of the indicator system were developed and carefully analyzed. Lastly, a strategic framework was proposed for the definition and identification of zoning indicators to deal with the issues of regional differences and imbalance in levels of AWLRU. This framework was used to devise strategies to achieve the goal of sustainable development of AWLR. Bayan Nur of Inner Mongolia was selected as the case study to understand the application of the new framework in Section 3. Section 4 discusses the proposed framework, including some limitations on its application. Finally, conclusions are presented in Section 5.

2. Developing an indicator system for the zoning of AWLRU

2.1. Definition of the zoning of AWLRU

The development of indicators must start with a carefully defined concept of the purpose of indicators (Huang et al., 1998). In the present study, the aim of zoning was to determine regional differentiation laws or patterns from the holistic point of view. It promotes awareness of regional differences and the issues of imbalance in AWLRU levels. The zoning of AWLRU can be referred to as the following: to study the present situation and regular pattern and features of AWLRU on the basis of comprehensive analysis of various agricultural production factors (especially the areal differentiation of natural factors); reveal the distribution pattern, and finally to improve the measures, directions and strategies for efficient utilization of AWLR for various types of regions. The final goal of this effort is to make full use of WLR, establish the mechanism of effective and sustainable utilization of AWLR, and achieve the greatest benefits (economic, social and ecological). Accordingly, zoning indicators should have two main functions: a description function, in which each indicator layer reflects essential features in a certain aspect about the utilization level of regional AWLR (and the whole indicator sets can be mirror the holistic characteristics of regional AWLRU) and a guiding function, which describes how the defined indicator system can play an instructive role in the future management and planning of AWLR and promote the effective and sustainable utilization of AWLR.

Zoning must also emphasize similarities in directions and levels of agricultural development alongside resource utilization condition in order to draw up and implement appropriate regional plans and policies. What is required is integration of internal and external factors of WLR to compose a coordinated and mutually promotive system. For these reasons, zoning indicators are derived from the following principles:

(1) The consistency principle on natural conditions and resources;
(2) The consistency on utilization characteristics and development directions of WLR;
(3) The principle of maintaining the integrality of administrative boundaries to be convenient for the uniform management and regulation of WLR;
(4) To form a balanced and self-promoting system between the internal and external factors of WLR, the zoning indicators also need to follow the coordination principle on AWLR supply capacity, society demand and environment.

2.2. Framework for indicator sets

Although the principles of establishing indicator sets have been identified, there is still an important consideration on how to organize these indicators more fully and comprehensively. Natural resource management is composed of a series of procedures, including the description of the current situation and characteristics, the identification of problems, and the formulation and implementation of management planning, etc. With regard to the specific purpose, different indicator systems should be developed varying in scope and composition as well (Weiland et al., 2011). The AWLRU system is a typical compound system made up of nature, economy and society. This system is the outcome of the interaction between nature and human activities. AWLRU zoning can be developed by taking effective and sustainable utilization of AWLR as the

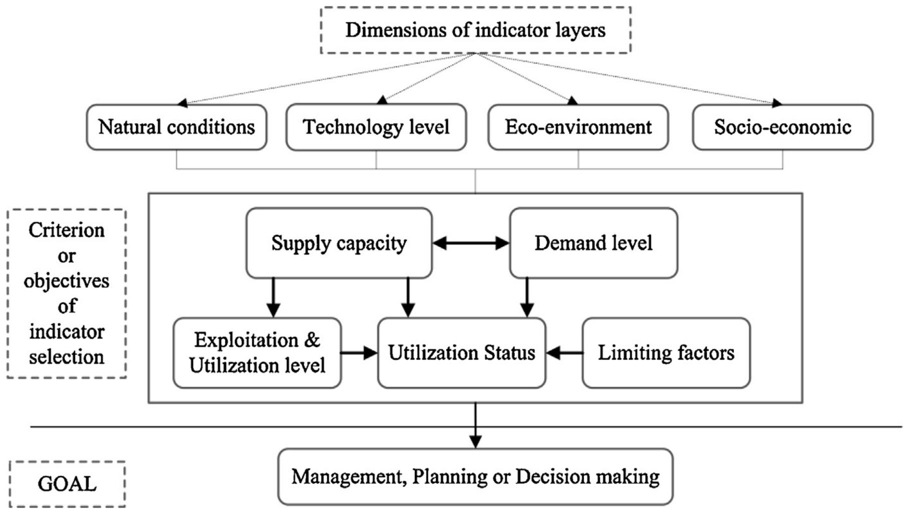

Fig. 1. The general framework for establishing indicator system of AWLRU zoning.

goal, WLR characteristics as the focus, the changes in supply, utilization, consumption and demand of AWLR as the foundation, the optimal allocation of AWLR as the means, the function of water and land's driving forces on the agro-ecosystem stability as the guarantee, and the assessment of the micro- and macroscopic efficiency and benefits as the basis.

Supply and demand (SD) analysis and the related driving forces are two essential aspects in the process of selecting indicators for AWLRU zoning. Particularly in the current situation, the WLR system is dynamic due to the driving function between internal and external factors, so that the SD analysis has greater significance in understanding the utilization characteristics of AWLR (Liu and Hu, 2008). On the other hand, DPSIR is a holistic and structural framework to develop indicator sets. The essence of DPSIR is consistent with characteristics of the AWLRU system in that both they derive from a concept of causality: human activities exert pressures on the environment and change its quality and the status of natural resources, and this reveals the interaction between human activities and nature. The model was employed and integrated with SD analysis for the design and use of indicators of AWLRU zoning. The general framework is shown in Fig. 1.

3. The case study of Bayan Nur

3.1. Study area

Situated in the west of the inner Mongolia autonomous region (40°13′–42°28′ N, 105°12′–109°53′ E), Bayan Nur contains seven banners and counties, covering an area of approximately 6.5×10^4 km^2 (Fig. 2). It connects with Baotou city to the east, borders on Alxa League to the west, faces the Yellow River and borders on People's Republic of Mongolia to the north. At the same time, the Yinshan Mountains traverse the region, and divide it into two distinct parts which have different physical environments and types of agricultural production. The northern region, comprising Urad Middle Banner and Urad Back Banner, is vast and open natural pastures, commonly referred to as the Urad grassland. This area is abundant in cattle, sheep and camel, and rich in various rare and special products (e.g. herba cistanches, hair weeds and Astragalus mongholicus). The southern portion is a fluvial plain formed by the Yellow River — the famous Hetao plain which enjoys the fame as "The Yellow River has no advantages but makes Hetao rich". Hetao irrigation district in Asia is the largest gravity irrigation district with sole water source, and is also one of the three largest irrigation districts across China. For these reasons, the region plays a key role in supporting local farms.

Located in the arid Northwest Plateau, Bayan Nur is a typical region in which agriculture is heavily dependent on irrigation. The region has little precipitation and abundant heat. The mean annual precipitation ranges from 130 mm to 250 mm, 70% of which occurs from July to September (Fig. 3a). The mean annual evapotranspiration is about 2000 mm, which is much greater than precipitation. The mean annual temperature is 6–8 °C, with monthly averages of −9.4 °C and 24.2 °C in January and July, respectively (Fig. 3b). There are 135–150 frost-free days and 3000–3300 sunshine hours per year.

Although the climate is arid, water resources for irrigation are rich in the region because the Yellow River runs from west to east through the city, flowing through Dengkou, Hanggin Rear Banner,

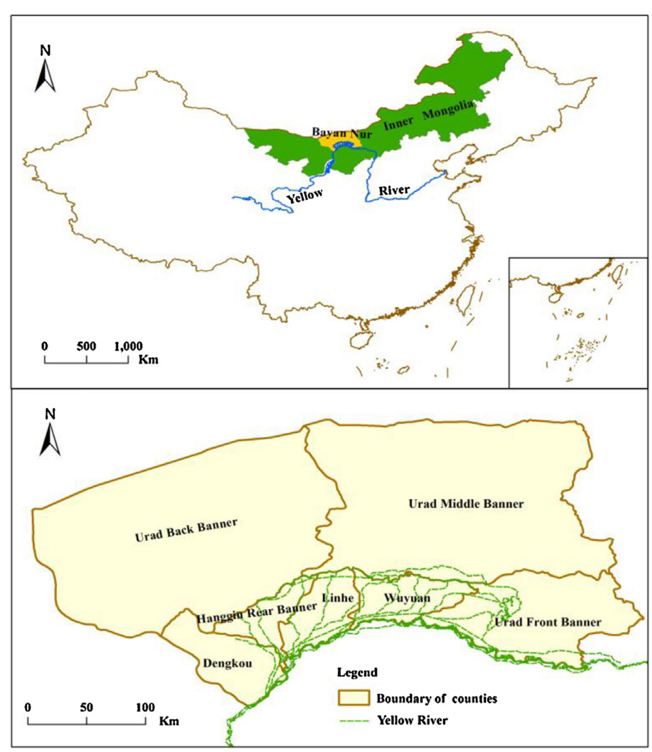

Fig. 2. Location of the study area.

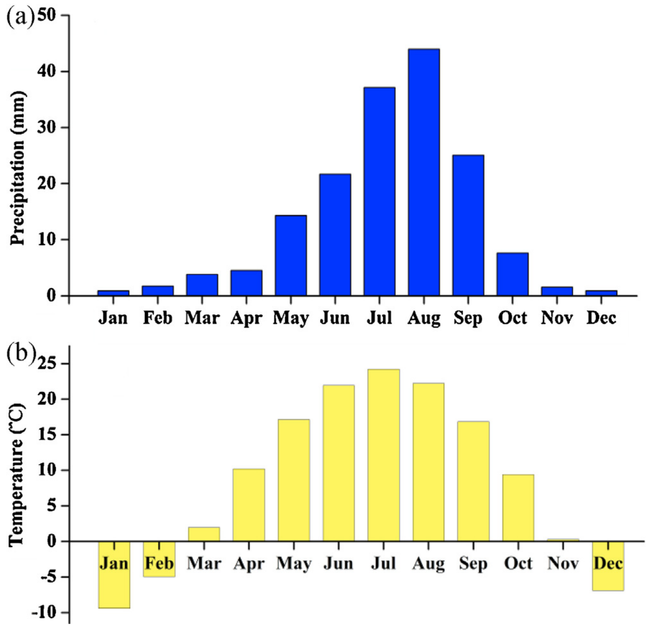

Fig. 3. Monthly average rainfall (a) and temperature (b) in Bayan Nur (1981–2010).

Linhe, Wuyuan and Urad Front Banner with 345 km within the region of the city. The annual average water passing by the region is 20.7 billion m^3. About 5.2 billion m^3 water is diverted each year from the Yellow River to irrigate this area (Qu et al., 2003; Wang et al., 2005; Xu et al., 2010; Yang, 2005). The irrigated area is up to 570,000 ha. Ulansuhai Nur, one of the eight largest freshwater lakes in China, is also located in the region. The city serves as the most important source of food and oil production within Inner Mongolia, as well as in China. The total cultivated area is 581,490 ha, mainly concentrated in the Hetao plain. The main crops include wheat, maize, sunflower, sugar beets, tomato and miscellaneous cereals. In 2010, the total grain output was 1.9 million tons, accounting for 8.2% in Inner Mongolia, and oil yields were nearly the half of total yields.

3.2. *The selection of indicators*

Understanding a complex whole requires knowledge about specific variables and how their component parts are related (Ostrom, 2009). Indeed, "one fixed set of indicators for each and every natural resource management system is inappropriate, as every system is unique, and specific criteria and indicators may or may not be relevant for all cases" (López-ridaura et al., 2005). In our study, the Delphi technique was used to identify potential indicators. This technique is normally used to solve complex problems or generate strategies (Delbecq et al., 1975; Bélanger et al., 2012). First, 97 potential indicators were filtered and listed based on a review of the previous literature. These indicators were further developed through a series of consecutive steps using a combination of bottom-up and top-down approaches to provide good results (King et al., 2000). Following this development of indicators, a question about the research subject and the proposed framework was sent to selected experts beforehand so that they would have an adequate time to consider them, and then a symposium was held to determine the candidate indicators. By summarizing the advice from every expert, 31 candidate indicators were selected. Next, we tested these indicators if they meet the critical criteria of indicators, including: easy to implement, immediately understandable, sensitive to variations, reproducible, available to the necessary data and adapted to the objectives (Bélanger et al., 2012). At the end of this step, indicators can be removed from the set, and then the final indicator set is completed. A total of 25 indicators comprised the indicator system in the current study.

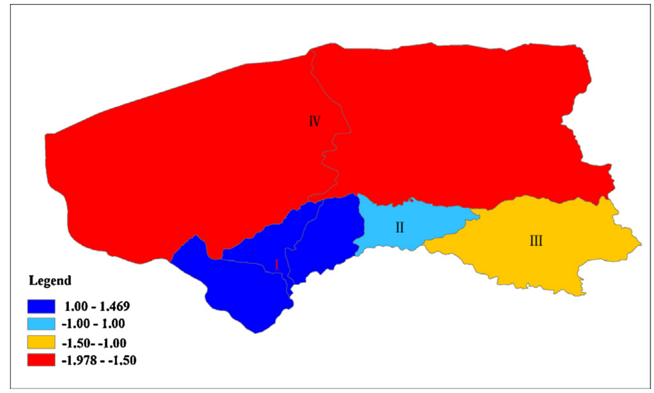

Fig. 4. The zoning map of AWLRU in Bayan Nur.

Five layers in the proposed framework were synthesized into three criteria when establishing the indicator sets for the current case study. This was done due to the multi-functions of indicators under the complex circumstances. The selected indicators contained every aspect from the SD analysis and DPSIR. For example, natural conditions impact the regional supply capacity, and also have certain limitations for the development of WLR. The technical level impacts the exploitation and utilization level of natural resources, and is related to the status of its utilization as well. A total of 25 indicators are shown in Table 1.

3.3. *The zoning of AWLRU in Bayan Nur, Inner Mongolia*

The Principal Component Analysis (PCA) was used to integrate and simplify the complex indicators. As shown in Table 2, four principal components were extracted. The accumulative total contribution rate was 96.09%, which maintains most of information of selected indicators. Then, a comprehensive factor score was calculated from weighted averages by considering eigenvalues of four extracted principal components as weights. The whole procedure was conducted by using SPSS software. Seven regions in Bayan Nur were classified by the support of GIS according to the scores. The zoning of AWLRU is shown in Fig. 4.

As shown in Fig. 4, among seven counties in Bayan Nur, four divisions were formed. Dengkou, Linhe and Hanggin Rear Banner (I) are in the same division. Wuyuan (II) and Urad Front Banner (III) are in a separate division, respectively. Urad Middle Banner and Urad Back Banner (IV) are in another division. From the spatial characteristics of divisions, division I is located in the source and upper region of the Hetao Irrigation District. The volume of water resource per unit area is 43.77×10^4 m^3/km^2. The endowment conditions of the water resource were good and provided an advantage for irrigation. Farming is the dominant industry in the region. Agricultural water resource per arable land is high, at a level of about 1146 m^3/ha. Agriculture production is similarly developed. Division II is located in the middle reaches of the Hetao Plain. The irrigation water resource here is still rich and the volume of water resource per unit area is 46.97×10^4 m^3/km^2. Agricultural water resource per arable land is 759 m^3/ha. The cultivated land resource is abundant and fertile. Cultivated land area per capita is 7.02 mu (i.e. 0.468 ha) while the use efficiency of WLR is high. Husbandry has been developed considerably, but agriculture still plays a major role in the regional economic development. Division III is located at the east end of the Hetao Plain. Agriculture and husbandry have been developed to a certain extent. This region is a comprehensive farming - pastoral ecotone. The agricultural production region includes the fertile area

Table 1
Indicator system of the zoning of AWLRU in Bayan Nur.

Objective	Criteria	Aspects	Indicators
To achieve the effective and sustainable utilization of AWLR	To reflect regional natural features and supply capacity of AWLR	Natural conditions	Average annual precipitation (mm)
			Average annual evapotranspiration (mm)
			Annual average temperature (°C)
			Speed (m/s)
			Altitude (m)
		Supply capacity	Water resources per capita (m^3)
			Cultivated land area per capita (mu)
			Water resources per unit area ($10^4\ m^3/km^2$)
			Agricultural water resource per arable land (m^3/ha)
	To reflect the situation and technological level of AWLU	Utilization status	Water consumption per peasant (m^3)
			The ratio of agricultural water use
			Rate of irrigated arable land (%)
			The ratio of cultivated area (%)
			Multiple cropping index
			Agricultural output value per arable land (RMB 10,000)
		Technological level	Economic productivity of agricultural water resources (RMB/m^3)
			Grain yield per unit area (kg/ha)
			Fertilizer consumption per arable land (t/ha)
			Water use efficiency of food crops (m^3/kg)
	To reflect the demands and effects of socio-economic system, ecological factors on AWLR	Socio-economic factors	Population density (person/km^2)
			GDP per capita (RMB)
			The net income per peasant (RMB)
			Water consumption per unit GDP ($m^3/10^4$ RMB)
		Ecological conditions	Forest coverage (%)
			Soil erosion intensity

Table 2
The variance analysis by PCA.

Component	Total variance explained								
	Initial eigenvalues			Extraction sums of squared loadings			Rotation sums of squared loadings		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1	11.078	44.311	44.311	11.078	44.311	44.311	9.675	38.701	38.701
2	6.649	26.595	70.905	6.649	26.595	70.905	7.159	28.637	67.339
3	4.920	19.681	90.587	4.920	19.681	90.587	5.091	20.365	87.704
4	1.375	5.500	96.087	1.375	5.500	96.087	2.096	8.383	96.087
5	.678	2.711	98.798						
6	.300	1.202	100						

Table 3
The zoning scheme of AWLRU in Bayan Nur.

Zone code	Zone name	Scope	Characteristics
I	The irrigated agricultural area in the upper reaches of Hetao Plain	Dengkou, Linhe, Hanggin Rear Banner	Irrigation water resources are rich, agriculture is developed and dominant. It has the advantage and potentiality in improving the agricultural production.
II	The irrigated agricultural area in the middle reaches of Hetao Plain	Wuyuan	The matching condition of water and land resources is good. The use efficiency of water resources and land productivity is high. Husbandry has the certain development, but agriculture still plays a major role in the economic development.
III	The comprehensive area with farming and pasture in the lower of Hetao Irrigation District and the north of the Yinshan Mountains	Urad Front Banner	Farming and husbandry have certain development. Water resource is relatively scarce. It is one part of farming–pastoral ecotone with no irrigation no agriculture.
IV	The pasture area in the north of the Yinshan Mountains and plateau regions	Urad Middle Banner, Urad Back Banner	Dominated by husbandry, it is the ideal ranching with vast natural pasture. Agriculture mainly distributed in the proluvial fan and Hetao alluvial plain in the south of the Yinshan Mountains. Water resource is severely scarce.

irrigated by the Yellow River and the dry mountain areas, which fully reflects the feature of "no irrigation no agriculture". Water resource per unit area is only 10.68×10^4 m^3/km^2. Division IV is dominated by husbandry. It is the ideal ranching with vast natural pastures. Water resource is relatively scarce with the total water resource per unit area measured at 1.23×10^4 m^3/km^2. Agricultural production is mainly distributed in the proluvial fan and Hetao alluvial plain in the south of the Yinshan Mountains. Agricultural water resource per arable land is 582 m^3/ha, which is only the half of division I. Table 3 shows the specific name and characteristics of the different divisions.

4. Discussion

Improper agricultural activities affect the quality of the environment and the exploited land, which influences the utilization of water resources due to strong interactions between land use and water resources (Barton et al., 2010; Huang et al., 2010). Vice versa, agriculture production is limited by the unreasonable land use and water resources. Developing a set of indicators is an analytical approach to describe such a complex system (Bockstaller et al., 1997). On the basis of SD analysis and the DPSIR model, this research developed a framework to organize these indicators in order to understand the regional characteristics of AWLRU. Several important points remain to be addressed, however.

It is first necessary to emphasize that ensemble modeling is important for the design and selection of indicators for AWLRU zoning. The AWLRU system is the concentrated reflection of the interaction between humans and natural environment. New methodologies should thus be rooted in thorough knowledge of the agro-technical possibilities and socio-economic boundary conditions (van Keulen, 2007). Although the basic idea of the DPSIR framework is consistent with characteristics of the AWLRU system, it has two major disadvantages when applied to the agricultural resources system. Firstly, five factors or aspects in the framework are rather confusing and difficult to accomplish since numerous indicators are needed, increasing the cost and time required for assessment. Secondly, the DPSIR model only contributes to pay attention to environmental problems and overlooks the socio-economic and cultural drivers (Bell, 2012). Accordingly, the model needs to be modified according to the specific purpose. The supply capacity is the prerequisite of exploitation and utilization of AWLR and demand or consumption impacts the status of AWLR, while over-exploitation and unreasonable utilization of resources will affect environment conditions, evoke eco-environment deterioration, so that the supply capacity of resources decreases, which leads to an unsustainable and vicious circle. A new framework was thus developed by integrating the DPSIR with SD analysis. It not only avoided the structural problems stated by Ness et al. (2010), but also can furthermore decipher the causal relationships at each of the levels and regional differentiation characteristics. Similar designations can be found, such as the FESLM aligned with the PSR/DPSIR frameworks by FAO and the World Bank (Rao and Rogers, 2006), and the cost-benefit analysis (CBA) combined with the DPSIR model (Bidone and Lacerda, 2004).

However, it should be pointed out that SD and DPSIR are not two independent procedures for developing the indicator system, but complementary and auxiliary to each other. The supply capacity and demand level are the basis of indicator sets among five layers. Another three layers delegate the specific expression of various characteristic elements within the AWLRU system, which are derived from the DPSIR theory and represent the zoning features of AWLRU from different aspects. For example, exploitation & utilization level reflect the technical level and capability of developing and using AWLR, which constitutes the driving force factors of AWLRU (i.e. D). Utilization status is the direct embodiment of the current state about AWLRU (i.e. S). It is the basic portraiture based on technology and socio-economic development levels. Meanwhile, exploitation and utilization level and utilization status are impacted by various limiting factors (i.e. I), such as terrain, climate, and vegetation. Additionally, pressures of the AWLRU system are mainly rooted in human demands (i.e. P). The corresponding Response (i.e. R) is to conduct the AWLRU zoning to formulate the effective management planning of WLR. Five layers formed a circular and complete structure in the system of natural resources utilization, and also fully reflected the contents of the DPSIR model and SD theory. The main procedure in establishing the framework and selection of indicators for the indicator system is summarized in Fig. 5.

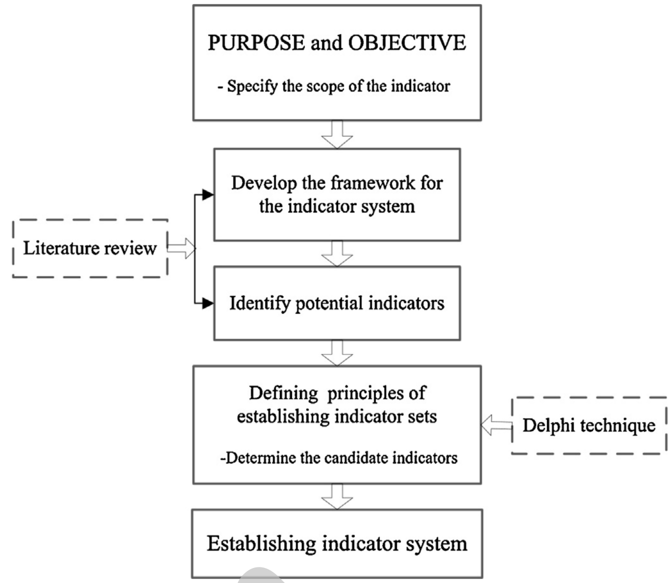

Fig. 5. The summary flowchart for the development of the indicator system for AWLRU zoning.

It also needs to be indicated that the same indicator may have different meanings or functions, just like the numeric values of indicators tend to have a special meaning to particular observers, a meaning that goes beyond the numerical value itself (Huang et al., 1998). Therefore, problems may arise that several fundamental indicators can be generally accepted, but it is difficult to define a standard scheme by using the most representative indicator set. For example, precipitation can be considered as the regional water supply capacity, but can also be a limiting factor when water resources are scarce and deficient. Population is related to the demand level, but it can restrict the resource utilization when overpopulation occurs and exerts pressure on WLR. As a result, five layers of the proposed framework were integrated into three specific criteria in the present case study, so that the DPSIR model does not appear in the indicator set.

Another issue is with respect to the specific study area. Bayan Nur was selected as a case because it has obvious regional characteristics including water conditions, land use and regional economic development. This area has previously been investigated and surveyed prior to our study. We can therefore verify and confirm that the zoning results were effective. Meanwhile, the result is satisfactory that the spatial distribution of zoning is consistent with the conditions and utilization status of AWLR. Water resource conditions play a key role on AWLRU in the water-scarce area, such as Bayan Nur. It is confirmed that the indicator framework is reasonable to apply the zoning of AWLRU. However, there are some limitations that must be acknowledged. For instance, the lack of any indicator or data in any study unit within a study area will restrict the operation of zoning and hinder the entire research. The smaller and more geographical units in the study area are the ones where zoning results are most accurate, but it is more difficult to collect detailed data for use in the index system since large amounts of data are required due to the number of indicators, especially for the large-scale study.

5. Conclusion

This paper develops an integrated framework to deal with the issues of regional differences and imbalance in levels of agricultural development in order to devise strategies to achieve the goal of sustainable development of AWLR. The SD theory combined with DPSIR framework was used as the framework for selecting indicators of AWLRU zoning. The five attributes or layers of AWLRU system are contained within the scheme corresponding to four aspects or dimensions of the AWLRU system (natural, technical level, socio-economic, ecological). The supply capacity and demand level form the basic layers of indicator sets. The core components were exploration and utilization level, utilization status and limiting factors. These components comprise a circular and interdependent structure in the AWLRU system, and reveal an interaction relation between nature and humans: Nature supplies various resources to meet the demand on subsistence and human development. The process by which humans explore and use natural resources impacts the regional eco-environment, but is also limited by environmental conditions, and so that it causes the utilization of natural resources exhibiting certain status and features.

Literature review and the Delphi technique were used for developing indicator sets according to the proposed framework. The application of the new framework took the city of Bayan Nur as a representative case, which displayed interesting results. The zoning of AWLRU has good consistency with water resource conditions and the characteristics of land use. The clear zonings were fully reflected between the irrigation district and arid mountain areas, and also between agriculture and husbandry. AWLRU has regional characteristics dictated by the Yellow River. The zonings were divided clearly from the upper reaches to the lower reaches of the Yellow River. The results show that the supply capacity of WLR plays a major role in the process of agricultural production and it determines the degree and direction of water and land resources utilization and the types of agricultural production.

The proposed framework can also be used to develop and prioritize the indicator system of zoning. It provides a fundamental structure for detailing and specifying the indicator sets which are inherent in the framework to produce detailed specifications of each of the identified components. It can therefore be used as a reference basis for guiding the sustainable development and utilization of AWLR at the regional level. However, the case study contains only seven units in this paper. Therefore, a more large scale study area can be considered for further verification and application of the framework, although it is difficult to collect detailed data for use in the index system.

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