Forecasting domestic water demand in the Haihe river basin under changing environment

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Abstract. A statistical model has been developed for forecasting domestic water demand in Haihe river basin of China due to population growth, technological advances and climate change. Historical records of domestic water use, climate, population and urbanization are used for the development of model. An ensemble of seven general circulation models (GCMs) namely, BCC-CSM1-1, BNU-ESM, CNRM-CM5, GISS-E2-R, MIROC-ESM, PI-ESM-LR, MRI-CGCM3 were used for the projection of climate and the changes in water demand in the Haihe River basin under Representative Concentration Pathways (RCPs) 4.5. The results showed that domestic water demand in different sub-basins of the Haihe river basin will gradually increase due to continuous increase of population and rise in temperature. It is projected to increase maximum 136.22 \times 10^8 m^3 by GCM BNU-ESM and the minimum 107.25 \times 10^8 m^3 by CNRM-CM5 in 2030. In spite of uncertainty in projection, it can be remarked that climate change and population growth would cause increase in water demand and consequently, reduce the gap between water supply and demand, which eventually aggravate the condition of existing water stress in the basin. Water demand management should be emphasized for adaptation to ever increasing water demand and mitigation of the impacts of environmental changes.

1 Introduction

Residential water demand is defined as the amount of water withdrawal for residential purposes such as in-house water use for drinking, food preparing, bathing, clothes and dishes washing, toilet flushing, etc. as well as outdoor water needs for gardening, lawn watering, etc. (Blokker et al., 2010; Wang et al., 2017a). Water demand is different from water consumption which indicates the portion of total water use that is not returned to the original water source. Generally, residential water withdrawal or demand are measured in household or regional levels and forecasted. The domestic water demand depends on number of factors including population growth, socio-economic development, climate change, urbanization, water saving technological advances, water tariff, etc. (Sebri, 2014; Wang et al., 2016). A number of recent studies assessed the impacts of those factors on domestic water demand in different regions (Dursun, 2010; Zachariadis, 2010; Protopapas et al., 2010; Karamouz et al., 2011; Jakimavičius and Kriauciūnienė, 2013; Browne et al., 2013; Wang et al., 2014, 2017b; Babel et al., 2014; Price et al., 2014; Walker et al., 2016; Froelich and Magiera, 2016). The studies revealed that the World will face a growing challenge to maintain safe and adequate water supplies due to continuous growth of population and changes in climate. Residential water demand shares a major portion of total water demand in urbanized catchment. Therefore, understanding possible changes in residential water demand due to environmental changes is important for water resources planning and man-

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The Haihe River (112–120° E and 35–43° N), flows through the major cities like Beijing and Tianjin (Fig. 1) plays a major role in national, economic, and social development of China. The Haihe River basin covers 8% of total area of China (318,000 km²), but about 10% of total population reside in the basin and about 13% of total GDP comes from the basin. About 45% area of the basin is urbanized. High population density, rapid urbanization and socio-economic development have caused a sharp increase in water demand, particularly residential water demand. This has made the basin one of the most water stressed region of China. However, water security in the basin has extreme importance in China’s economic development and societal safety (Liu and Speed, 2009; Wang et al., 2015). Therefore, forecasting residential water demand is very important for the basin.

2 Materials and methods

2.1 Data and sources

The population, domestic water use and urbanization rate data for the period 1980–2012 were collected from Chinese Water Resources Bulletins (MWR, 2000–2012). The recent data of domestic water use in four sub-basins of Haihe River basin, namely, the Luanhe River and Coastal areas in Eastern Hebei (LE), Northern Haihe (NH), Southern Haihe Region (SH), Tuhai Majiahe Region (TM) as well as for the entire Haihe River basin (HR) were collected from the Haihe River Water Resources Bulletins (HRCC, 2001–2012).

The bias corrected daily temperature data of the basin for the period of 1961–2012 were obtained from National Climate Center of China (NCCC). The bias corrected future projections of daily average temperature by an ensemble of 7 GCMs namely BCC-CSM1-1, BNU-ESM, BNU-ESM, CNRM-CM5, GISS-E2-R, MIROC-ESM, PI-ESM-LR, and MRI-CGCM3 under the Representative Concentration Pathways (RCPs) 4.5 were also collected from NCCC.

2.2 Modeling domestic water demand

According to the water resources planning technical specifications in China, domestic water demand is forecasted by multiplying the projected population ($10^4 P$) with the projected per capita water consumption ($L^{-1} p^{-1} day^{-1}$; Zhang, 2005; Wang et al., 2017b). The advances in water saving technologies, water pricing, possible changes in people’s lifestyles, etc. are considered in projection of per capita water consumption. However, it does not consider the influence of climate change in water demand. We attempted to improve the exiting method of water demand forecasting by incorporating climate change factor.

The most common approach for considering the effect of climatic conditions on water demand is to include temperature and precipitation variables in the regression equations as there is a common conception that higher temperature and less rainfall make people consume more residential water. However, the influence of rainfall on domestic water consumption is often found negligible (Slavíková et al., 2013; Zhou, 2016). Zhou (2016) found the residential water demand elasticity of rainfall is insignificant for China, while it is significantly positive (0.4299) in case of daily average temperature. Slavíkoná et al. (2013) also reported no impact of rainfall on residential water demand in Czech Republic. Therefore, only the impact of temperature rise due to climate change is considered to modify the existing equation of residential water demand forecasting. The changes in residential water demand $\Delta LW^T$ can be expressed as:

$$\Delta LW^T = d_T \cdot \Delta T \cdot LW^T$$

(1)

Where, $LW^T$ is the residential water demand ($10^4 m^3$) forecasted using existing method; $\Delta T$ is the change in temperature ($^\circ C$) due to climate change; $d_T$ is the temperature elasticity of domestic water demand, which is defined as,

$$d_T = \frac{\Delta LW}{\Delta T}$$

(2)

Where, $\Delta LW$ is the changes in residential water demand in $10^4 m^3$ due to changes in temperature ($\Delta T$) in $^\circ C$.

In this paper, a linear regression model was developed with domestic water use data as independent variable and temperature as dependent variable in order to estimate the temperature elasticity of domestic water demand. The regression model was developed separately for each sub-basin for the estimation of $d_T$ of each sub-basin.
Table 1. Daily average temperature projected by different GCMs in the Haihe River basin.

<table>
<thead>
<tr>
<th></th>
<th>BCC-CSM1-1</th>
<th>BNU-ESM</th>
<th>CNRM-CM5</th>
<th>GISS-E2-R</th>
<th>MIROC-ESM</th>
<th>MPI-ESM-LR</th>
<th>MRI-CGCM3</th>
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<td>(1961–2000)</td>
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<td></td>
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<tr>
<td>2020</td>
<td>11.26</td>
<td>10.63</td>
<td>10.16</td>
<td>9.85</td>
<td>11.08</td>
<td>10.04</td>
<td>10.64</td>
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<tr>
<td>2030</td>
<td>10.53</td>
<td>11.59</td>
<td>10.27</td>
<td>10.86</td>
<td>10.57</td>
<td>10.64</td>
<td>9.98</td>
</tr>
</tbody>
</table>

3.3 Projection of domestic water demand

The water resources planning technical specifications in China estimated per capita water consumption considering the advances in water saving technologies, water tariff, changes in socio-economic condition, etc. Urbanization (shown in Fig. 2) is considered as proxy for socio-economic condition. The per capita water consumptions projected for year 2020 and 2030 were multiplied with projected population (shown in Fig. 2) to estimate the amount of residential water demand due to population growth, water saving technological advances and socio-economic development. The temperature elasticity of water demand and temperature rises projected by different GCMs were then used to estimate the domestic water demand using Eq. (1) in order to incorporate climate change factor in water demand. The water demand projected by different GCMs for different sub-catchments as well as the whole Haihe River basin for years 2020 and 2030 are presented in Fig. 3.

The figure shows that domestic water demand in Haihe River basin will continuously increase due to population growth and temperature rise. The results were found to vary for different GCMs. The BCC-CSM1-1 projected the highest increase in residential water demand in the basin (110.37 × 10^8 m^3) in 2020, while the GISS-E2-R projected the lowest increase (85.82 × 10^8 m^3). In 2030, the BNU-ESM projected the highest increase in domestic water demand (136.22 × 10^8 m^3), while the CNRM-CM5 projected the lowest increase (107.25 × 10^8 m^3). The results indicate large uncertainty in projection of domestic water demand in the Haihe River basin under projected scenarios.

The changes in water demand were also found to vary for different sub-basins. The highest increase was projected in the SH sub-basin, followed by NH. The SH and NH are the most populated regions of the Haihe River basin. Therefore, it can be anticipated that increased water demand will accelerate the condition of growing water stress in the basin.

4 Discussion and conclusion

A model has been developed for forecasting domestic water demand in the context of climate change, population growth and technological development. The model is applied in the Haihe River basin of China which is considered as one of the most economically and politically impor-
Figure 3. Projection of domestic water demand in different sub-basins of the Haihe River in years (a) 2020; and (b) 2030.

The authors declare that they have no conflict of interest.

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References


Browne, A. L., Medd, W., and Anderson, B.: Developing Novel Approaches to Tracking Domestic Water Demand Under Uncertainty – A Reflection on the “Up Scaling” of Social Science Ap-


