Desalination and Water Treatment
www.deswater.com
doi: 10.1080/19443994.2014.922311

53 (2015) 3111–3117
March

Taylor & Francis
Taylor & Francis Group

Drought assessment based on real-time drought index

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Received 10 September 2013; Accepted 11 December 2013

ABSTRACT

The continuous increase in water demand is primarily caused by the explosive population growth rate due to urbanization and industrialization, and thus, is accelerated in both agricultural and residential parts. Drought adversely affects the quality of life and the whole economic situation of the country, and therefore, an accurate assessment of the incidence of water shortage is required. The existing researches for calculating drought indices do not consider the water demand and the water supply from irrigation facilities, streams, and water storages; thus, existing hydrological drought indices have many limitations in determining actual drought situations in the country. Only water supply without water demand is considered on the existing hydrological drought index therefore, water shortage cannot be calculated. On the other hand, real-time drought index (RDI) evaluates drought on a daily basis in real-time and calculate water shortage according to residential, agricultural, and industrial water. In this study, the water shortage based on real-time water supply and demand is calculated and a new drought index corresponding to such shortage is developed. The drought assessment is performed using the proposed drought index during national drought events from year 2008 to 2009. Based on the results of this study, it turns out that the regions supplied by small reservoirs and streams are more vulnerable in drought as compared with regions supplied by large-scale dams and rivers. The applicability of the proposed drought index is proved to be appropriate, from the comparison results between major historical drought situations and the corresponding situation modeled by this study.

Keywords: Drought; Real-time drought index; Water demand; Water supply

1. Introduction

Due to the growth of population and expansion of agricultural, energy, and industrial sectors, water demand has increased manifold and even water scarcity has been occurring almost every year in many parts of the world. Other factors such as climate change and contamination of water supplies have further contributed to several water scarcity events [1].

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Presented at the 5th IWA-ASPIRE Conference & Exhibition, September 8–12, 2013, Daejeon, Korea

Drought is one of the major disasters which might have consequences like hunger and poverty [2]. Drought natural hazards and human activities impacted on the sustainable development of water resources [3,4]. Since drought, unlike floods, causes gradual damage to crops, properties, as well as living conditions, its quantitative estimation is difficult. Drought is generally caused by the shortage of rainfall but human beings realize drought occurrence only when the water supplied is less than the amount of water required. Drought is a naturally occurring phenomenon that exists when precipitation has been significantly below the normal recorded levels, causing serious hydrological imbalances that adversely affect land resources production system [5]. Droughts can be classified into four categories as meteorological, hydrological, agricultural, and socio-economic [6–8]. Palmer drought severity index (PDSI) [7] and standardized precipitation index (SDI) [9] are the most typical meteorological drought indices being used. However, Soil Moisture Drought Index [9] and Crop Moisture Index [10] are also used as the agricultural drought index. On the other hand, hydrological drought is related to a period where in there is inadequate surface and subsurface water resources for an established water use of a given water resources management system. Stream flow data have been widely applied for hydrologic drought analysis [11–17]. In South Korea, meteorological drought indices such as SPI and PDSI have been used to evaluate a drought event. Meteorological drought is defined as lack of precipitation over a region for a period of time. Precipitation has been commonly used for meteorological drought analysis. [18–21] In the existing drought monitoring system in South Korea, the intake stations, dams, and reservoirs are factors to be considered in estimating the drought index. Also, imbalance of water supply and demand for residential, agricultural, and industrial water should be considered for hydrological drought [22]. In this study, a real-time drought index (RDI), which can be classified as one of the hydrological drought indices, is proposed to evaluate drought situation in South Korea. The proposed drought index is estimated using the supply and demand of residential, agricultural, and industrial water. As a sample study, the applicability of RDI is tested using a historically severe drought event recorded from October 2008 to March 2009.

2. Materials and methods

The RDI is estimated by water shortage based on the imbalance of water supply and water demand. The drought index is made up of water supply system by water intake and non-water intake as shown in Fig. 1. Water sources from the water intake system are stream flow, dam, and reservoir storage while the water source of non-water intake system is rainfall. Total RDI could be estimated only after RDI of each system is already calculated.

2.1. Study area

Estimation of RDI and the corresponding drought assessment are performed on 160 administrative districts in South Korea. Most area of north-central districts such as Gyeonggi province, Gangwon province, Chungcheongbuk province, and Chungcheongnam province are supplied by regional water works from multi-purposed dams or large-scale rivers. On the other hand, most area of south district such as Jeollabuk province, Jeollanam province, Gyeongsangbuk province, and Gyeongsangnam province are supplied by local water works from reservoirs or river (Fig. 2). The population of Gyeonggi province including the Seoul and Incheon metropolitans makes up half of the nation's population and they consume a lot of residential water. In contrast, south districts consume a lot of agricultural water compared with residential water.

2.2. Water supply and demand data

Water source of water intake system is comprised of stream flow, dam storage, and reservoir storage. These are used for residential and industrial water through intake stations. Reservoirs are classified into two categories: one is for residential and industrial water demand and the other is for agricultural water demand. In case of the non-water intake system, the only water source is rainfall and is used for residential and agricultural water [22] (Table 1).

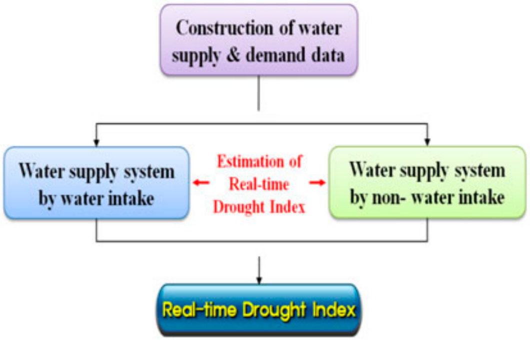


Fig. 1. RDI concept.

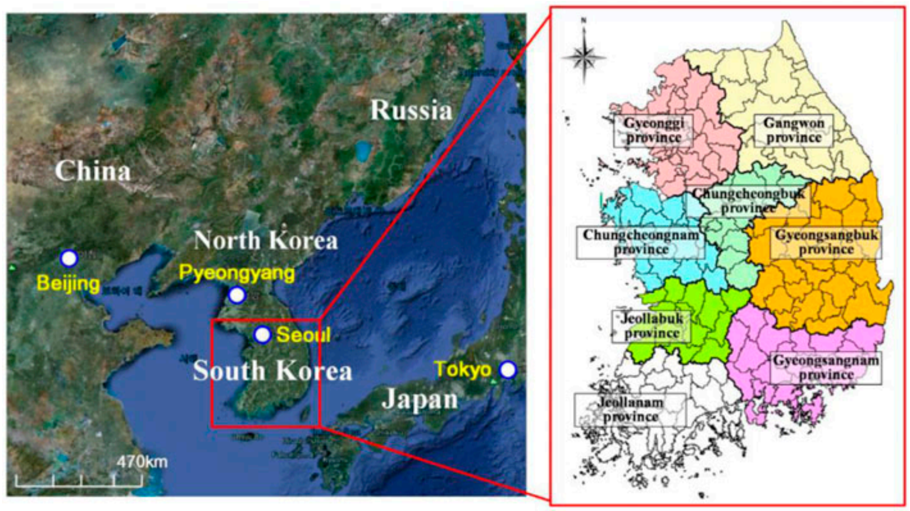


Fig. 2. Study area showing location of administrative districts.

Table 1
Water supply system

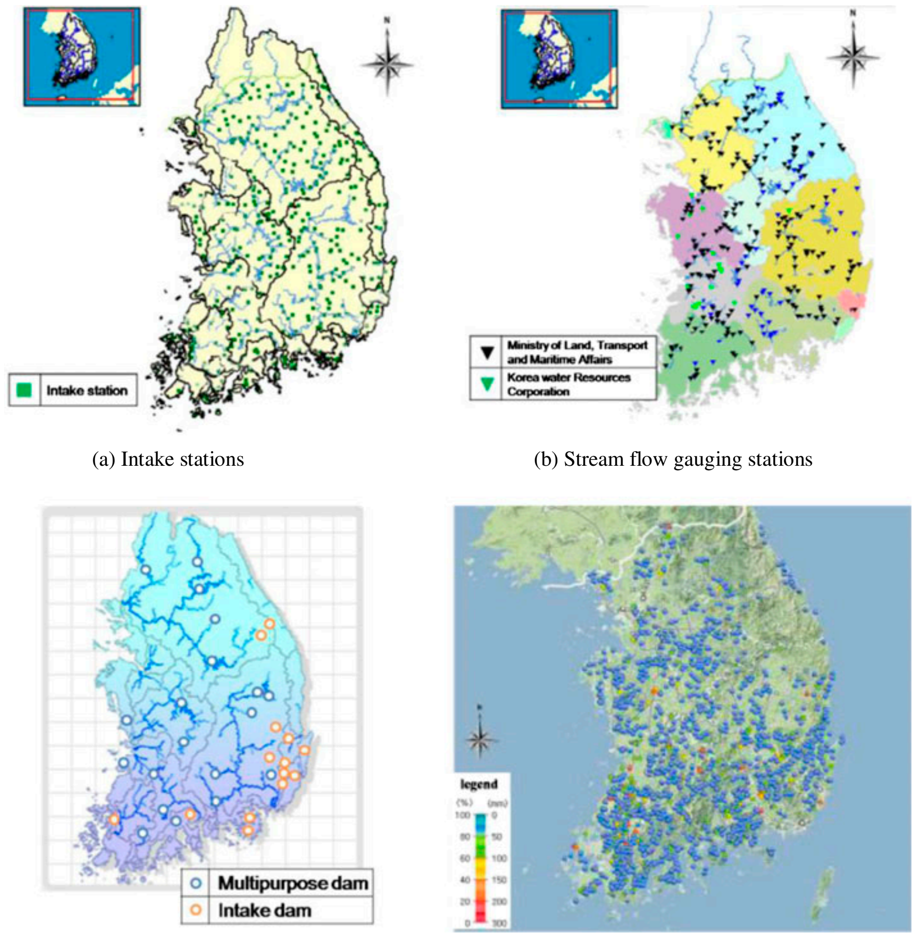
Water supply system	Water sources	Use of the water
Water intake	Stream flow	Residential and Industrial Water
	Dam storage	
	Reservoir (1)	
	Reservoir (2)	Agricultural water
Non-water intake	Rainfall	Residential and Agricultural Water

The stream flow and dam storage data can be obtained from the Water Management Information System of Korea Water Resources Corporation as shown in Fig. 3(a)–(c). The reservoir storage data is gathered from Rural Agricultural Water Resources Information System of Korea Rural Community Corporation as shown in Fig. 3(d). The period of the data is from October 2008 to March 2009 when South Korea experienced an extremely severe drought event.

Water demand comes from two sources: first is from the water intake system and the other one is from the non-water intake system as shown in Fig. 4. Water intake system is supplied by water resources management system from river, dam, and reservoirs and the non-water intake system is supplied by rainfall only. Therefore, the areas in the non-water intake system are vulnerable to drought during dry season. Residential water demand is divided into two parts: the water demand from regional and local water works and the water demand from non-regional and local water works. Agricultural demand is also made up of irrigation and non-irrigation water supplies. Industrial water demand is supplied by water intake system which is composed of organized and disorganized areas [22]. The water demand data is constructed from Water Vision (2011–2020) [23].

2.3. RDI classification

RDI severity is classified by combining each severity of water intake and non-water intake system using categories as shown in Table 2. In case of water intake system, the severity is estimated through the ratio of the water shortage to water demand [22]. For both water intake and non-water intake system, if available amount of water is greater than or equal to the water demand, the severity is classified into D0. For water intake system, if the shortage rate (the ratio of the water shortage to water demand) is ranging from 0 to 0.25, the severity is D1. D2 means that the shortage rate is between 0.25 and 0.50. The drought situation D3 is in the shortage range from 0.50 to 0.75. Finally, D4 is beyond 0.75. On the other hand, from the non-water intake system, it is D1 if the shortage rate is greater than 0. The RDI classification is assigned combining severity classifications estimated from Table 2.



(a) Intake stations (b) Stream flow gauging stations

(c) dams (d) Reservoirs

Fig. 3. Water supply data.

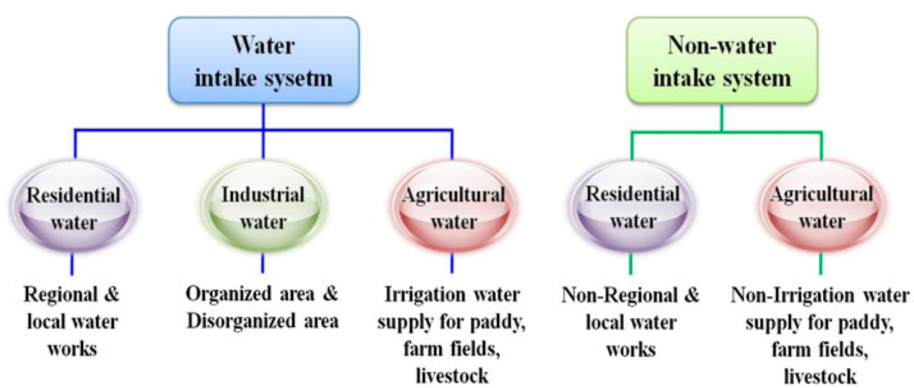


Fig. 4. Water demand data.

For the Normal drought intensity, severity is D0 if both the water intake and non-water intake system are D0. “Moderate” means that if D0 and D1 are obtained from water intake and non-water intake system (in any order) and if both are D1. It is classified into “Severe”, “Extreme”, or “Exceptional” in the case that if the water intake system is D2, D3, or D4, respectively.

Table 2
RDI classification

Severity	Drought intensity	Drought condition	Drought value
D0	Normal	Water intake system : D0 Non-water intake system : D0	0 ≥ Shortage rate
D1	Moderate	Water intake system : D1 Non-water intake system : D0	0 < Shortage rate ≤ 0.25
		Water intake system : D0 Non-water intake system : D1	
		Water intake system : D1 Non-water intake system : D1	
D2	Severe	Water intake system : D2	0.25 < Shortage rate ≤ 0.50
D3	Extreme	Water intake system : D3	0.50 < Shortage rate ≤ 0.75
D4	Exceptional	Water intake system : D4	0.75 < Shortage rate

3. Results and discussion

RDI severity was calculated using the real-time hydrological data during the past extreme drought period in South Korea. Adaptability verification was conducted by comparing actual drought condition investigated by the National Institute for Disaster Prevention (see Fig. 5(a)) and results of RDI severity (see Fig. 5(b)–(e)). Fig. 5(a) shows chronically drought-striken area, drought area, area of restriction on water supply, and area of water transportation. Fig. 5(b)–(e) shows the results of RDI severity according to water sector.

RDI severity for residential water shows the drought occurred in a few districts of north-central regions on 31 October 2008. Since such districts are supplied by large-scale stream or dam such as Paldang, Daecheong, Chungju, and Andong, the drought did not occur in most areas in spite of drought season. On the contrary, the drought affected most area of Jeollabuk province and Jeollanam province.

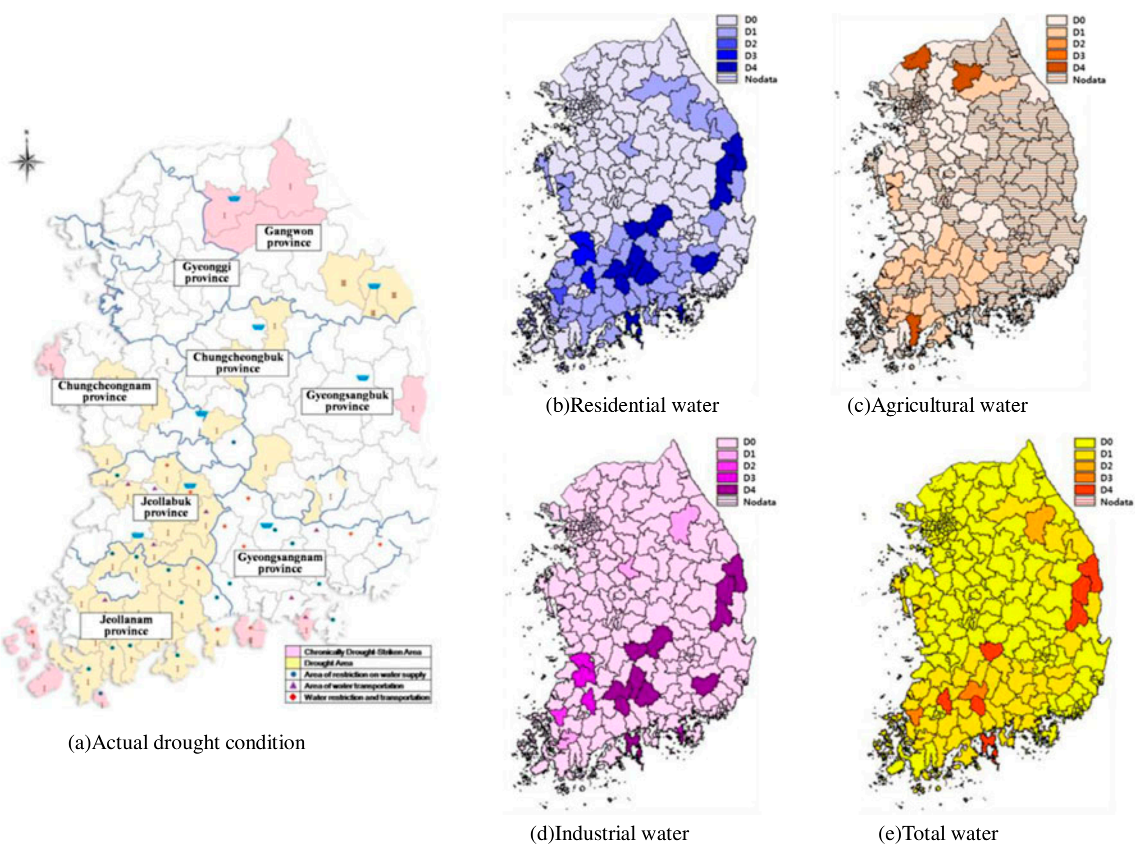
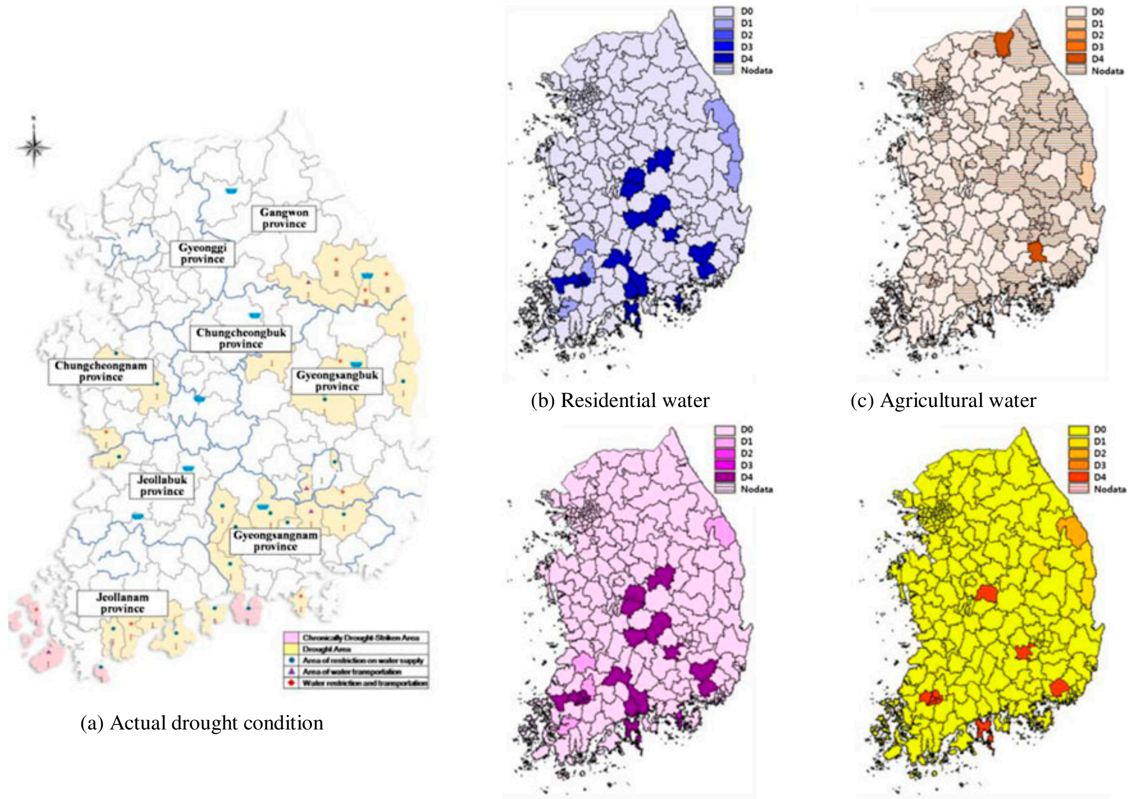


Fig. 5. Drought assessment during drought period in South Korea (31 October 2008).



(a) Actual drought condition

(b) Residential water

(c) Agricultural water

(d) Industrial water

(e) Total water

Fig. 6. Drought assessment during drought period in South Korea (20 March 2009).

This is because the areas are supplied from small-scale local water works or reservoir that reduces its storage in every drought season. One can see that actual drought condition during the period is similar to the result of RDI for residential water. In case of agricultural and industrial water, the drought affected partial areas of Jeollabuk province and Jeollanam province. The districts that have no agricultural water supply data show a deviant crease line in the map.

Fig. 6 shows that RDI severity is reduced and this means that the districts were gradually relieved from drought due to frequent rainfall during March. The actual drought condition in the same period showed a similar aspect with the results of the RDI severity. Drought severities of most area of Jeollabuk province and Jeollanam province classified into D1 to D4 in Fig. 5 are turned into D0 as shown in Fig. 6(b)–(e). The RDI map has an ability to predict which drought condition is most likely to happen. As shown in Fig. 6, the RDI map has less drought districts compared to the map of actual drought condition. This happens mainly because of the natural rainfall activity which relieved drought.

4. Conclusions

In this study, RDI was estimated applying real-time hydrological data such as stream flow, reservoir storage, dam storage, and rainfall to evaluate real-time drought situation in the administrative districts in South Korea from 31 October 2008 to 20 March 2009. The results showed that the districts having a well-developed regional water works from large-scale river and dam storage such as Gyeonggi province, Gangwon province, Chungcheongbuk province, and Chungcheongnam province are capable of dealing with drought events. On the other hand, the districts that have a river and local water works from reservoirs are vulnerable to drought because most of the area is not supplied by regional water works which has a large amount of water. Such difference in terms of water supply system makes it difficult to determine whether the districts can be flexible in responding to drought or not. RDI can consider such difference in terms of water resources management system, so that it can be useful in identifying which districts are in actual drought condition. In addition, the result from the non-water intake system was expected to be used as early drought warning because the actual drought condition can be occurred first at the region that provided water demand from the non-water intake system. The proposed RDI will be helpful to plan drought prevention measures and cope with the situation.

Acknowledgement

This research was supported by a grant [NEMA-09-NH-03] from the Natural Hazard Mitigation Research Group, National Emergency Management Agency of Korea.

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