Estimation of Potential Water Resources in Mega Cities in Asia

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ABSTRACT: The water shortage in mega cities in Asia, which face a rapid growth in urban population, is an outstanding problem. It is important, therefore, to accurately estimate the water balance in each city in order to use the limited water resources effectively. In this study, we estimated the potential water resources in し sixteen mega cities in Asia. The target cities were Delhi and Calcutta, India; Colombo, Sri Lanka; Dhaka, Bangladesh; Yangon, Myanmar; Bangkok, Thailand; Kuala Lumpur, Malaysia; Singapore; Jakarta, Indonesia; Hanoi, Vietnam; Beijing and Hong Kong, the People's Republic of China; Seoul, the People's Republic of Korea; Manila, the Philippines, and Sapporo and Tokyo, Japan. The potential water resources were estimated by subtracting the actual evaporation from the amount of rainfall. The actual evaporation was estimated using the potential evaporation obtained by Hamon's equation which requires the air temperature and the possible hours of sunshine. When the results of Hamon's and Penman's evaporation equations were compared, a considerable error appeared in the low latitude region. The estimation using Hamon's equation was corrected with the linear regression line of Hamon's and Penman's equations. A classification of the land cover was carried out based on satellite photographs of the target cities, and the volume of surface runoff for each city was obtained using the runoff ratios which depended on the land cover. As a result, the potential water resources in the above mega cities in Asia were found to be greater than the world average. However, the actual water resources which are available for one person to use are probably very limited.

1 INTRODUCTION

The water environment is one of the most important factors which form sustainable development and the ecosystem. Human beings cannot live without water; water is needed in order for all forms of life to survive on this planet. Unfortunately, water resources are limited. The shortage of water has become a serious problem, especially in Asia where mega cities face a recent rapid growth in urban population. Therefore, it is important to estimate the water balance and to quantify the potential water resources in these mega cities in order to utilize the limited water resources in an effective manner. The ultimate purpose of this study is to estimate the potential water resources in mega cities in Asia using rainfall data and actual evaporation statistics which are calculated by a simple method based on meteorological data from the past few years. In general, it is needed to consider an inflow from the outside of the city when estimating its water balance. However, the purpose of this study is to know the self – regulated water resources at the city; therefore, we didn't consider the inflow from outside of the city.

2 SELECTED CITIES AND DATA

We selected seventeen mega cities in Asia, each having a population of more than a million persons, where the population growth is remarkable and the shortage of water will be a serious problem in the future. The boundaries of these cities were the political jurisdictions.

We used the "World Meteorological Database" and "CLIMAT" published in CD-ROM form by the Japan Meteorological Agency. Data on temperature, humidity, and wind velocity were taken from the World Meteorological Database, while data on sunshine were taken from CLIMAT. The average data from 1996 to 2005 were used.

3 METHODS

3.1 Runoff Fraction

Surface runoff Q was estimated by

$$Q = P \sum_{i=1}^{m} (c_i \times A_i) \tag{1}$$

where Q is the surface runoff (mm/year), P is the precipitation (mm/year), i is the index number from the land cover classification, c_i is the runoff ratio of i, and A_i is the ratio of land i. m is the number of classifications.

In this study, we classified the land surface into three types, namely, urban, water, and rural. Each runoff ratio, c_i, was used as shown in Table 1 (Gouda 1967). Each area of land cover was determined using satellite photographs.

Table 1 Runoff rate

Urban	Water	Rural
0.6	1.0	0.2

3.2 Potential Evaporation

The potential evaporation was estimated by Hamon's equation which requires the air temperature and the possible hours of sunshine. It is shown as

$$ET_P = 0.14 D^2 P_t \tag{2}$$

where ET_P is Hamon's potential evaporation (mm/day), D is the possible hours of sunshine, and P_t is the saturated absolute humidity (g/m^3) for the mean monthly temperature (℃).

Hamon's equation is a simple formula. However, when compared with Penman' potential evaporation, the difference in the potential evaporation estimated by the two equations tends to increase in the low latitude region (Kayane and Kobayashi 1973). Therefore, we selected five cities, Sapporo, Tokyo, Hong Kong, Colombo, and Singapore, where the meteorological data necessary for Penman's equation exist, and obtained the linear regression line between Hamon's and Penman's evaporation rates. The potential evaporation corrected by the linear regression line was used in this study.

3.3 Actual Evaporation and Potential Water Resources

The actual evaporation and the potential water resources were estimated, respectively, by

$$E = (P - Q') \times \beta \tag{3}$$

$$\beta = ET_P / P \tag{4}$$

$$\text{Potential Water Resource} = P - E \tag{5}$$

where E is the actual evaporation (mm/year), Q′ is the surface runoff, except for the water area (mm/year), and β is the dry ratio. Since inflow and runoff are always repeated, the water area was removed from the surface runoff.

In regions where the potential evaporation is more than the precipitation, the actual evaporation was obtained as β=1.

4 RESULTS AND DISCUSSION

4.1 Potential Evaporation

Fig. 1 shows the relationship between Hamon's evaporation and Penman's evaporation in the five mega cities

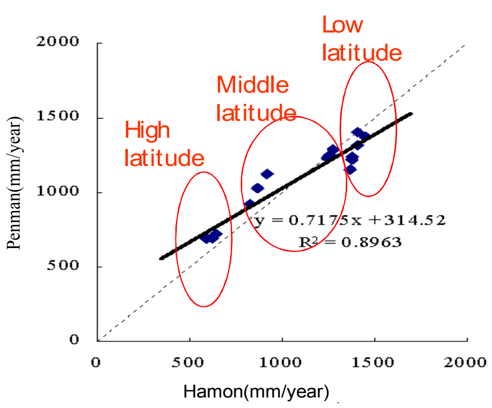

Fig. 1. Comparison of the potential evaporation by Hamon's and Penman's equations

for three years from 2002 to 2005. Hamon's evaporation was underestimated in the high latitude region, compared with Penman's, and overestimated in the low latitude region. Table 2 shows the RMSE (root mean square error) between Hamon's and Penman's evaporation rates before and after the correction of the linear regression. The values of the RMSE decreased due to the correction.

Table 2 RMSE before and after the correction of the potential evaporation

	Hamon(mm/year)		**Penman (mm/year)**
	Before corrected	**After corrected**	
Sapporo	619	757	700
Tokyo	876	941	1,027
Hong Kong	1,225	1,191	1,254
Singapore	1,371	1,295	1,206
Colombo	1,407	1,320	1,364
RMSE	24.1	21.5	

4.2 Surface Runoff

Fig. 2 shows the surface runoff in each city. The volume of surface runoff in Dhaka, about 1150 mm/year, was the highest among the cities. The city with the next highest volume of runoff was Singapore with about 1100 mm/year. The city with the lowest volume of surface runoff was Beijing with about 300 mm/year. Since the amount of precipitation was so small in Beijing, the volume of surface runoff was also low. Although the city which had the largest amount of precipitation was Hong Kong, the volumes of surface runoff in Dhaka and Singapore were higher than in Hong Kong. This is because the ratios for the rural areas in Dhaka and Singapore were smaller than in Hong Kong. In general, surface runoff seems to occur more in urban and water areas than in rural areas.

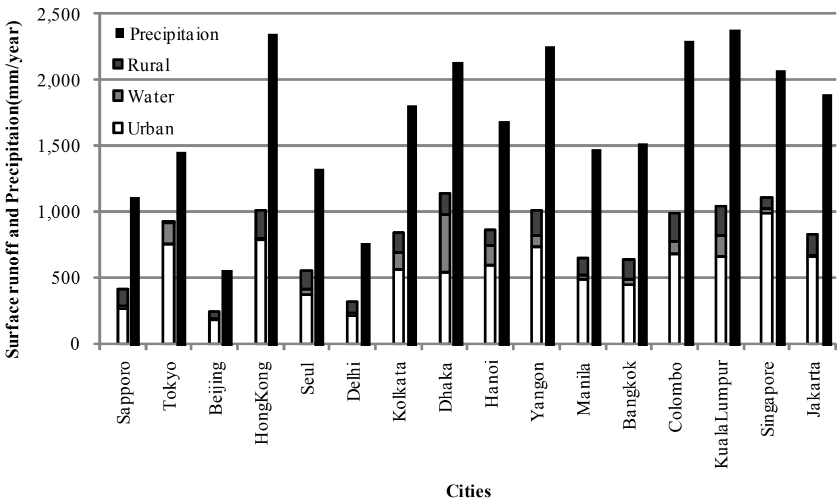

Fig. 2. Volume of surface runoff and precipitation in mega cities in Asia

4.3 Actual Evaporation and Water Resources

Fig. 3 shows the precipitation, the actual evaporation, and the potential water resources for each city. In Beijing and Delhi, where the precipitation was less than 1000 mm/year, the actual evaporation was less than 500 mm/year. In Tokyo, however, where the precipitation was about 1500 mm/year, the actual evaporation was less than 300 mm/year. This is because the proportion of surface runoff to precipitation was large. The amount of potential water resources per unit area in Beijing was the smallest among the cities at about 250 mm/year, whereas in Kuala Lumpur the amount was the largest at 1500 mm/year. The average for the potential water resources of all the cities in this study was about 1100 mm/year. The potential water resources seem to be sufficient in mega cities in Asia when compared with the world average of 320 mm/year (World Resources Institute 2001).

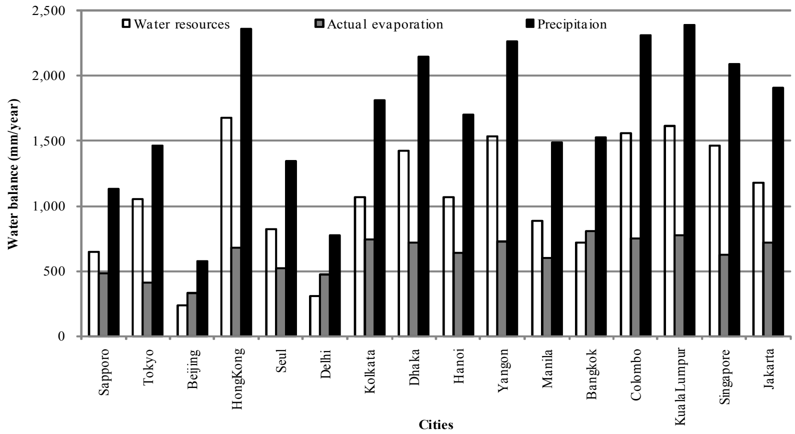

Fig. 3. Water balance in mega cities in Asia

4.4 Water Resources per Person and Future Predictions

Fig. 4 shows the potential water resources per person and the long-term changes in three cities where the

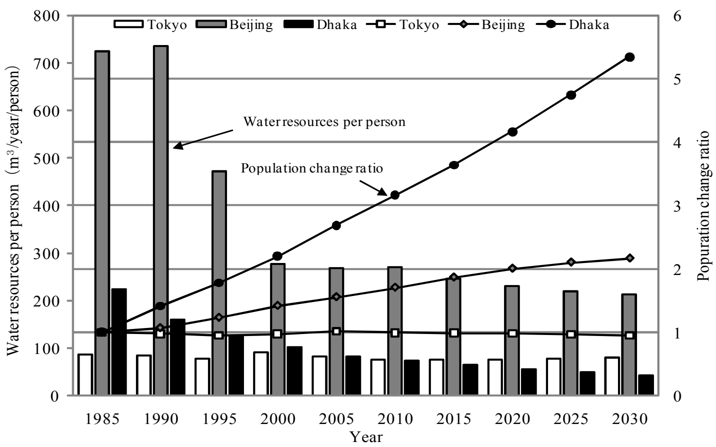

Fig. 4. Potential water resources per person and long-term changes in population

characteristic patterns for changes in population are shown. In Dhaka, where the population growth is remarkable, it is expected that the population in 2030 will be about 5.4 times that in 1985. As a result, the potential water resources per person of 230 m^3/year in 1985 will decrease to around 40 m^3/year by 2030; this is only about 20% of the 1985 rate. As the population in Tokyo has not increased, but decreased from 1985 to 2005, the water resources per person have remained almost constant at around 90 m^3/year. And, since the population is expected to continue to gradually decrease even further after 2005, the water resources per person will increase little by little in the future. In Beijing, however, the water resources per person of about 730 m^3/year in 1985 rapidly decreased to about 280 m^3/year by 2000. After 2000, the rate of water resources per person has been decreasing slowly; this is because the population has grown and will continue to grow slowly. Fig. 5 displays a map for the average potential water resources (mm/year and m^3/year/person) from 1996 to 2005. This map indicates that the amount of potential water resources per person in a given city, for example, Tokyo, of which the population density is high, is small, and yet it is large in a city like Sapporo where the population density is low. In general, it is believed that a serious water shortage will occur when the potential water resources per person are less than 1000 m^3/year (Clark and King 2006). In this study, no city showed a level of potential water resources per person of more than 1000 m^3/year. Although the potential water resources are presently sufficient in mega cities in Asia, it is predicted that there will be a great shortage of water resources per person in the future.

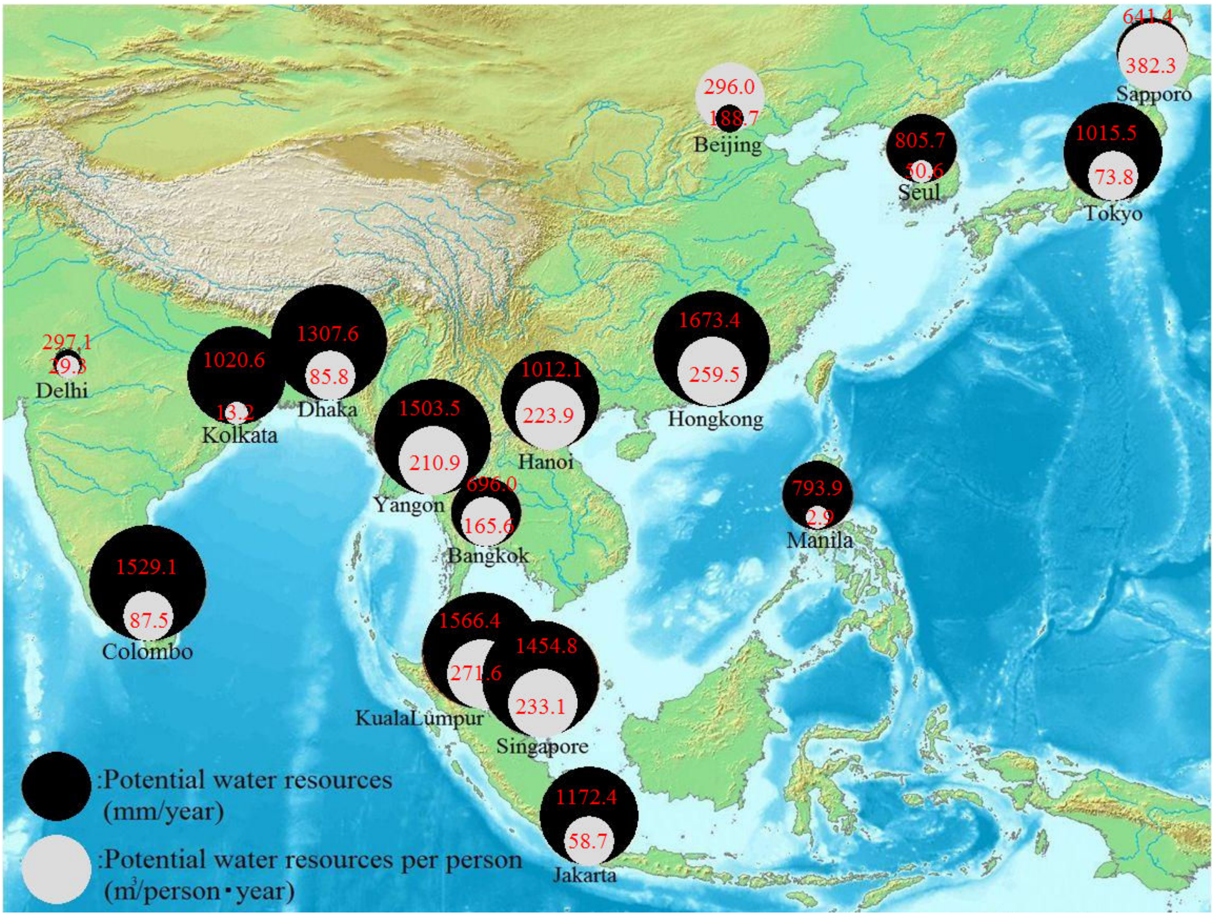

Fig.5. Map for the average potential water resources in mega cities in Asia from 1996 to 2005

5 CONCLUSION

In this study, we used Hamon's equation which requires the air temperature and the possible hours of sunshine to estimate the potential evaporation. However, in the tropical zone of the low latitude region, Hamon's evaporation rates were underestimated compared with Penman's. Therefore, Hamon's evaporation rates were corrected by the linear regression equation between Hamon's and Penman's evaporation rates. The water balance and the potential water resources in sixteen mega cities in Asia were estimated using the corrected evaporation. The population of each city and the ratio of land cover of the city area affected the estimations of the water balance. The potential water resources were sufficient in the mega cities in Asia; however, those per person were very inadequate. The simple method applied in this study is probably useful for estimating the water balance and the water resources in mega cities in Asia.

6 ACKNOULEDGEMENTS

This research was carried out under the research project "Risk-based Management of Self-regulated Urban Water Recycle and Reuse System" (Leader: Prof. Hiroaki Furumai, The University of Tokyo), which was supported by the Core Research for Evolutional Science and Technology (CREST) of Japan Science and Technology Agency. The authors are grateful for their supports.

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