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Full Paper

INTERNATIONAL ANALYSIS AND PROJECTION OF DOMESTIC WATER USE

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Abstract

In this study, several factors believed to affect per capita water use were investigated for selected countries. Per capita GDP converted by Purchasing Power Parity (PPP) and urban population ratio were found to be major factors, and two forecasting models of water demand were developed based on these two indices. Assuming two scenarios of economic development, these models were applied and domestic water use in 2015 and 2030 were estimated in countries all over the world.

KEYWORDS: *domestic water use, GDP/PPP, urban population, projection, country*

1. Introduction

Today already many developing countries suffer from drought frequently, and the situation is expected to get worse because of water demand increase caused by population growth and living standard improvements. In order to achieve a sustainable development it is important to assess future water availability and demand in various regions of the world.

Extensive research has been done on the hydrological mechanisms, and many forecasting models of water availability in various regions of the world have been devised. In contrast, little research has been done on forecasting of water demand in various parts of the world. Important water demand sectors are: agriculture, industry, domestic use and power generation. Agricultural water demand is much larger than the others in most regions, and more accurate forecasts are highly needed for this sector. Domestic and industrial water demand are not so large compared to agriculture, but since population growth, economic development and improvement of living standard will have strongly influence domestic and industrial water demand in developing countries, it is important to make improved forecasts also for these sectors.

Among these sectors, domestic water use and factors assumed to influence domestic demand were analyzed in this paper. Forecast models of domestic water use were developed, and these models were used for a projection of domestic water use in countries all over the world.

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2. Factors Influencing Domestic Water Use

2.1 Current status of domestic water use forecasting

On local scales, projections of domestic water use have been made in many cities to support water supply and sewage planning. In order to build water purification and sewage treatment plants at an appropriate rate, it is necessary to estimate the change of water use for a long period. In most cases, future water use was estimated from past trends in per capita use and projected population. Some waterworks authorities used regression equations including factors such as average household size and household income to estimate per capita water use. The relationship between water charge and water use was also analyzed by many researchers, and a software for domestic water use on a local scale was developed by Baumann et al. (1997). In this software, domestic water use was estimated by household income, household size, density of houses, maximum temperature, precipitation, cooling degree days, water charge and other factors. In the operation of water supply facilities, forecasts of hourly change of water use are needed, and its forecast was done using weather condition and a day of the week in most of the cases.

The above-mentioned methods were applied to single cities or regions, they are not universal models to forecast water use in various regions. Some researchers have tried to forecast domestic water use on a global scale, but they have used relatively simple models. Seckler et al. (1998) developed a projection model using per capita GDP. Takahashi et al. (2000) considered the trend of efficiency of water use for a number of regions, and estimated water demand based on population projections and climate scenarios.

2.2 Factors for domestic water use

Before examining factors which influence domestic water use, it is necessary to make clear the definitions of some terms which are used in this paper. In Figure 1, "water demand" is the potential water use when users have no restrictions. Therefore, it is influenced by lifestyle and climate conditions, but not by economic conditions or water resources availability. "Water use" is the actual water use under various restrictions. "Water consumption" is the actual loss through water use, such as evaporation or infiltration, and it might be small in domestic water use. Since discharged water is often reused downstream, "water consumption" might be an appropriate measure to use in water resource assessments. However, since most statistical data are available only as "water use", this measure is used for the present analysis.

The factors used for existing studies were economic factors such as GDP and household income, climate factors such as temperature and precipitation, water price, household size and so on. In addition to the above factors, service level of water supply and sewage system, public awareness of water scarcity, cultural differences of water related activities might be important factors. Furthermore, there might be a strong correlation among some of these factors. In this study, national statistical data on these probable factors were collected and analyzed.

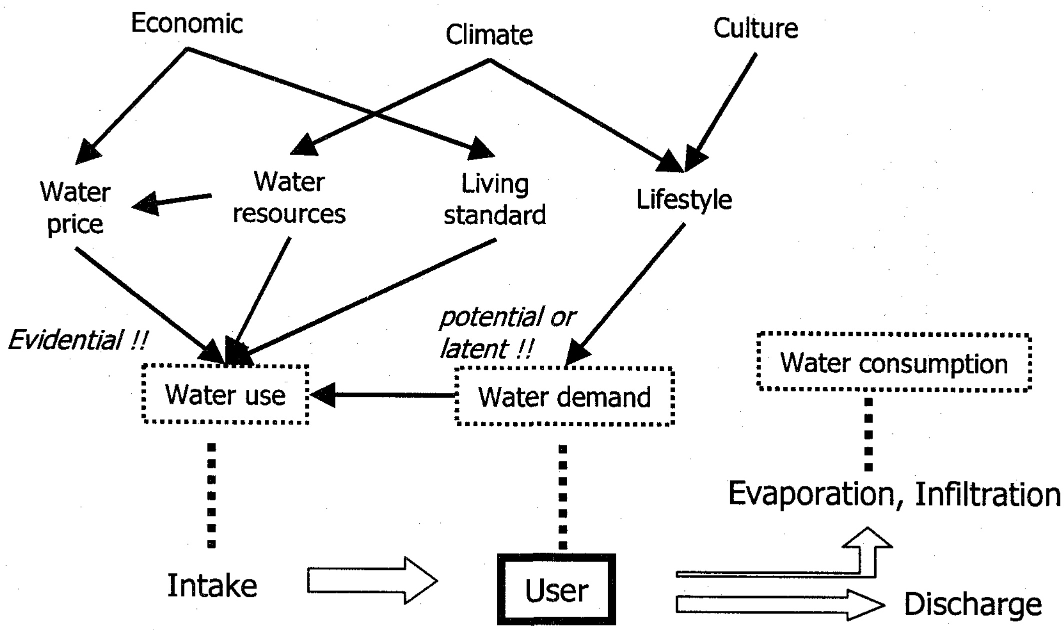

Figure 1. Factors which influence domestic water use and demand.

2.3 Data collection

In order to analyze cause-effect relationships, it is better to use data-sets that cover many countries, including developing countries. Therefore, factors for which it was possible to get information for many countries were used in the analysis. The factors considered were as follows; per capita water resources (World Resources Institute, 2000) as a factor related to "water resources" in the figure, population, population density and urban population ratio provided in the database of the United Nations as indirect factors related to "Living standard" or "Lifestyle", per capita GDP and GDP adjusted by Purchase Power Parity (GDP/PPP) provided by the World Bank as factors related to "Living standard". GDP is usually used as indicator of economic condition, but GDP/PPP might better represent the living standard of each country.

The surveyed year of "domestic water use" (World Resources Institute, 2000) was different in each country, so datasets of the above factors in the surveyed reference year of domestic water use were collected in each country. Data on domestic water use were available for 144 countries, but the data on Mauritania was not used because it seemed to be an extreme value.

3. Relationships between Assumed Factors and Water Use

Figure 2 indicates the relationships between the factors investigated and per capita domestic water use, where n denotes the number of countries and r denotes the correlation coefficient. Population density had no significant correlation, but urban population ratio had a correlation of r=0.70. In most of the countries with urban population ratios lower than 30 (%), per capita water use

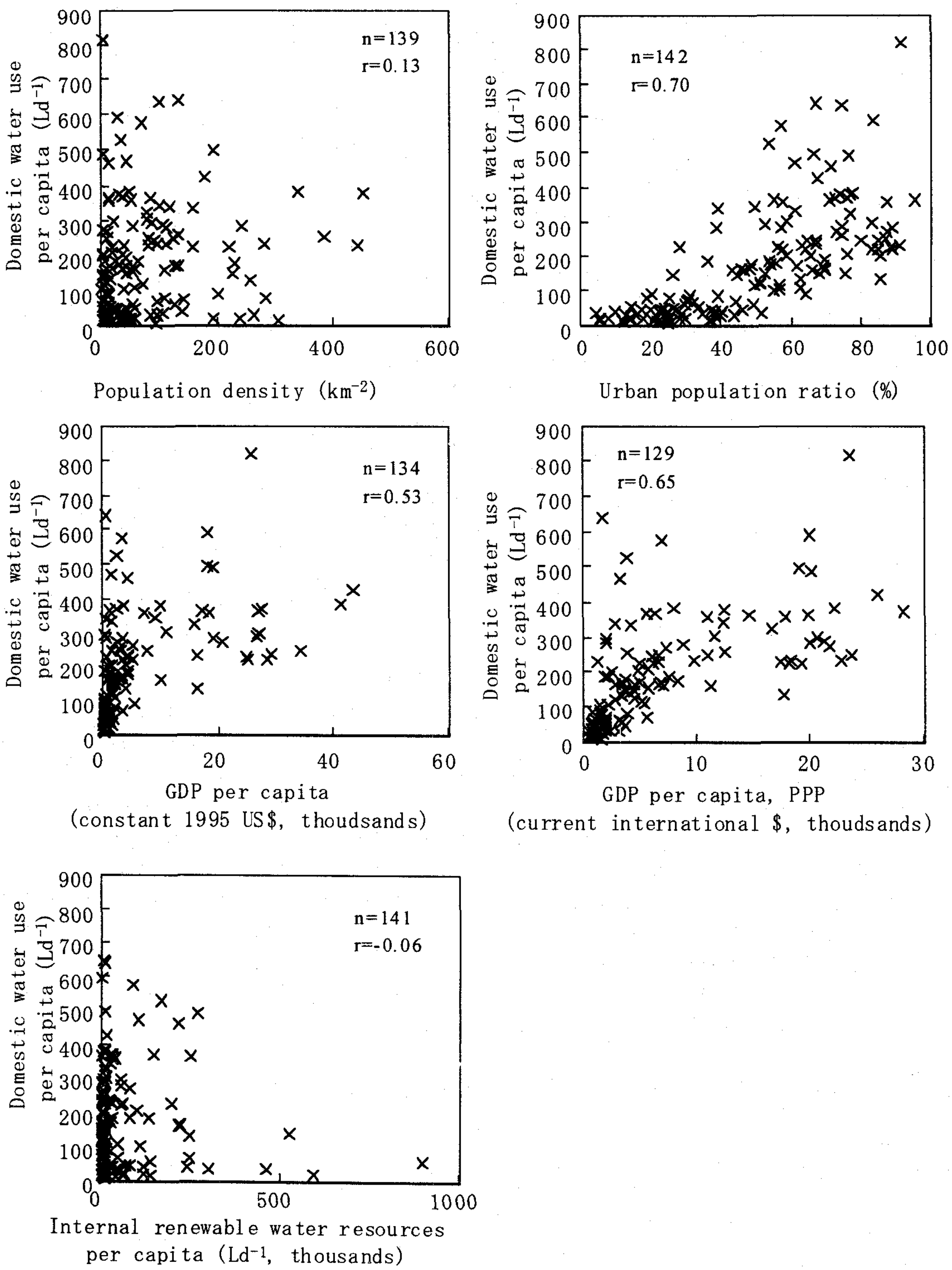

Figure 2. Scatter plots showing the relationship between per capita domestic water use and each of the factors investigated.

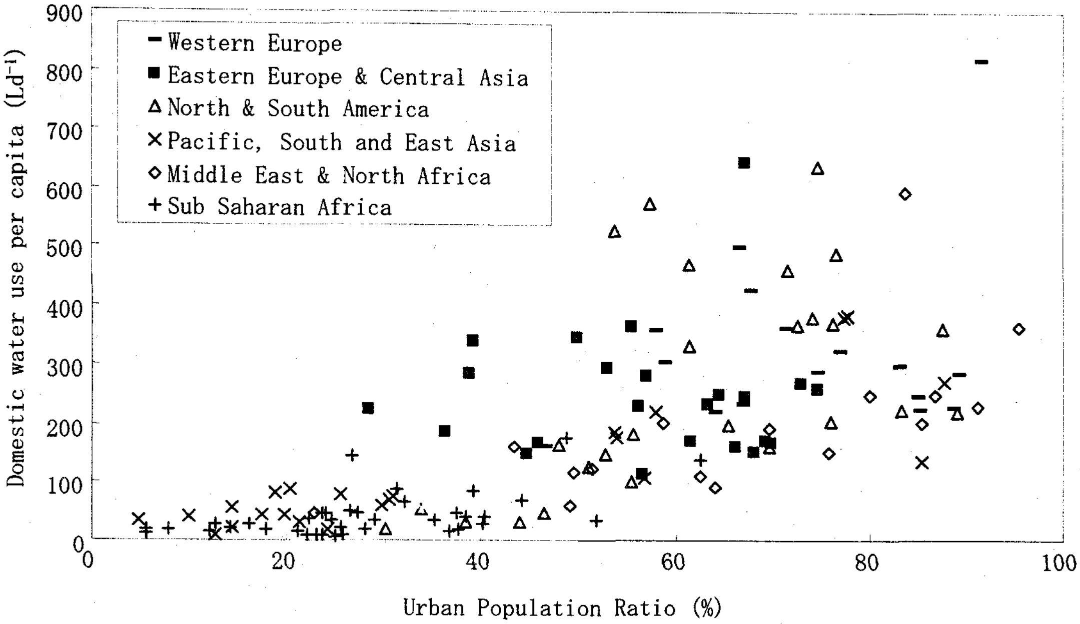

Figure 3. Urban population ratio and per capita domestic water use for six regions.

was less than 50 (Ld^{-1}). On the other hand, per capita water use was more than 100 (Ld^{-1}) in most of the countries in which the urban population ratio was higher than 50 (%). Per capita GDP was correlated with per capita domestic water use, but GDP adjusted by PPP had a stronger correlation. Per capita water use increased with per capita GDP until 10,000 (current international $) of GDP/PPP, but it had no clear tendency above 10,000 (current international $) of GDP/PPP. Per capita water resources had no correlation with per capita water use. It was less than 10,000 (Ld^{-1}) in most of the countries, but it had no tendency even in this range.

Figure 3 shows the relationship between urban population ratio and domestic water use per capita for six regions. Most of the countries in which per capita water use was more than 400 (Ld^{-1}) belong to the North and South America. Per capita water use tended to be higher in countries in Eastern Europe and Central Asia than in other countries with the same urban population ratio.

4. Projection of Future Water Use per Country

4.1 Regression models of domestic water use

Using per capita GDP/PPP and urban population ratio, which were found to have the strongest correlation among the factors in analyzed in Section 3, regression analysis was done for estimating per capita water use. Data for 129 countries were used for this analysis because of lack of data for other countries.

Several regression models were proposed, and the following model (1) was selected among them, based on the adjusted *R* squares.

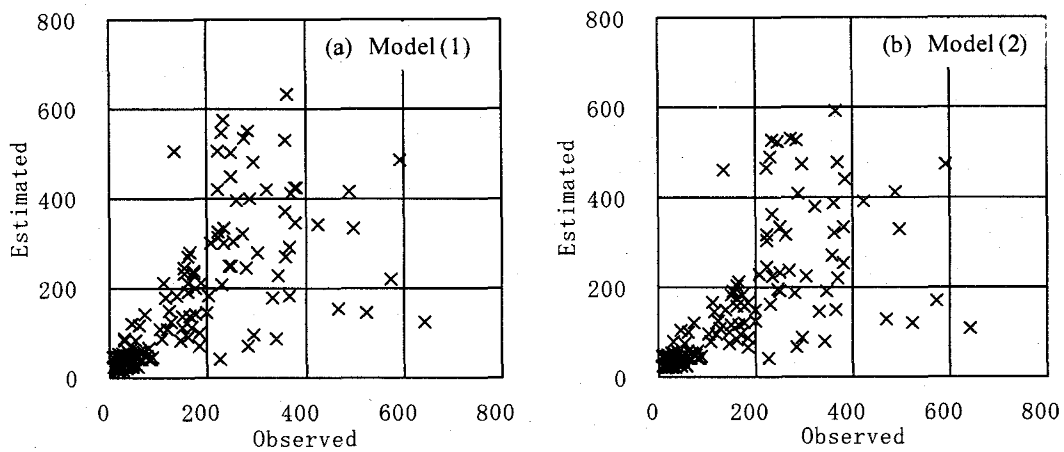

Figure 4. The observed and estimated domestic water use per capita (Ld^{-1}) by two models for each country.

$$\ln(Water) = -0.124 + 0.0199 \times (Urban) + 0.466 \times \ln(GDPPPP) \quad (1)$$

where, *Water* denotes per capita water use (Ld^{-1}), *Urban* denotes urban population ratio (%) and *GDPPPP* denotes per capita GDP adjusted by PPP (GDP/PPP, current international $).

Per capita GDP/PPP was shown to have no correlation with domestic water use in countries where it exceeded 10,000 (current international $). Therefore, a regression analysis using data on 100 countries in which per capita GDP/PPP was less than 10,000 was carried out, and the following regression model (2) was selected.

$$\ln(Water) = -0.960 + 0.0227 \times (Urban) + 0.570 \times \ln(GDPPPP) \quad (2)$$

When this model is applied to countries in which GDP/PPP exceed 10,000, *GDPPPP* is assumed to be 10,000.

Figure 4 indicates the relationship between the observed and estimated value of domestic water use per capita by two models for each country. In some countries with the observed domestic water use more than 200 (Ld^{-1}), the estimated value does not represent well. These countries belong to the Europe, Central Asia, Middle East and Latin America, and a further analysis using other factors might be needed for these countries. Because of the lack of collected data, the above models were used for the following analysis in this paper.

4.2 Projection of population, urban population ratio, GDP/PPP

In this paper, domestic water use in 129 countries in the years 2000, 2015 and 2030 was estimated using the above models. For that purpose, projected values of population, urban population ratio and GDP/PPP for each country were necessary. The estimated values of population according to the medium variant and urban population ratio by the United Nations were used.

Table 1. Scenarios for economic development and economic growth. (%)

	High income		Upper middle income		Lower middle income		Low income	
	High growth	Low growth	High growth	Low growth	High growth	Low growth	High growth	Low growth
2000-2015	2.8	2.5	3.6	2.7	5.8	3.4	8.4	3.1
2015-2030	1.7	0.8	4.4	2.7	7.8	3.4	12.8	3.1

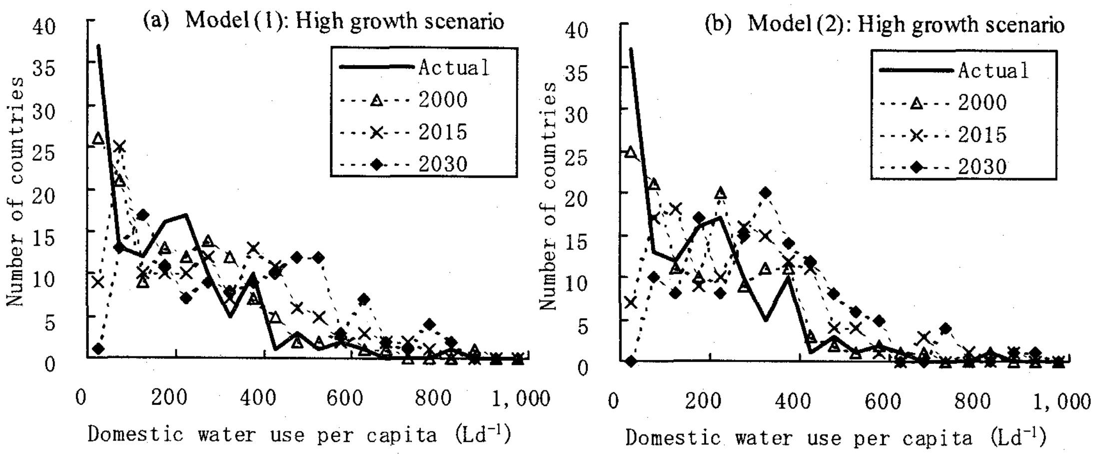

Figure 5. Frequency distribution of per capita water use in each country.

Regarding the GDP/PPP, average GDP/PPP for the past 25 years was calculated for 4 categories of countries (high income, upper middle income, lower middle income and low income) based on the World Bank's classification. Then the rate of economic growth for 2000-2015 and 2015-2030 was assumed using linear and polynomial equations, and the economic growth rate was estimated for two growth scenarios. Table 1 shows the assumed economic growth for each category. Finally, these values were multiplied by the current GDP/PPP of each country, and future GDP/PPP for each country was assumed.

4.3 Projection of per capita domestic water use

Firstly, per capita water use for 129 countries was estimated by Model (1) and (2). As mentioned earlier, the year of current per capita water use data (reference year) was different in each country, so per capita water use in the target year of estimation was estimated using the following process. First, per capita water use was calculated using urban population ratio and GDP/PPP for the reference year and target year of estimation. Then the change of per capita water use was calculated and it was added to the current value of per capita water use.

Figure 5 shows the frequency distribution of per capita water use in 129 countries for the high growth scenario. "Actual" means the distribution of per capita water use in the surveyed year, and the other years show the values estimated by the models. Per capita water use in 2030 exceeded 400 (Ld^{-1}) in more than one-third of countries in Model (1), but increase was much smaller in Model (2).

Table 2. Domestic water use per available water resources in 129 countries.

	Model (1)		Model (2)	
	High growth	Low growth	High growth	Low growth
Actual data	0.71			
2000	0.91	0.91	0.91	0.91
2015	1.45	1.35	1.44	1.33
2030	2.12	1.80	2.08	1.81

Per capita water use has stabilized in most developed countries by now, and according to Model (2) it was assumed to stabilize in many developing countries after a period of rapid increase. From that point of view, Model (2) was considered to better represent future conditions of water use.

4.4 Projected water use per available water resources

Total domestic water use in each country was calculated by multiplying the projected population and per capita water use, and the ratio to available water resources was estimated. This ratio does not include water use in agriculture and industry, but it gives some indication of the stress on water resources.

Table 2 shows the average of this ratio for 129 countries. There was no substantial difference between the two models, the assumptions of the economic scenarios have stronger influence on the result. The ratio was estimated to double in all scenarios, so domestic water use would be more important for considering water stress in future.

Figure 6 shows this ratio for each country in the high growth scenario of Model (2). Countries colored by white in this figure were not the target countries in this projection. This ratio was estimated to be the highest in Africa, the Middle East countries, the South Asian countries and China.

5. Conclusion

In this paper, correlation analysis was done for several factors that might influence per capita domestic water use, and it was shown that urban population ratio and per capita GDP/PPP both are strongly correlated with domestic use. Based on these findings projection models of domestic water use for each country were developed. Using those models domestic water use in 2015 and 2030 were estimated for each country.

The results presented in this paper are still preliminary ones, and their accuracy should be improved in further studies. A limited number of factors were considered because of data availability, and more factors, such as percentage of tap water supply, should be examined in future correlation analysis. Furthermore, a city or regional scale analysis, not a country scale, is necessary for more accurate estimation.

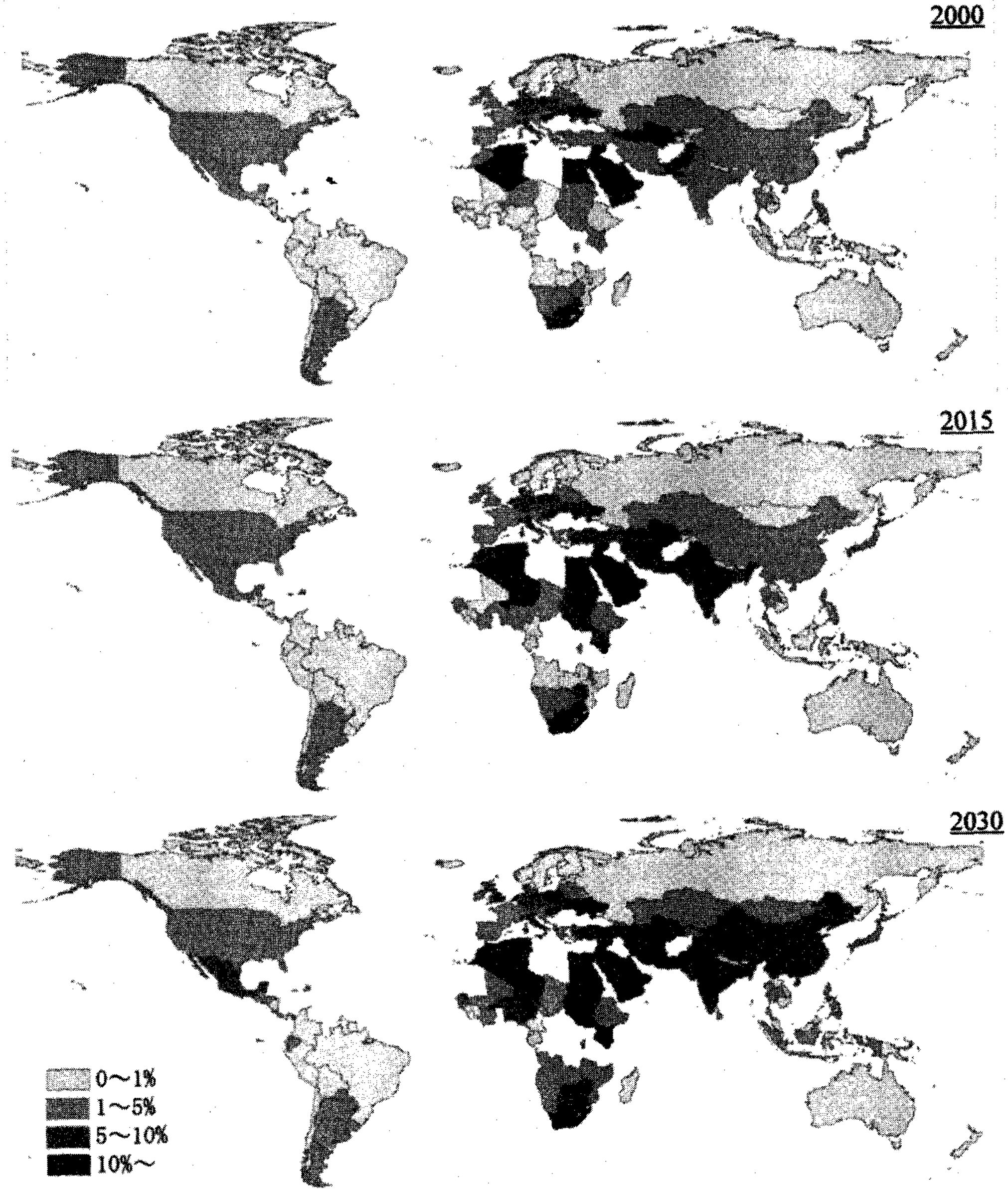

Figure 6. Domestic water use per available water resources for each country.
(Model (2), high growth scenario)

Acknowledgements

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