KSCE Journal of Civil Engineering (2012) 16(3):357-365
DOI 10.1007/s12205-012-1357-3

Information Technology
www.springer.com/12205

A Real-Time Online Drought Broadcast System for Monitoring Soil Moisture Index

Won-Ho Nam*, Jin-Yong Choi, Seung-Hwan Yoo***, and B. A. Engel******

Received October 21, 2010/Revised 1st: February 21, 2011, 2nd: April 7, 2011/Accepted May 19, 2011

Abstract

Drought is a complex phenomenon that varies in intensity over space and time. Due to the spatial and temporal variabilities of drought, better tools are required to assess its severity and spatial extent at any point. Because agricultural drought is influenced by several factors such as rainfall, soil characteristics, and crop type, we propose an analysis method using the soil moisture index to assess drought conditions. Effective drought management can be achieved using drought monitoring if the current conditions can be assessed and future drought development predicted, and decision-makers have required drought response operations that should be available and accessible for use in a short period of time and need to be updated on the latest drought situation. In this study, we developed a web-based geographic information system technology that can broadcast drought conditions in real-time over the Internet and can assist drought management to improve the quality of their decision-making and increase efficiency and effectiveness due to the demand for interaction between decision-makers in the drought management, particularly during drought response. The primary objective of a real-time online drought broadcast system is to provide real-time drought data accessibility and analysis by permitting access to drought's intensity, duration, patterns, and clearly illustrating the spatial extent of drought through the Web, and to contribute to better policy and decision making for drought management. Users can access the WWW graphical user interface and be able to readily access for current drought condition, respond to drought events more effectively, and provide comparisons of the current drought event to past events. In addition, users can obtain a daily soil moisture index map and evaluate the severity of the agricultural drought based on soil moisture changes. Our system can be used by decision-makers to assess current drought conditions, thereby allowing for informed drought management decisions. Our real time web-based drought broadcasting system is accessible over the web at the following URL: http://ruralwater.snu.ac.kr/drought.

Keywords: *world wide web, geographic information systems, web-gis, agricultural drought, soil moisture index*

1. Introduction

Droughts, considered a natural disaster, are a normal, recurrent, yet relatively infrequent climatic occurrence. Damage from droughts can exceed that resulting from any other natural hazard. Compared to other natural hazards such as floods and tsunamis, a drought can impact a large area, and its effects generally emerge gradually over a long period and often last for many years. Drought is a complex phenomenon that is difficult to describe accurately because its definition is both spatially variant and context-dependent (Quiring and Papakryiakou, 2003). Because of the spatial and temporal variabilities of drought and its consequences, tools to determine the onset, severity, spatial extent, and end of drought conditions are required. Tools that make use of the available data to map and monitor droughts could also potentially help mitigate the impacts of drought.

Drought indices integrate various hydrological and meteorological parameters such as precipitation, evapotranspiration, runoff, and other water supplies. These drought indices can be useful tools for decision-makers in government and for public stakeholders (Quiring and Papakryiakou, 2003). These tools can be used to provide an early drought warning system (Lohani and Loganathan, 1997; Mendicino and Versace, 2007), to examine the spatial and temporal characteristics of drought and the severity of drought, and to compare different drought indices (Komuscu, 1999; Narasimhan and Srinivasan, 2005; Bhuiyan *et al*., 2006). Various drought assessment methods and indices have been developed to date. Meteorological droughts are most commonly defined as precipitation deficits relative to average conditions or are defined in terms of water balance indices; hydrological drought is analyzed by assessing flow discharge. However, a meteorological drought is not necessarily the same as an agricultural drought, because an agricultural drought is influenced by several additional factors such as rainfall, soil charac-

*Member, Ph.D. Candidate, Dept. of Rural Systems Engineering, Seoul National University, Seoul 151-742, Korea (E-mail: wh531@snu.ac.kr)
**Member, Associate Professor, Dept. of Rural Systems Engineering, Research Institute for Agriculture and Life Sciences, Seoul National University, Seoul 151-742, Korea (Corresponding Author, E-mail: iamchoi@snu.ac.kr)
***Postdoctoral Research Associate, Dept. of Rural Systems Engineering, Research Institute for Agriculture and Life Sciences, Seoul National University, Seoul 151-742, Korea (E-mail: crom97@snu.ac.kr)
****Professor, Dept. of Agricultural and Biological Engineering, Purdue University, West Lafayette, IN 47907-2093, USA (E-mail: engelb@purdue.edu)

teristics, and crop type. The severity of an agricultural drought can be estimated by the close relationship between drought and soil moisture levels (Ghulam *et al*., 2007). In the real-time estimation of drought for agricultural applications, it is particularly important to understand soil moisture conditions. Soil moisture depletion due to a shortage of rainfall is highly correlated with drought, especially for crops and vegetation; droughts can therefore be evaluated using soil moisture conditions. To evaluate the drought severity affecting upland crops in South Korea, Kim *et al*. (2006) proposed the Soil Moisture Index (SMI). The SMI was developed to measure drought conditions using a soil moisture model and frequency analysis for return periods. The run theory was applied to quantify the depletion in soil moisture during drought conditions in terms of severity, magnitude, and duration. Kim *et al*. demonstrated that the SMI is an effective tool for quantitatively evaluating drought severity.

Effective and efficient drought management relies on accurate and prompt drought monitoring. In the past, conventional drought monitoring approaches based on climatic and meteorological observations have been the primary tools for measuring the severity of droughts (Ghulam *et al*., 2007). Also, effective drought management depends on drought monitoring and the ability to assess current conditions and predict future drought development. Recent widespread, severe, and long-lasting droughts have heightened interest in how to better monitor drought and its impacts. The National Drought Mitigation Center (NDMC), United States Department of Agriculture (USDA), the National Oceanic and Atmospheric Administration's (NOAA) Climate Prediction Center (CPC), and the National Climatic Data Center (NCDC) have partnered to improve existing spatial and temporal drought monitoring capabilities and have developed the U. S. Drought Monitor (http://drought.unl.edu), a weekly, comprehensive drought assessment product based on a simple five-category severity classification. Furthermore, the NCDC, CPC, USDA, NDMC, and scientists from Canada and Mexico are collaborating to publish a monthly experimental North American Drought Monitor (http://www.ncdc.noaa.gov). The Western Governor's Association and NOAA are developing a framework for a National Integrated Drought Information System (NIDIS) (http://www.drought.noaa.gov). The New Mexico Department of Agriculture maintains a statewide network of crop statuses and soil moisture monitoring sites and provides weekly and monthly analyses of this data in both a printed newsletter format and on their web site at http://www.nass.usda.gov**.** Howe However, these drought-monitoring systems are poorly suited to real-time applications and are often not well integrated with spatial datasets such as Geographic Information System (GIS) datasets. The current systems also lack flexibility, customizability, and accessibility to a range of end-users. The primary objective in this study is to examine the current status of real-time soil moisture conditions used for drought condition broadcasting and demonstrate how web-based systems can overcome some of the limitations of existing systems.

At the present time, traditional desktop-GISs have limits of accessible users and centralization of most of all resources and performance on the local machine (Chang and Park, 2004). Due to the limits of resources in desktop-GISs and the absence of suitable dissemination on the network, related problems occur that the limited sharing of data and information (Zhu *et al*., 2001). Furthermore, the primary drawbacks of using desktop-GISs are the preparation of data for each application requires a long and demanding period of data analysis (Romanowicz *et al*., 1993; Al-Sabhan *et al*., 2003). Traditional drought analysis and forecasting is normally based on manual calculations using stand-alone computer programs. Owing to the complexity of drought processes, however, manual calculation is not only difficult to apply, particularly for novice engineers, but is also error-prone process, even for experts, so users are required technical expertise to use. In addition, it is a very time-consuming task because of limited and delayed access to real-time data collection. Advances in information technology have overcome many difficulties in the use of timely and spatially scattered resources in decision-making processes (Chio *et al*., 2003; Engel *et al*., 2003). Web-based GIS relies on pre-processors and post-processors that facilitate the integration of sub-applications (Al-Sabhan *et al*., 2003). Pre-processors are tools that require considerable data collection in order to properly function. Post-processors comprise tools that can be used to analyze the data and are generally rapid and easy to operate. These tools include a variety of statistical and graphical tools that can be used to assist in decision-making, along with a user-developed interface to display and analyze results (Al-Sabhan *et al*., 2003). Therefore, web-based GISs require a great deal of programming and data management for pre-processing and a customized menu-driven user interface that allows easy information access by users.

Decision-makers have required drought response operations that should be available and accessible for use in a short period of time for drought analysis and need to be updated on the latest drought situation. However, there are currently substantial problems with availability, access and usage of reliable, up-to-data and accurate data for drought management. Delay in data collection, access, usage and dissemination has negative impacts on the quality of decision-making in drought response. It can be a quite vulnerable aspect to drought response as timely, up-to-data and spatial extent describing the current drought situation. A web-based GIS can assist drought management agencies to improve the quality of their decision-making and increase efficiency and effectiveness in drought management due to the demand for interaction between decision-makers, particularly during drought response. Moreover, the web-based GIS can support unlimited users and can be accessible from anywhere and at any time through the Web. Decision-makers can obtain desired information from a database on the Web whenever they need, from other Internet access points. They also look for simple tools that can provide them with drought information for determining policies in a clear, the most flexible, and easy-to-use query interface possible.

We describe the development of a web-based drought broadcasting system that permits integrated handling of real-time soil moisture data from a monitoring network. This system requires weather data and soil physical characteristic data as inputs and calculates regional soil moisture contents using a thiessen network and watershed boundaries. The web-based system of spatial distribution is integrated on the basis of this incoming data, approximating real-time to produce soil moisture data on the hydrologic unit watershed scale in South Korea. The data can be accessed from any WWW graphical user interface, and users can analyze a drought's status, intensity, duration, patterns, and spatial extent together with its impacts. Results from the web-based drought broadcasting system for monitoring the soil moisture index are not presented in the format of forecasts. Rather, current drought conditions are portrayed in terms of drought intensity, spatial extent, and resultant impacts on a daily basis. The system can be used to provide current drought conditions and basic data for drought evaluation. This study focuses on developments in interfacing this system with end-users. This system can potentially help decision-makers by identifying drought warning conditions and may facilitate the implementation of suitable drought mitigation measures through continuous monitoring of drought dynamics both in terms of hydrological variables and meteorological and soil variables. Additionally, decision-makers responsible for agricultural drought plans and management can easily identify the spatial extent of areas vulnerable to upcoming droughts.

2. System Development

2.1 System Design and Construction

The web-based drought broadcasting system that we designed comprises a graphical user interface in a web browser, a server side engine application, and executable application systems, as described in Table 1. This system provides tools such as user interfacing, data integration, presentation of dynamic processes in GIS, and modeling programs to allow users access to real-time drought data. On a daily basis, this system operates two sub-model systems: a weather data collection system and soil moisture index broadcast system. The weather data collection system was developed using shell script and the practical extraction and report language (Perl) to collect the following daily weather data: precipitation, mean temperature, wind velocity, sunshine duration, and relative humidity from the Korean Meteorological Administration web site (http://www.kma.go.kr). Web-based data access using shell script and Perl results in a tool that is powerful, flexible, and easy to use. Furthermore, the end-users have access to real-time data. After data collection, the soil moisture index broadcast system is then used to process the weather data. This system is linked to external potential evapotranspiration and soil moisture index calculation programs in which operations are performed using programming languages that are suited to mathematical calculations, such as C. To use the external programs from the web-based GIS, the programs are used to calculate certain parameter data and to store the resulting text-based data. Operating the web-based drought broadcasting system via the Internet requires management of a large amount of geographical information that has to be delivered frequently using display control functionality including zoom in, zoom out, and panning. Furthermore, this system requires the efficient management of large spatial and temporal data sets, which involves data acquisition, storage, and processing of model inputs, as well as the manipulation, reporting, and display of results.

MapServer, an open source development environment, is widely used to implement web-based GIS solutions to display dynamic spatial maps over the Internet. Therefore, we developed the user interface in our web browser using the MapServer web-GIS application (MapServer, 2001), Hyper Text Markup Language (HTML), JavaScript, Java applets, and PHP. The MapServer application was selected as the Common Gateway Interface (CGI) engine for developing the web-based GIS user interface. The CGI, running on the server side, provides a light-weight page on the client side. Thus, a server powerful enough to control the processes from multiple connections within a reasonable connection time is preferred, as this minimizes concerns regarding client computer capability and connection speed.

A schematic diagram of our web-based broadcasting system is shown in Fig. 1. Most web-based user interfaces can be regarded as client-operated environments. The user interface has menus that are used for graphical display controlling and links to other

Table 1. Description of the Web-Based Broadcasting System Components

System	CGI and programming language	Type	Functionality
data collection system	shell script, Perl	executable application	- weather data collection
SMI broadcast system	shell script, C	executable application	- calculation of PET - calculation of Soil Moisture Index
server side engine application	MapServer CGI, Perl	CGI application	- file management - application operation - HTML standard out
user interface in web browser	MapServer CGI, HTML, Java applets, JavaScript, PHP	CGI, web pages	- date selection - display map control - print map, query mode - result SMI map display - graph of soil moisture variation - SMI map moving picture

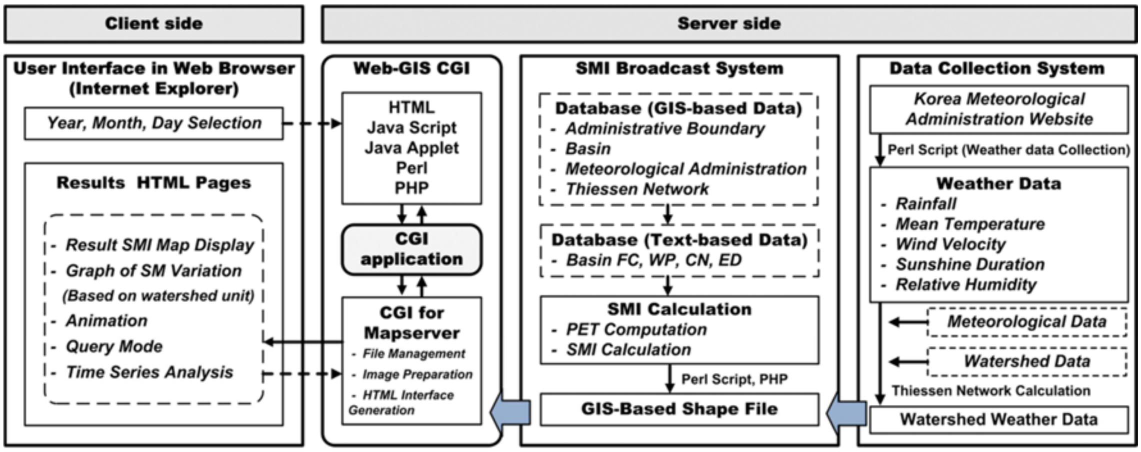

Fig. 1. Schematic Diagram of the Web-Based Broadcasting System

functions including print map and query mode. The interface also uses HTML form protocols to submit data with MapServer CGI variable values. The main advantage of CGI is that it is fast and it reduces the processing time spent redrawing dynamic maps requested by the client within a web browser. When the web page is accessed by a user, the server side engine application is executed on the web server. When a menu button is selected, the client-side system communicates with the server-side engine via the network using a specified protocol. Therefore, the web-based system requires communication to interface between the application and the server, and a network application that follows network protocols is required to complete the web-based system. Although several languages have been used for data exchange between client and server, in this study, Perl was used to connect the client and server side applications. Perl is the language typically used for CGI and supports the protocol for HTML form input and HTML standard out.

2.2 Model Component

Our web-based drought broadcasting system contains an agricultural drought evaluation model that can be used to simulate soil moisture. While soil moisture responds to precipitation anomalies on a relatively short time scale, ground water, stream flow, and reservoir storage reflect longer-term precipitation anomalies (Komuscu, 1999). In studying agricultural droughts, many investigators believe that soil moisture shortage is the most practical indicator and a key early drought parameter. Kim *et al*. (2006) suggested a soil moisture index for agricultural drought evaluation based on a water balance model of the soil moisture demand. The SMI can be used to determine the spatial and temporal variations in soil moisture deficit and is based on soil moisture simulation, drought evaluation, and frequency analysis. First, a soil moisture simulation is performed on a daily basis using a spatially distributed water balance model. Our model follows the original approach presented by Kim *et al*. (2006) and is based on theoretical methods for simulating runoff and soil moisture variations. Daily soil moisture is first estimated at the level of the standard hydrologic unit of a watershed using the simplified water balance model shown in Eq. (1):

$$\Delta SMC = RF - (DR + DP + ET) \tag{1}$$

where ΔSMC is the change in soil moisture (mm), RF is daily rainfall (mm), DR is the surface drainage (mm) determined using the Natural Resources Conservation Service (NRCS, U.S.A.) Curve Number (CN) method, DP is deep percolation (mm), and actual evapotranspiration (ET, mm) in the soil-water balance procedure is estimated considering the FAO Penman-Montieh method recommended in the methodology of FAO paper no. 56 (Allen *et al*., 1998). The non-irrigation and model description are shown in Fig. 2.

Second, the drought index quantitatively evaluates drought using the changes in soil moisture and the run theory (Yevjevich, 1967). Three indicators of drought are defined based on the run theory: Duration (D), Magnitude (M), and Severity (S), as shown in Eq. (2). We assumed that drought occurs when soil moisture is lower than the given truncation level, which we set at 50% of the available soil moisture according to soil type. The method is based on the statistical theory of runs for analyzing a sequential time series. The following statistical properties of the distribution of soil moisture deficits - run-length (drought duration) and run-sum (deficit volume or severity) - are recommended parameters for the definition of at-site agricultural drought. The timing of a drought has several different definitions; it can be defined based

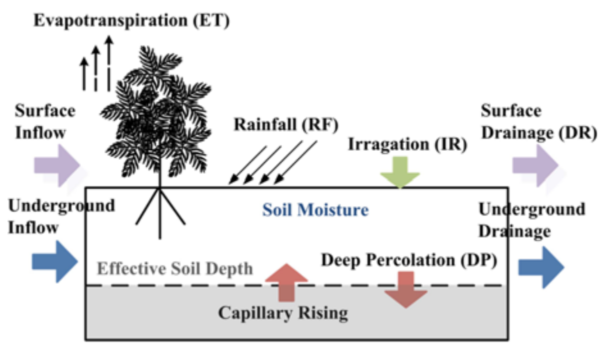

Fig. 2. Schematic Diagram of the Soil Water Balance

on the starting date of the drought, the mean onset of the drought, the termination date of the drought, or the date of minimum water flow. Another drought index, the drought intensity, is defined as the ratio of the drought deficit volume and the drought duration. A defined drought event can therefore be characterized by three parameters: duration, magnitude, and severity:

$$D\,(day) = end\ day\ of\ AW\ 50\% - start\ day\ of\ AW\ 50\%$$
$$S(mm \times day) = \sum_{i=start}^{end} SMD_i \qquad M\,(\%) = \frac{S}{D} \tag{2}$$

where AW 50% indicates that soil moisture is less than 50% of the available water, and soil moisture deficit (SMD, %) is the difference between AW 50% and soil moisture (%) at day i.

Finally frequency analysis of the severity indicator is conducted, and then a new drought index, SMI, is classified based on the probability. SMI can be represented as an integer value from -5 to -1 corresponding to a drought severity ranging from extreme drought to mild drought, as described in Table 2.

2.3 Database Component

One of our aims is to allow access to real-time data and analyses via the web to allow end-users to determine the severity, spatial extent, pattern, and potential end date of drought conditions. The key requirement of real-time drought broadcasting based on meteorological data is accurate data. Meteorological data, including model parameters and hydrological basin data, are stored in databases. In particular, our database contains real-time meteorological data collected by the Korean Meteorological Administration based on information recorded by 76 meteorological stations in Korea, as described in Table 3. The location data provided by the user is used within a CGI script written in Perl to query a database on the web server to obtain the daily precipitation data required for the SMI calculation. Because soil physical characteristic data can be used in SMI calculations, a NRCS curve number map based on a combination of land use data and hydrologic soil map data can be created. The field capacity, wilting point, effective soil depth, and NRCS curve number at the mid-range level of the hydrologic unit watershed scale in South Korea can be calculated from the soil map using an area-weighted method (Kim *et al*., 2006).

Table 2. Soil Moisture Index Classification According to Kim *et al*., 2006

Severity (X)	Probability	Soil Moisture Index	Drought stage
$X < \mu - 2\sigma$	0.96~1.00	-1	mild drought
$\mu - 2\sigma \leq X < \mu - 1\sigma$	0.68~0.96	-2	moderate drought
$\mu - 1\sigma \leq X < \mu + 1\sigma$	0.32~0.68	-3	severe drought
$\mu + 1\sigma \leq X < \mu + 2\sigma$	0.04~0.32	-4	very severe drought
$\mu + 2\sigma \leq X$	0~0.04	-5	extreme drought

X: cumulative soil moisture deficiency, μ: mean, σ: standard deviation

2.4 Analysis Component

2.4.1 Graphical User Interface

When developing a web-based drought broadcasting system, the single most important aspect of implementation is to use an appropriate GUI that determines the interaction between the computer system and the end-users. Our system allows interactive communication between web services and end-users based on various tools and also provides the end-user access to a variety of tools that facilitate both the visualization and analysis of the spatial distribution of model parameters and simulated state variables at different spatial and temporal scales. This system is initiated by a menu request at the URL: http://ruralwater.snu.ac.kr/drought from the client, as shown in Fig. 3. The web-GIS interface supports date selection, layer selection, graphical display map control, display control, reference map, legend, and print map buttons. The user interface is designed with a GUI to provide convenient buttons to display an SMI map selected date, a graph of soil moisture variation, and SMI map animation. Using the menu, users can choose the date and then select the functions of interest simply by clicking on the buttons.

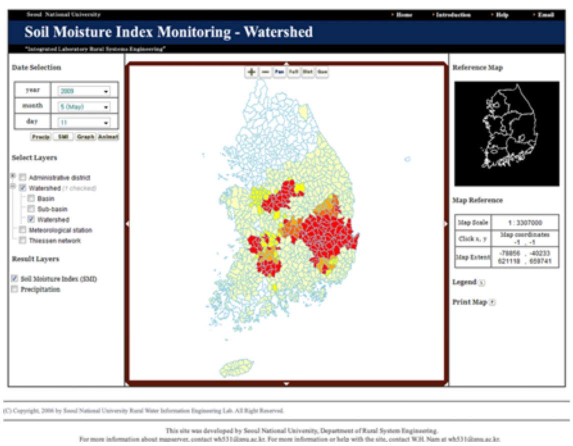

Fig. 3. GUI of the Web-based Drought Broadcasting System

Table 3. Input Data Required by the Soil Moisture Index Calculation

Data classification	Source and parameter	Data description
weather data	weather data sets from the Korean Meteorological Administration	temperature (ºC), relative humidity (%), wind velocity (m/s), duration of sunshine (hr), precipitation (mm)
meteorological station data	meteorological station parameters	meteorological station code, longitude, altitude (m), thiessen coefficient
soil characteristic data	generated from the Rural Development Administration soil map and National Geographic Information System land use map	field capacity (%), wilting point (%), effective soil depth (mm), NRCS curve number

2.4.2 WWW Broadcasting

In designing this web-based drought broadcasting system, we focused on making the web site user-friendly, simple to use, and the results easy to visualize. As described above, when a user clicks on a date of interest, they are taken to a page that contains detailed information for that date. The soil moisture model results are presented as graphs in the user's web browser. Using the menu, users can choose the date for which they want to know the SMI conditions and then click the SMI submit button. The user interface obtains the date and submits the date selected to the MapServer CGI. The MapServer CGI works in a similar manner to general CGI applications. An HTML page with a query string with the HTML GET method sends variable values to the server, and the MapServer CGI parses the variables, reads digital maps described in a map file, draws maps and ancillary graphics, prepares an HTML page for publishing, and sends the HTML page to the client browser. Operation of the MapServer CGI allows users to obtain SMI maps from throughout the nation. Furthermore, the use of PHP allows the display of web pages that are dynamically generated based on actions performed by the user.

2.4.3 Advanced Analysis Component

A web-based drought broadcasting system targeted at novice and expert users should provide additional functionalities to help users understand the drought response results in several different formats. Such functionality can make the results more helpful and will help users to analyze and understand the results. In our system, we included several advanced analysis components for graphing soil moisture variation and to provide an animated SMI map. Fig. 4(a) shows a graph of soil moisture variation and trend analysis of drought severity. The graph helps end-users to understand drought onset, severity, patterns, and the predicted end of the drought, and provide historical comparisons of the current drought event to past events. Time-series drought maps that allow the spatial extent of a drought and underlying drought processes to be understood can be generated in a web-based environment using SMI, as shown in Fig. 4(b).

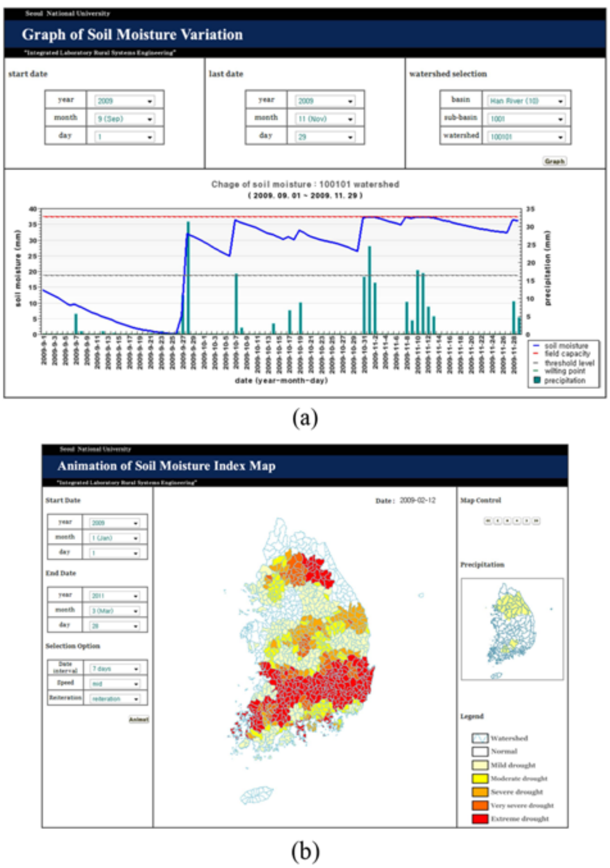

Fig. 4. Advanced Analysis Component: (a) Graph of Soil Moisture Variation and (b) Animation of Spatial Drought Aspect

3. System Utilization

3.1 System Application

The primary objective of a real-time online drought broadcast system is to contribute to better policy and decision making for drought management. The target users are government policy decision makers, local communities, and research scientists. They will be able to readily access for current drought condition, respond to drought events more effectively, clearly illustrating the spatial extent of drought, and its severity, and provide historical comparisons of the current drought event to past events.

According to the available data, Korea experienced a severe drought between 2008 and 2009, especially in the south. Analysis of this drought using our web-based drought broadcasting system indicated an extremely intense drought phenomenon during 2009. The spatial distribution of drought severity is illustrated in Fig. 5. Hydrologic unit watershed maps from December 2008 and May 2009 are shown, with yellow pixels indicating severe drought and red pixels showing extreme drought. Fig. 5(a) shows the spatial distribution and evolution of drought conditions in December 2008, during which time a drought that began in the north extended southward. Figs. 5(b) and 5(c) show the evolution of a widespread drought that affected Korea in 2009. According to the SMI calculations and the spatial patterns of the drought, about 50% of all watersheds in Korea except those in western regions suffered from drought; in particular, southern areas of Korea experienced severe drought in February 2009. The SMI monitoring results revealed that the SMI values were generally lower than –3, indicating severe drought, especially in the southeastern regions of the province. The information provided by the SMI is consistent with the actual drought status during this period. As shown in Figs. 5(d) - 5(f), droughts can be very variable, either affecting specific regions or covering wide areas. An analysis of all recorded drought periods in Korea revealed that in general, droughts usually affect specific regions, with the exception of more extreme droughts.

3.2 System Improvement

The main areas that this research can assist are relevant to availability, accessibility and interoperability of spatial data for drought management. One of the aims is to provide real-time

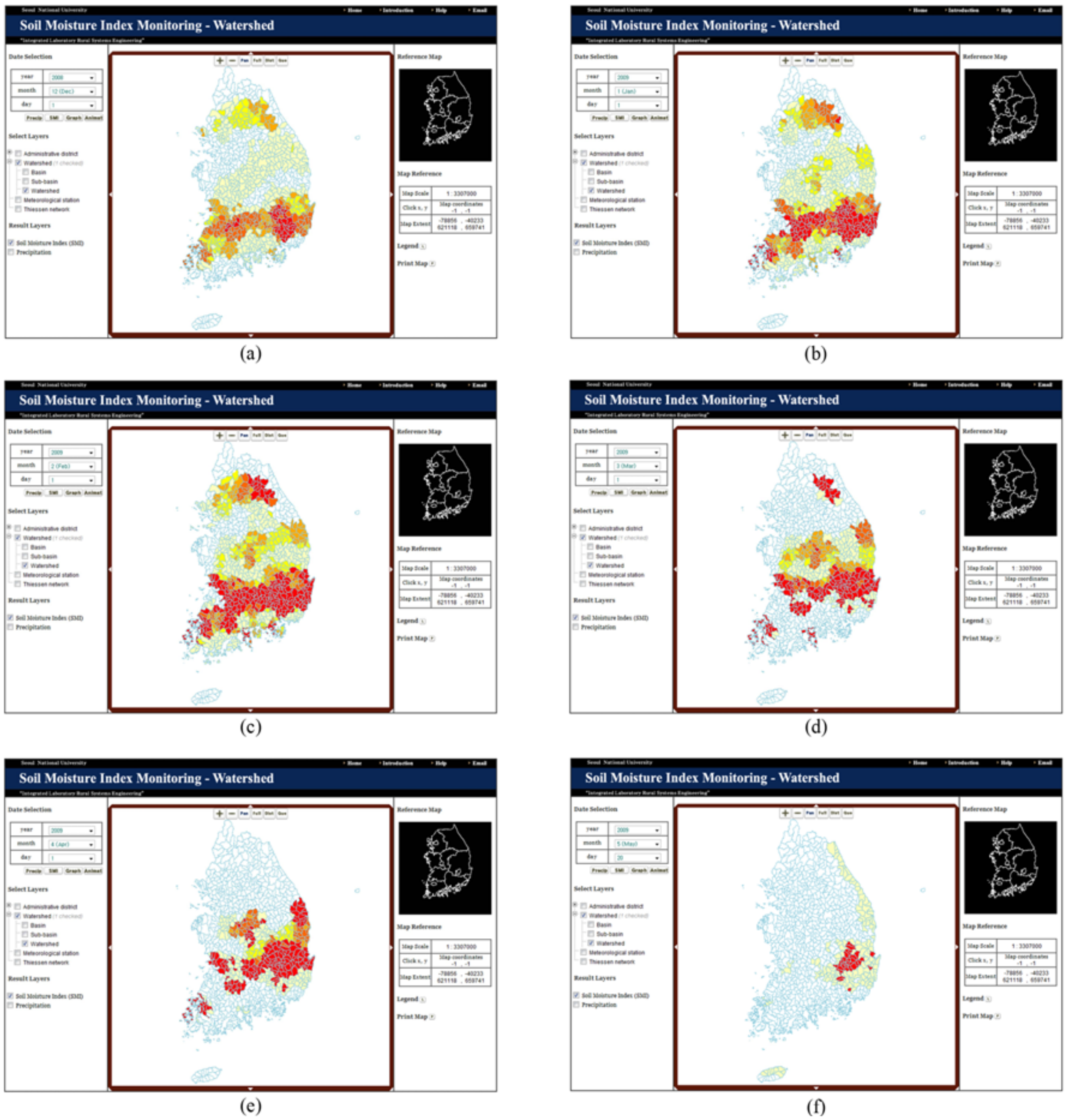

Fig. 5. Web-Based Presentation of the Spatial Distribution Changes in the SMI in 2009 during Spring Drought Periods in South Korea: (a) December 2008, (b) January 2009, (c) February 2009, (d) March 2009, (e) April 2009, and (f) May 2009

drought data accessibility and analysis by permitting access to drought's intensity, duration, patterns, and spatial extent through the Web. Traditional and conventional approach, user preparing for drought monitoring, is multiple steps for calculation of drought analysis model and drought information broadcasting. Because of end users for drought management usually would not expert, they often spend a great amount of time to running and analyzing a drought simulation model, so they needed to require a possibly small amount of technical knowledge to handle. Compared with conventional approach, web-based drought broadcasting system is simple step for decision-makers by selection of date through more convenient user interface in web browser, and contained improved functions for more advanced drought management. An additional aim is to provide data accessibility and analysis regardless of the computing platform so that whoever has access to the Internet can run the drought simulation model, so animated results of the temporal and spatial drought processed in a Web and then displayed immediately in the client machine from any computer in the world. The improved drought assessment steps of this web-based drought broadcasting system and comparison of user preparing for drought monitoring are shown in Fig. 6.

The drought simulation and information systems on the Web have been developed during the last decade in Korea. Those indicate the web-based systems designed and implemented by the KICT (Korea Institute of Construction Technology, 2004, http://www.drought.re.kr), RRI (Rural Research Institute, 2006, http://adis.ekr.or.kr), and KMA (Korea Meteorological Administration, 2008, http://www.kma.go.kr). Most of existing drought information systems provides drought information using hydro-

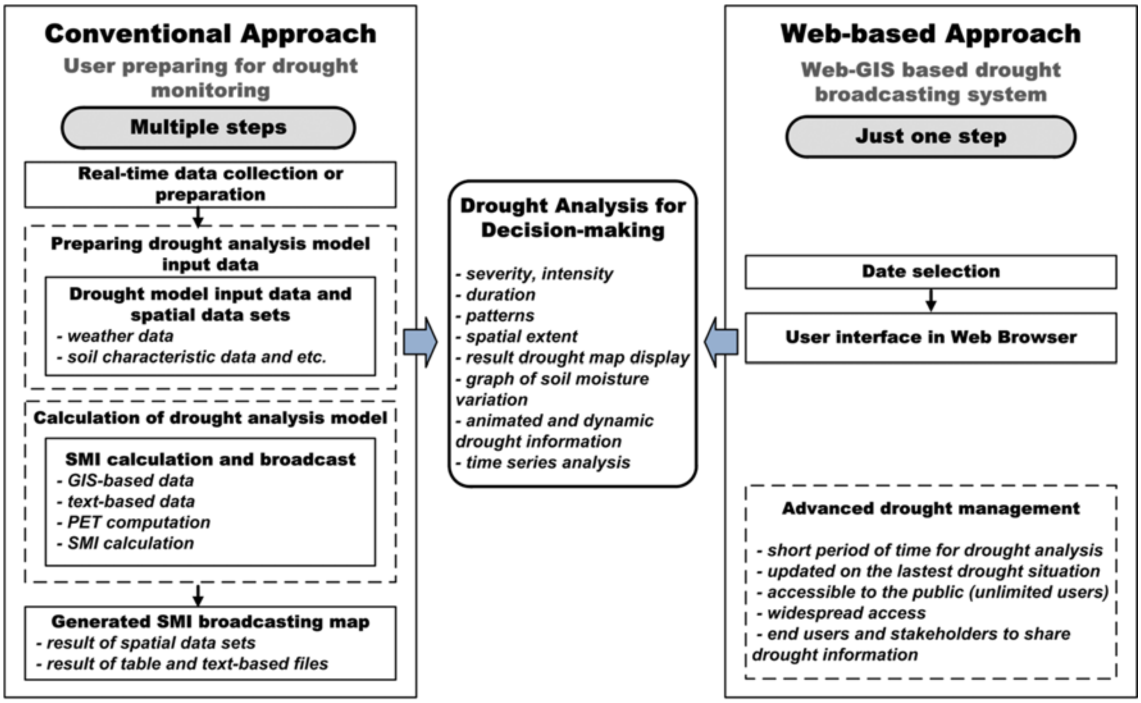

Fig. 6. Comparison of Drought Assessment Steps between Conventional and Web-Based Approach

Table 4. Comparison between Previous Drought Information Systems and Real-Time Online Drought Broadcast System for Drought Management

System	KICT (2004)	RRI (2006)	KMA (2008)	Nam *et al*. (2010)
drought index	SPI, PDSI, SWSI, precipitation	precipitation, reservoirs storage rate	SPI, PDSI, deciles	precipitation, Soil Moisture Index
drought classification	hydrological, meteorological	hydrological, meteorological	meteorological	agricultural
time interval	one month	ten days	one day	one day (real-time)
spatial resolution	dam watershed	si-do boundary	si-do boundary	watershed boundary
method of broadcasting	map, table	map	map	map, table, graph, query, animated time-series map
map scales	one scale	one scale	one scale	user map control
additional functions	-	-	-	layer selection, print map

logical and meteorological drought indices, but the system developed in this study provides real-time Soil Moisture Index for agricultural drought based on soil moisture modeling in a watershed. This web-based system contained a variety of functions for decision making including animated time-series drought map, graph of soil moisture variation, user map control, and print map. The improved performance of this web-based GIS that permits integrated handling of real-time weather data from KMA through the Internet and comparison to previous systems are shown in Table 4.

4. Conclusions

In agriculture, drought is a major natural hazard by reason of impact a large area, drought effects generally emerge gradually over a long period, and last for many years. Agricultural drought management in the past is based on meteorological observations and water supply, but decision-makers have required drought response operations that should be available and accessible for use in a short period of time and need to be updated on the latest drought situation, especially soil moisture conditions. Effective drought management can be achieved by monitoring current conditions and predicting future drought development. We developed a web-based drought broadcasting system that permits integrated handling of real-time soil moisture data from a monitoring network. The primary objective of a real-time online drought broadcasting system is to provide integrates drought evaluation using soil moisture condition and results transportation through the Internet to the users who are willing to know drought condition for drought management. This system is focused on drought broadcasting for current drought conditions using real-time weather data, and respond to drought events more effectively. Our web-based drought broadcasting system allows drought evaluation using soil moisture index in near real-time via the Internet. When we used our system to evaluate the drought in South Korea in 2009, the spatial and temporal features of the drought were recovered fairly accurately. The capabilities of our system are as follows; 1) It is accessed via a WWW graphical user interface, and users can analyze the status, intensity, duration, and spatial extent of a drought as well as its impacts, 2) It can provide a daily soil moisture index maps at the level of mid-range hydrologic units and is able to evaluate agricultural drought based on soil moisture changes, 3) It comprises a user-driven GUI that can support decision-makers, 4) It provides data related to current drought conditions to allow for comprehensive drought evaluation, and historical comparisons of the current drought event to past events. A web-based GIS can assist drought management agencies to improve the quality of their decision-making and increase efficiency and effectiveness in drought management due to the demand for interaction between decision-makers in the drought management, particularly during drought response. Future research plans include predicting drought conditions for effective drought management in terms of areal expansion and severity. A drought prediction requires weather data generation for the future, thus it could be suggested a system enhancement integrating with weather data generation system for effective drought response and preparation.

References

Allen, R. G., Pereira, L. S., Raes, D., and Smith, M. (1998). "Crop evapotranspiration: Guidelines for computing crop requirements." *FAO irrigation and drainage paper 56*, Food and Agriculture Organization of the United Nations, Rome, Italy.

Al-Sabhan, W., Mulligan, M., and Blackburn, G. A. (2003). "A real-time hydrological model for flood prediction using GIS and the WWW." *Computers, Environment and Urban Systems,* Vol. 27, pp. 9-32.

Bhuiyan, C., Singh, R. P., and Kogan, F. N. (2006). "Monitoring drought dynamics in the Aravalli region (India) using different indices based on ground and remote sensing data." *International Journal of Applied Earth Observation and Geoinformation*, Vol. 8, pp. 289-302.

Chang, Y. S. and Park, H. D. (2004). "Development of a web-based Geographic Information System for the management of borehole and geological data." *Computers & Geosciences*, Vol. 30, pp. 887-897.

Chio, J. Y., Engel, B. A., and Yoon, K. S. (2003). "GIS and web-based DSS for preliminary TMDL development." *Water Engineering Research*, Vol. 4, No. 1, pp. 19-30.

Choi, J. Y. and Engel, B. A. (2003). "Real-time watershed delineation system using Web-GIS." *Journal of Computing in Civil Engineering*, pp. 189-196.

Engel, B. A., Choi, J. Y., Harbor, J., and Pandey, S. (2003). "Web-based DSS for hydrologic impact evaluation of small watershed land use changes." *Computers and Electronics in Agriculture*, Vol. 39, pp. 241-249.

Ghulam, A., Qin, Q., Teyip, T., and Li, Z. (2007). "Modified Perpendicular Drought Index (MPDI): A real-time drought monitoring method." *ISPRS Journal of Photogrammetry and Remote Sensing*, Vol. 62, pp. 150-164.

Kim, O. K., Choi, J. Y., Jang, M. W., Yoo, S. H., Nam, W. H., Lee, J. H., and Noh, J. K. (2006). "Watershed scale drought assessment using soil moisture index." *Journal of the Korean Society of Agricultural Engineers*, Vol. 48, No. 6, pp. 3-13 (in Korean, with English abstract).

Komuscu, A. U. (1999). "Using the SPI to analyze spatial and temporal patterns of drought in Turkey." *Drought Network News*, Vol. 11, No 1, pp. 7-13.

Lohani, V. K. and Loganathan, G. V. (1997). "An early warning system for drought management using the Palmer Drought Index." *Journal of the American Water Resources Association*, Vol. 33, No. 6, pp. 1375-1386.

MapServer (2001). http://mapserver.org/.

Mendicino, G. and Versace, P. (2007). "Integrated drought watch system: A case study in Southern Italy." *Water Resources Management*, Vol. 21, pp. 1409-1428.

Narasimhan, B. and Srinivasan, R. (2004). "Development and evaluation of Soil Moisture Deficit Index (SMDI) and Evapotranspiration Deficit Index (ETDI) for agricultural drought monitoring." *Agricultural and Forest Meteorology*, Vol. 133, pp. 69-88.

Quiring, S. M. and Papakryiakou, T. N. (2003). "An evaluation of agricultural drought indices for the Canadian prairies." *Agricultural and Forest Meteorology*, Vol. 118, pp. 49-62.

Romanowicz, R., Beven, K., and Moore, R. (1993). "GIS and distributed hydrological models." *Geographical Information Handling-Research and Applications*, pp. 197-205, Chichester, UK: John Wiley & Sons.

Yevjevich, V. (1967). "An objective approach to definitions and investigations of continental hydrologic drought." *Hydrology Paper*, Vol. 23, Colorado State University, Fort Collins, Colo.

Zhu, X., McCosker, J., Dale, A. P., and Bischof, R. J. (2001). "Web-based decision support for regional vegetation management." *Computers, Environment and Urban Systems*, Vol. 25, pp. 605-627.