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A geogrid-based framework of agricultural zoning for planning and management of water & land resources: A case study of northwest arid region of China

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ABSTRACT

Agricultural zoning is recognized as an effective approach to utilization of agricultural water & land resources (AWLR), especially in a large-scale region. The main objective of this work is to explore a new zoning method of classifying and dividing the AWLR of a larger area such as the Northwest Arid Region of China (NWAR). In this study, models of AWLR zoning of the NWAR were constructed. Data on 13 selected indicators were gathered from its 394 administrative counties, and processed and imported into 227100 Geogrid files. Then they were analyzed through four contradistinctive zoning approaches. And zoning results were tested and validated. The Geogrid-based PCA − SOFM scheme is the most effective, concise, and applicable. Finally, the NWAR was divided into 5 AWLR zones which were delineated according to the climate and geographic features and the administrative boundaries of counties or county-level districts. This work has established a novel methodological framework for AWLR zoning of a large-scale area.

1. Introduction

The Northwest Arid Region (NWAR) of China has got world's attention in the field of agricultural science due to its unique climate and meteorological conditions, ecological research values as well as its special agricultural geographical circumstances for food production (Shen et al., 2013; Chen et al., 2015). Since the 1950s, many works on effective and sustainable utilization of agricultural water & land resources (AWLR) have emerged, looking at and analyzing the agricultural factors (Sun et al., 2010; Wu et al., 2014), soil and water conservation (Zellner, 2007; Biswadip et al., 2015), the morphological characteristics (Zhang et al., 2009; Zhao and Liu, 2015) and zoning practices of the NWAR (Geng et al., 2014). And agricultural zoning approaches have been proposed to address many of the critical problems caused by inappropriate agricultural policies, by providing a mechanism for coordinated management and utilization of water or land resources that also takes into account the cumulative effects of multiple human activities (Kappel et al., 2009; Geng et al., 2014; Alan et al., 2016). However, because of the huge area, complex terrains, limited information of the NWAR and technologies available, it is very difficult to conduct a comprehensive and thorough research on AWLR zoning and its spatial distribution both macroscopically and quantificationally.

The zoning approach to use of water and land resource in the past can fall into two categories: rule-driven strategies and automated methods. The former employ predefined threshold values representing the water and land resources division boundaries which are usually based on water and land resources use index such as development potentialities, carrying capacity, and matching coefficients (Wu and Huang, 2001; Liu et al., 2011; Liu et al., 2006). However, the process was partly subjective since thresholds were often predefined on the basis of discernible changes in some important components of the global ecosystem (e.g. alignment with major watersheds, agricultural administrative districts and geographic conveniences) and experts judgment (Kostopoulou and Jones, 2007; Abatzoglou et al., 2009; Jacobeit, 2010). The latter are data-driven methods avoiding the direct specification of classification rules while utilizing some forms of multivariate statistical techniques, e.g. cluster analysis (CA) (Fovell, 1997; Geng et al., 2014). And the CA techniques have allowed use of self-generating classes for that purpose according to particular statistical

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Table 1
The AWLR zoning index system in the NWAR.

Objective	Criterion	Index		Supplemental
		Basic		
Comprehensive AWLR Zoning	Climate	I_1	Annual precipitation (mm)	1 Evaporation (mm)
		I_2	Aridity (mm mm^{-1})	2 Humidity
		I_3	Average annual temperature (°C)	3 Wind speed (m s^{-1})
		I_4	Effective accumulated temperature (°C)	4 Sunshine hours (h)
	Terrain	I_5	Altitude (m)	5 Per capita arable land resources (hm person^{-1})
	Supply and constraints	I_6	Cultivated land index − Percentage of arable land resources (%)	6 Per capita water resources (m^3 person^{-1})
		I_7	Water resources index − Water resources volume per unit area of arable land (m^3 Hm^{-2})	

criteria by grouping individual factors.

Currently, the data statistics are mainly collected according to administrative boundaries, while division and classification of water and land resources are carried out in term of natural units and environmental backdrops of climate and geographic features. How to extract and convert data collected according to administrative division into data for physiographical features remains an issue to be resolved. Meanwhile, the resulting classification strategies with the implementation of policies are carried out within certain administrative units. Furthermore, the agricultural land resource is coupled with the agricultural water resource and they interact with each other during the process of food production. Therefore, the main objective of this work is to explore a new zoning method to classifying and dividing AWLR, which may help overcome the limitations on data derived from administrative units, better reflect the reality of the AWLR and improve the precision and accuracy of zoning results of a larger area such as the NWAR.

2. Material and methods

2.1. Study area

The NWAR of China, named for its major geographic and climatic features, covers 6 jurisdictional provinces (or autonomous regions) including Xinjiang, Ningxia, Gansu, Qinghai, Inner Mongolia, Shaanxi, comprising 394 counties in total. It is located in the center of the Eurasian continent with geographical coordinates of N31°33′ to 49°11′ and E73°28′ to 119°54′. The region spans about 3800 km from east to west and 2100 km from north to south. The total ground area is 3.73×10^6 km^2, accounting for 38% of the total land surface area in China. It is a transitional area from semi-arid climate of eastern China to the arid region of the north-western China. It is one major agricultural region with a huge potential for agricultural production in the country. The conflicts between environmental resources and population, especially poor population, are the major problems in this region.

The key factors that lead to the imbalance of the ecology of the region and restrain the economy come from the scarcity of water, that is, the water resource per capita and per acre which are respectively 24.1% and 14% of national level. In the NWAR, irrigation plays a crucial role to increase crop productivity, whether irrigation is successful or not determines the fate of the agriculture (Gao, 2006). Effective irrigation area accounts for 52.26% of the total area. At present, the water use coefficient for canal irrigation ranges between 0.28–0.50 and the water-use efficiency (0.5–1.0 kg per cubic) for irrigation is merely 30%–40% in the region, less than half of the levels in developed countries (Zhao, 2005).

The NWAR is a vast expanse with effective farmland of mere 4.39×10^6hm^2 which accounts for 1.02% of the total region. The cultivated land per capita by total population and total agricultural populations are respectively 3.59×10^{-2} hm^2 and 5.83×10^{-2} hm^2, which is twice as high as national level. However, arid land dominates this region which is characteristic of infertility in the soil and inferiority of cultivated fields. For a long time, in order to meet urgent economic and societal demands caused by explosion of population and improvement of life quality, too much land has been reclaimed and water resources over tapped into, and therefore the ecology and the water and soil conditions are deteriorating quickly (Kang et al., 2002).

2.2. Methods

The formation of agricultural conditions is mainly dominated by the macro components e.g. climate and topography that vary in different geographic locations (Zhang et al., 2011). Therefore, the AWLR show obvious regional disparities in the system structure and function as well as the boundary characteristics.

2.2.1. Zoning index system

When dividing and classifying a large region like NWAR, taken into account are three dominant aspects such as climate, terrain and supply constraints. Supplemental factors should be considered too. A zoning index system is proposed to reflect regional spatial characteristics of AWLR system (Table 1).

2.2.2. Geo-Grid method

The geographic grid (GeoGrid) is a system designed to pinpoint any location on Earth by laying out a vertical and horizontal grid over the Earth's physical conditions. When characterizing physical features, application of smaller units of data statistics will reflect regional differences more accurately, and increase the geographical analysis precision to a large extent. However, that makes it difficult to ensure the geometrics calculation accuracy (Wang and Yue, 2004).

Currently, the method to build a grid-based statistical dataset is to create an area weighted fishnet grid within administrative units (Dunning et al., 2011). The accuracy of grid cells depends on the raster resolution. So the "smallest polygon" determines the fineness of the cells of the fishnet grid which applies the equation: $H = even\ (sqrt\ (min\ (A_i)))$, where H stands for the length of the cell, Ai stands for the area of the smallest administrative unit (about 11 km^2), and *even()* as a function which rounds up the nearest positive even integers. Accordingly, a homogeneous 4km × 4 km quadrilateral grid is constructed for the case study. The grid is generated to cover the NWAR with 227,100 independent raster cells, and zoning factors are incorporated into homogeneous geographic grid cells as basic calculation units (Wei et al., 2016).

2.2.3. PCA method

PCA is a mathematical procedure that transforms a number of possibly correlated variables into a smaller number of uncorrelated variables called principal components. The first principal component accounts for as much of the variability in the data as possible, and each succeeding component accounts for as much as possible of the remaining variability (Wotling et al., 2000; Wu and Bao, 2012).