Science of the Total Environment 634 (2018) 407–416

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Promoting inclusive water governance and forecasting the structure of water consumption based on compositional data: A case study of Beijing

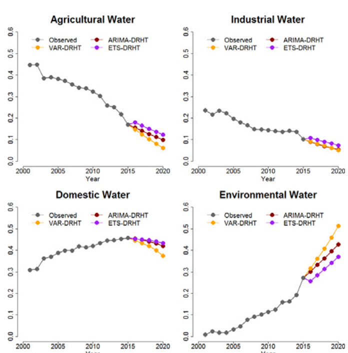
Yigang Wei [a,b], Zhichao Wang [a], Huiwen Wang [a,b], Tang Yao [a,b,*], Yan Li [c]

[a] School of Economics and Management, Beihang University, Beijing, China
[b] Beijing Key Laboratory of Emergency Support Simulation Technologies for City Operation, China
[c] Business School, Shandong University at Weihai, Weihai, China

HIGHLIGHTS

- Governance of water use is critical for relieving water use conflicts.
- Models are used to forecast the structure of water usage.
- VAR-DRHT is the best performing model in this study.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 18 January 2018
Received in revised form 26 March 2018
Accepted 26 March 2018
Available online xxxx

Editor: Simon Pollard

Keywords:
Water governance
Inclusive development
Sustainable development
Water consumption structure

ABSTRACT

Water is centrally important for agricultural security, environment, people's livelihoods, and socio-economic development, particularly in the face of extreme climate changes. Due to water shortages in many cities, the conflicts between various stakeholders and sectors over water use and allocation are becoming more common and intense. Effective inclusive governance of water use is critical for relieving water use conflicts. In addition, reliable forecasting of the structure of water usage among different sectors is a basic need for effective water governance planning. Although a large number of studies have attempted to forecast water use, little is known about the forecasted structure and trends of water use in the future. This paper aims to develop a forecasting model for the structure of water usage based on compositional data. Compositional data analysis is an effective approach for investigating the internal structure of a system. A host of data transformation methods and forecasting models were adopted and compared in order to derive the best-performing model. According to mean absolute percent error for compositional data (CoMAPE), a hyperspherical-transformation-based vector autoregression model for compositional data (VAR-DRHT) is the best-performing model. The proportions of the agricultural, industrial, domestic and environmental water will be 6.11%, 5.01%, 37.48% and 51.4% by 2020. Several recommendations for water inclusive development are provided to give a better account for the optimization of the water use structure, alleviation of water shortages, and improving stake holders' wellbeing. Overall, although we focus on groundwater, this study presents a powerful framework broadly applicable to resource management.

* Corresponding author at: School of Economics and Management, Beihang University, Beijing, China.
E-mail addresses: weiyg@buaa.edu.cn, (Y. Wei), wangzc1415@buaa.edu.cn, (Z. Wang), yaot@buaa.edu.cn. (T. Yao).

https://doi.org/10.1016/j.scitotenv.2018.03.325

1. Introduction

With the rapid and continuous progress of urbanization, industrialization and modernization, contradictions between substantial water demands and the increasing shortage of water resources have become even more prominent. Water resources have gradually become a restricting factor for regional socio-economic and environmental development. The water consumption structure is the result of water resources distribution in each sector of industry and civil life, and its characteristics reflect the status of the sustainable development of water resources (Zhai, 2011). Water consumption structure is an embodiment or yardstick of urban sustainability and social inclusiveness. Adjusting the water consumption structure is the first step in achieving optimal allocation of water resources and solving the contradictions involved in water resources utilization.

Without considering the conflicts surrounding resources endowment and consumption, the objectives of developing society would no longer be plausible (Kooy et al., 2016). In the face of common and intense contradictions between social demands and resource endowments, ecological sustainability is widely recognized as a goal of utmost importance for human socio-economic development. How to integrate ecological sustainability with social inclusion and do it well is also a challenging mission for the development of society in the present and the future. Looking at developed countries with hindsight indicates the progress of sustainable development often makes a trade-off to propel economic growth at the cost of social inclusions (Gupta et al., 2015). Some large institutions are criticized for their so-called sustainability wisdom and practices by scarifying inclusiveness. For example, they usually reconcile economic goals with ecological conservation, but neglect or aggravate social inequalities (Atkisson, 2013).

Inclusive development is defined by Gupta et al. (2015) as "development that includes marginalized people, sectors and countries in social, political and economic processes for increased human well-being, social and environmental sustainability, and empowerment." (p. 546). Inclusive development emphasizes the mutual development of different levels and different types of economic sectors in order to meet the needs of various classes of production and lifestyles. An inclusive development strategy and practice will be concerned with social justice, equity, and the wide participation of all stakeholders in social development, addressing the common issues of being excluded from development, unfairness, and marginalization (Beall and Fox, 2007; Sachs, 2012).

As the capital of China, Beijing's rapid economic development has attracted a large number of immigrants in recent years. According to the Beijing Statistics Bureau, the resident population of Beijing was 21,729,000 at the end of 2016 (Beijing Municipal Bureau of Statistics, 2016). The rapid increase of population and the limited carrying capacity of the environment indicate that the issue of water shortage in Beijing has become increasingly prominent (Wei et al., 2015a, 2015b). A shortage of water resources and unbalanced utilization has become an important factor restricting the sustainable development of Beijing for a long time into the future (Wei et al., 2016). Therefore, an accurate analysis and scientific prediction of the water consumption structure of Beijing is the premise and basis for making scientific plans for water resources utilization, and the main basis for adjusting and optimizing the structure of industry in the city, which will be important and of significance for the coordinated development of the socio-economy and resource environment in Beijing.

Water related literature has traditionally been focused on forecasts of the absolute volume of water consumption, which has received huge concern from practitioners and academia. Many forecasting methods for time series data have been widely used, including the Moving Average (Reghunath et al., 2005; Kang et al., 2014; Boubaker, 2017), Exponential Smoothing (Kang et al., 2014; Caiado, 2009), Regression Analysis (Maidment and Miaou, 1986; Fildes et al., 1997; Jain et al., 2001; Bougadis et al., 2010), the Artificial Neural Network (Jain and Kumar, 2007; Coulibaly and Baldwin, 2005; Liu et al., 2001; Bennett et al., 2013; Liu et al., 2003a, 2003b), Grey Forecasting (Fang and Tao, 2014; Hou, 2015; Wang et al., 2014), and System Dynamics (Sun et al., 2016; Ghasemi et al., 2017; Chhipi-Shrestha et al., 2017). These methods are good for ease of understanding and verifiability. The shortcomings are also remarkable, including things such as a high number of errors, and susceptibility to random factors, etc.

In the contrast, there is a dearth of studies concerned with water use structure, and the forecasts remain mainly qualitatively based. The main statistical approaches include Information Entropy (Ma et al., 2012; Liu and Liu, 2014; Su et al., 2008), Ecological Niche (Jiao et al., 2011), Grey System (Lv and Du, 2012; Bao and Fang, 2006; Chen et al., 2008), Linear Regression, (Bao and Fang, 2006; Chen et al., 2008; Gu and Wang, 2012), Water Footprint (Zhang et al., 2014; Mekonnen and Hoekstra, 2011; Mekonnen and Hoekstra, 2012; Gerbens-Leenes and Hoekstra, 2011; Xu et al., 2017), System Dynamics, (Zhang et al., 2015; Zarghami and Akbariyeh, 2012; Winz et al., 2009; Qi and Chang, 2011), and Gini Coefficients (Wang et al., 2012; Hu et al., 2016; Wang et al., 2011). However, the performance of these forecasting techniques is highly conditional, dependent on the data and the presumptions made, and a lack of insight into temporal-geographic changes.

Compositional data are usually used to describe the internal structure of a system, such as an investment structure, industrial structure, or a consumption structure, etc. The objective of a forecasting model using compositional data is to derive the forecasted water consumption structure based on historical data and evolutionary trends. The traditional solution is to derive the forecasted proportion of each component, respectively. However, this may cause difficulty understanding the results and the untenable result that the sum of the forecasted proportions is not equal to 1. In contrast, compositional data is good at understanding and predicting internal structure of a system.

The aim of this paper is to forecast the dynamic changes expected in Beijing's water use structure during the period from 2016 to 2020. A host of forecasting models based on compositional data has been developed. To achieve reliable forecasting results, estimation results of different models are compared according to their precision to derive the best performing model. Concrete and tenable solutions are recommended to promote inclusive water governance.

This study has rich and important implications. Applying the concept of inclusive development to water resources utilization offers an opportunity to consider relations between ecological sustainability and the utilization of water. On one hand, the inclusive development of water resources utilization is an important component of socio-economic sustainable development strategy. On the other hand, inclusive water governance for sustainable development is one of the top goals in a global agenda. Consumption of water should consider a trade-off between competing or even conflicting benefits. By means of inclusive water governance, potential competition can be avoided given an appropriate inclusion of an interests sharing mechanism. The concept of inclusive development reduces the uncertainty of water governance. For example, local governance elites and policy makers used to have an incomplete understanding of the changes in water resources and variations in water consumptions, and thus had limited control over the determinants of effective water governance. This uncertainty creates an impressive need for adaptability, viable alternative choices, and the capability of governments and planners to carry out appropriate policies and action plans for successful water governance. In view of the present water shortage and conflicts in Beijing, it is necessarily important to scientifically investigate the water consumption structure and predict its development trends. The research results provide valuable hints for effective utilization and conversation of water resources. The findings will be conducive to the efficient allocation of water resources and the implementation of an inclusive water development strategy.