International Journal of Disaster Risk Reduction 21 (2017) 11–26

Contents lists available at ScienceDirect

International Journal of Disaster Risk Reduction

journal homepage: www.elsevier.com/locate/ijdrr

Development of flood alert application in Mushim stream watershed Korea

Muhammad Azam[a,*,1], Hyung San Kim[b], Seung Jin Maeng[a]

[a] Department of Rural and Agricultural Engineering, Chungbuk National University, Republic of Korea
[b] K-Water Research Institute, Republic of Korea

ARTICLE INFO

Keywords:
Natural disasters
Flash floods
Early flood warning system
HEC-HMS
Weather forecast
Mitigation measure
Flood hazard map

ABSTRACT

Korea repeatedly experiences flash floods and droughts that cause traumatic environmental conditions with huge economic impact. Recently due to climate change, the frequency and magnitude of natural disasters associated with extreme hydrologic events increased rapidly in Korea. Floods caused the greatest damage among all natural disasters. To prevent this damage it is important to inform people about ongoing and upcoming flash flood events to avoid the loss of life and property. In this study hardware and software based smart technology is used to develop an early flood warning system for Mushim stream watershed to send to end users early flood warning messages about potentially impacted areas. Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) is the core of flood alert application provides the forecast with sufficient lead time and decides the threshold conditions of runoff/stage. Short range weather forecasts from Korea Meteorological Administration (KMA) at every three hours interval, are stored in hydro-meteorological database and fed in HEC-HMS for identification of flood risks. Server-Client based program used to visualize the real time flood condition and to deliver the early warning message. The findings of this study are expected to be used as basic data required for designing of flood mitigation measures at Mushim stream watershed to cope with the flash flood events in future. The flood hazard maps thus developed will be useful to policy-makers and responsible authorities, as well as to local residents in finding suitable measures for reducing flood risk in the study area.

1. Introduction

Most countries in Asia facing the serious problem of flooding due to extreme weather conditions cause the significant economic damages and loss of livehood. A flash flood is generally defined as a rapid onset flood of short duration with a relatively high peak discharge. Or the flood that rises and falls quite rapidly with little or no advance warning, usually as the result of intense rainfall over a relatively small area [1]. A major distinction of a flash flood from a river flood is the short basin response time to rainfall that allows for very short lead time for detection, forecast and warning of a flash flood [2]. In Korea natural disasters are getting special attention because of increase in frequency of disasters. In July 1996 massive flood damages caused the collapse of a dam and flood embankments in northern Gyeonggi province suffered a huge loss of life and property. Particularly, highest recorded rainfall (870.5 mm) up to 24 h in August 2002 due to Typhoon Rusa in Gangneung area caused the urban flooding, and loss of life [3]. In 2010, the Seoul area experienced a heavy rainfall (259.2 mm) in one day with a maximum intensity of 98.7 mm/h damaged of 17,645 houses [3]. In 2011, there was a heavy rainfall (587.5 mm) in Seoul within three days having maximum intensity of 113 mm [3]. It brought severe flooding and land sliding in southern part of Seoul. September 2012 Cheongju City faced heavy rainfall at Mushim stream and bed of parking lot was almost submerged. The detailed description about the return period of the mushim stream is discussed in this article [4]. The repetitive occurrence of such disastrous floods emphasizes the investigation on expanding the technological infrastructure for flood prevention and protection.

Usually heavy rainfall is the major cause of flash floods but it can also occur from a dam break, a levee break, or even ice jams in rivers during the winter and spring months. Increase in urbanization is also creating the major problem of flash flooding. Impervious surfaces like concrete or compacted bare soils cause sudden contribution in runoff from heavy rainfall that can destroy roads and buildings very quickly. So the intensity of the rainfall event and spatial distribution of land cover largely affect the hydrologic response of the watershed. Therefore, flash floods should be analyzed at both spatial and temporal scales to compute exact response time of the watershed (time of concentration). Preventive measures such as the construction of dams, headworks or dykes, aimed at reducing the impact of floods. Although

---

* Corresponding author.
E-mail address: azam@chungbuk.ac.kr (M. Azam).

[1] Department of Agricultural and Rural Engineering, Chungbuk National University, 1 Chungdae-ro Seowon-Gu, Cheongju, Chungbuk 28644, Republic of Korea.

http://dx.doi.org/10.1016/j.ijdrr.2016.11.008
Received 12 July 2016; Received in revised form 14 November 2016; Accepted 14 November 2016

these measures may reduce the impact of floods or level destructions, it is unlikely that floods can ever be totally stopped. Furthermore, changing in climate and precipitation patterns also pose serious problems of flash flooding. Global warming is the major cause of climate changes and cause the intensification of the global water cycle with a consequent increase in flood risk [5]. However, the substantial natural variability and changes in streamflow trends makes the issue further complicated.

When preventive measures are not sufficient, flood damage can still be reduced by alerting communities for ongoing and upcoming floods. In development of flood alert system, warning lead time is very important. So greater the warning lead time, earlier the people will be aware about flood damage. An early flood alert system is an integrated package of data collection and transmission equipment, forecasting models, warning and human resources [1]. The number of avoidable and unnecessary deaths and property damage could be reduced with an effective warning lead time.

Flood hazard that lead to flood risk is defined as the probability of the occurrence of a flood event of a certain magnitude in a given area within a specific period of time [6]. In this study the flood hazard indicators are flood depth, flood duration, flood velocity, flood peak, the impulse of flood (product of water level multiplied by velocity), flood volume, the rate of the rise of floodwater levels, and flood warning time. Flood vulnerability is defined as the degree of damage caused by a hazard of a given magnitude for a specific element at risk (e.g. a stage-damage function) [6]. In general, the indicators of vulnerability cover loss potentials derived from the susceptibility of an individual or a community. In this study it includes houses, residential areas, farmlands, infrastructure, social structure and environmental surroundings, human health. However, vulnerability evaluation procedure (e.g., flood vulnerability index, social vulnerability index, and environmental vulnerability index) is beyond the scope of this manuscript. In this study the hazard indicators can be estimated using the hydrologic modeling of the floodplain.

The major technological infrastructure required for the flood warning system is operating system and hardware (for forecast center), application program (effectively collection, processing, analyses and display of earth observation data), redundancy and maintenance program (to ensure the data availability and processing capability at all the time) [1]. Flood alert application program usually has the following functions; 1) streamflow forecasting using rainfall data, water level data and remotely sensed topographic data of the watershed; 2) real time processing and storing of data; 3) checking the data for exceedance of threshold value; 4) determination of parameters using observed data; 5) display of analyzed and predicted water level information.

1.1. HEC-HMS hydrologic model

The main objective of flood forecasting system is to mitigate loss of life, property, and commerce by providing accurate warning with sufficient lead time to the users and emergency managers. Lead time depend upon the efficiency and forecast quality of the hydrologic model. In flood forecasting system forecasted hydrometeorological data are the sole bases for coupling meteorological forecasts with hydrologic model. Meteorological forecasting is accomplished using regional numerical weather prediction models. The detailed objective of flood warning system is 1) to detect and forecast the hazards and developing hazard warning messages 2) to assess potential risks and integrate risk information into warning messages 3) to disseminate timely, reliable, and understandable warning messages to authorities and at risk public 4) to community-based emergency planning, preparedness and training focused on eliciting an effective response to warnings to reduce potential impact on lives and livelihoods.

There are different kinds of hydrologic models available; their use varies according to the kind of results needed and availability of hydrological data. The deterministic models can be classified according to whether the model gives a lumped or distributed description of the considered area, and whether the description of the hydrological processes is empirical, conceptual, or more physically-based. Therefore, in modern days the hydrological models can be classified into empirical models, lumped conceptual models and distributed physically-based models. Out of these models empirical models need accurate rainfall and runoff data for calibration while distributed physically based models require a large amount of spatial and temporal data (e.g., topography, land use, land covers, type of soil, rainfall and flow monitoring data) to calculate the runoff for a given rainfall. Lumped conceptual models need moderately accurate rainfall and runoff data and average physical characteristics of the area concerned. Parameters of these models can be calibrated and verified with historical data available [7]. To separate the application of the hydrologic model to each sub-basin, the watershed is divided into sub-basins according to drainage network and other geospatial characteristics of the stream and watershed.

Modeling also can be event based or continuous. Event based calculations need initial conditions while continuous models need data of soil type to calculate soil moisture content and atmospheric data as well to calculate evaporation losses [7]. Event-based modeling studies basin characteristics (peak discharge, total runoff, and peak) by using initial conditions for rainfall events. For this case study we calculated the initial condition by SCS Curve Number method. This method uses initial abstraction and expresses the runoff potential in relation to initial condition of the soil permeability, land cover and basin area. The detailed description about the estimation of initial conditions is given in Section 2.3.

In this study HEC-HMS Model was selected for the runoff forecasting which play a key role in early flood warning. Program was developed by the US Army Corps of Engineers Hydrologic Engineering Center (HEC) and is the replacement for HEC-1 [8]. HEC-HMS improved upon the capability of HEC-1 and provides additional capabilities for distributed modeling and continuous simulation. Application of HEC-HMS and the accuracy of calibration and validation play an important role for the development of EFWS. HEC-HMS model is able to simulate precipitation-runoff and routing processes in both natural and controlled environment.

HEC-HMS is a relatively simple conceptual model and has successfully been implemented worldwide by many researchers [3,9]. It is good for simulation of peak flow as compared to Revitalised Flood Hydrograph (ReFH) model because of semi-distributed modeling concept [3]. ReFH is a rainfall-runoff model used for simulation of design flood events. ReFH rainfall runoff model has been used as a standard rainfall runoff model for UK flood estimation projects. It is known as a suitable model for rural catchments due to soil moisture accounting model which is based on natural hydrological process in natural catchments [3]. Ref. [10] investigated the performance of both semi-distributed model HEC-HMS and fully-distributed model Basin Pollution Calculation Center (BPCC) by simulating the rainfall runoff process at the mountain area and the results showed the slight difference between two models.

HEC-HMS is a mathematical model computes the runoff response the dendritic watershed considering the soil and land use pattern of watershed. It includes all necessary components of runoff such as loss, direct runoff, channel routing and baseflow.

1.1.1. Loss model

HEC-HMS consists of twelve loss models and rainfall-runoff process is performed after computing the volume of water that is intercepted, infiltrated, evaporated, or transpirated and then subtracting it from the total precipitation [7]. The SCS loss method is recommended and most widely used in Korea [3,11] and is also selected for this study.

1.1.2. Direct runoff model

Direct runoff is the transformation of excess precipitation into runoff. There are total seven transformation methods available in HEC-HMS [7]. In this study hydrologic simulation was performed using both Snyder's and Clark's unit hydrograph methods to select a better transformation method for the Mushim stream watershed.

1.1.3. Routing model

The routing is the method of transformation of all sub-basin hydrograph to combine hydrograph at outlet. HEC-HMS has the total of six routing methods, Muskingum and Muskingum-Cunge methods are widely implemented in Korea [3].

1.1.4. Baseflow model

Baseflow is the sum of temporarily stored runoff prior to precipitation and subsurface runoff from the current storm [7]. Out of six baseflow methods recession method is selected for this study. Recession method is recommended method for baseflow simulation as it has successfully applied previously in Korea [3].

1.2. Early flood warning system (EFWS)

EFWS has the capability to provide real-time and historical awareness of hydrometeorological conditions of the flash flood. Forecasted rainfall data is fed to HEC-HMS hydrologic model to forecast the flash flood. In order to accomplish this task robust communications between the hydrometeorological observation networks and the forecast center are crucial to the success of EFWS. Without the timely, reliable transmission of data from hydrometeorological observation to the forecaster (hydrologic model), it is not possible to assess and act upon flash flood threats. A forecast center requires a variety of hardware, software (including computer applications and programs), and communication capabilities to deliver warning messages to end users.

There are many types of EFWS developed according to the type of flood risk faced by the people and available technology infrastructure. The EFWS can be broadly classified into manual EFWS and automated EFWS. The manual EFWS is simplest and least expensive approach comprised of local data collection system, a community flood coordinator, a simple to use flood forecast procedure a communication network to distribute warnings, and a response plan. Flood forecasting procedure normally consists of tables, graphs, or charts that use forecasted rainfall and an index for flood potential to estimate a flood forecast [1]. Automated EFWS is comprised of automatic rainfall gauges, communication system, automated data collection and processing, microprocessor analysis and forecasting software [1]. Another Automated EFWS developed in Sacramento California-Nevada River Forecast Center named Automated Local Evaluation in Real Time (ALERT) that consists of automated event-reporting meteorological and hydrologic sensors, communications equipment, and computer software and hardware [1] available from: http://www.alertsystems.org. Furthermore U.S. National Weather Services (NWS) supports a computer software and network application Integrated Flood Observing and Warning System (IFLOWS) designed to assist state and local emergency services as well as NWS offices in detecting and managing flash flood events [12]available from: http://www.afws.net.

The European Flood Alert System (EFAS) is developed in 2002 by European Commission initiative to increase preparedness for riverine floods across Europe [13]. The hydrological model used for EFAS is LISFLOOD. The model is a hybrid between a conceptual and a physical rainfall-runoff model combined with a routing module in the river channel. This model is fed with several medium-range weather forecasts, including full sets of Ensemble Prediction System (EPS). The multi-streamflow output is analysed and visualised through concise and easy to understand way [13]. In this system early warning information is comprised through combined deterministic and probabilistic forecasts using EPS. It provides early flood warning information in all over Europe with lead time up to 10 days.

Flash floods are not simply caused by meteorological phenomena. It results when specific condition of meteorological and hydrological phenomena exists. Specific condition includes rapid water level rise in a stream or high peak discharge that can be triggered by a variety of events including intense rainfall, failure of natural (e.g., glacial lake debris) or manmade (e.g., dam, levee) structure [1]. So flash floods not only depends on amount and duration of rainfall but also on hydrologic characteristics of the watershed. Hydrologic characteristics of the watershed include the magnitude of runoff, antecedent moisture content condition, streamflow, drainage area, soil type, land use characteristics and topography of the watershed.

Flash Flood Guidance System (FFGS) consider the hydrologic characteristics of the watershed to give early warning information of flash flood. FFGS developed by Hydrologic Research Center (HRC) in collaboration with NWS and currently has number of regional FFGS projects established all over the world.

The system is based on the concept of Flash Flood Guidance which is the amount of rainfall of a given duration over a small stream basin needed to create minor flooding (bankfull) conditions at the outlet of the stream basin. For flash flood occurrence, durations up to six hours are evaluated and the stream basin areas are of such a size to allow reasonably accurate precipitation estimates from remotely sensed data. Flash Flood Threat is the amount of rainfall of a given duration in excess of the corresponding Flash Flood Guidance value. The Flash flood threat when used with existing or forecast rainfall then is an index that provides an indication of areas where flooding is imminent or occurring and where immediate action is or will be shortly needed [2].

Important technical elements of the FFGS are shown in Fig. 1. It is started with the development and use of a bias-corrected radar and/or satellite precipitation estimate field and the use of air temperature, spatial land cover and climatological characteristics in hydrologic modeling (snow model and soil moisture model). The key model components consist of Threshold Runoff Model (drainage network characteristics) that is computed once for each sub-basin. Estimated precipitation from several sources like satellites, radar as available, and gauges as available are input into a snow model which estimates snow water equivalent (SWE) and inputted into soil moisture accounting model (SAC-SMA) to estimate upper level soil moisture (soil water deficit). The Flash Flood Guidance (FFG) numerically estimate the rainfall and time duration needed to cross the threshold runoff to initiate the flooding. Threshold runoff is the fixed value computed according to the topography, streamflow characteristics and hydrologic characteristics of the watershed [2]. Rainfall-runoff model is required because rainfall-runoff relationship of the watershed keeps changing with the change in soil moisture condition due to recent rain or snowmelt shown in Fig. 1.

Korea Flash Flood Guidance (KoFFG) has also developed over the Han River basin. KoFFG consider all components of FFG (Threshhold runoff, soil moisture accounting and radar rainfall estimates) and composed of Regional Data Assimilation and Prediction System (RDAPS) to forecast a flash flood warning and watching [14].

The purpose of this study is to assemble several existing technologies operated using gauges and communication systems to develop a smart phone early flood alert application for Mushim stream watershed. It increases the lead time for watches and delivers the early warning message to the people at locations subject to flood risk. For early flood warning purposes, required runoff forecasting was accomplished by using Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) model. In addition, hourly rainfall data and basin parameters such as slope, area etc, are required for model calibration and validation that can be extracted from the GIS tool. Real time monitored precipitation data is transferred from rainfall station to KMA for the forecasts and then forecasted precipitation data is further saved in hydro-meteorological database of EFWS. Then forecasted precipitation data was converted into hydro-meteorological model

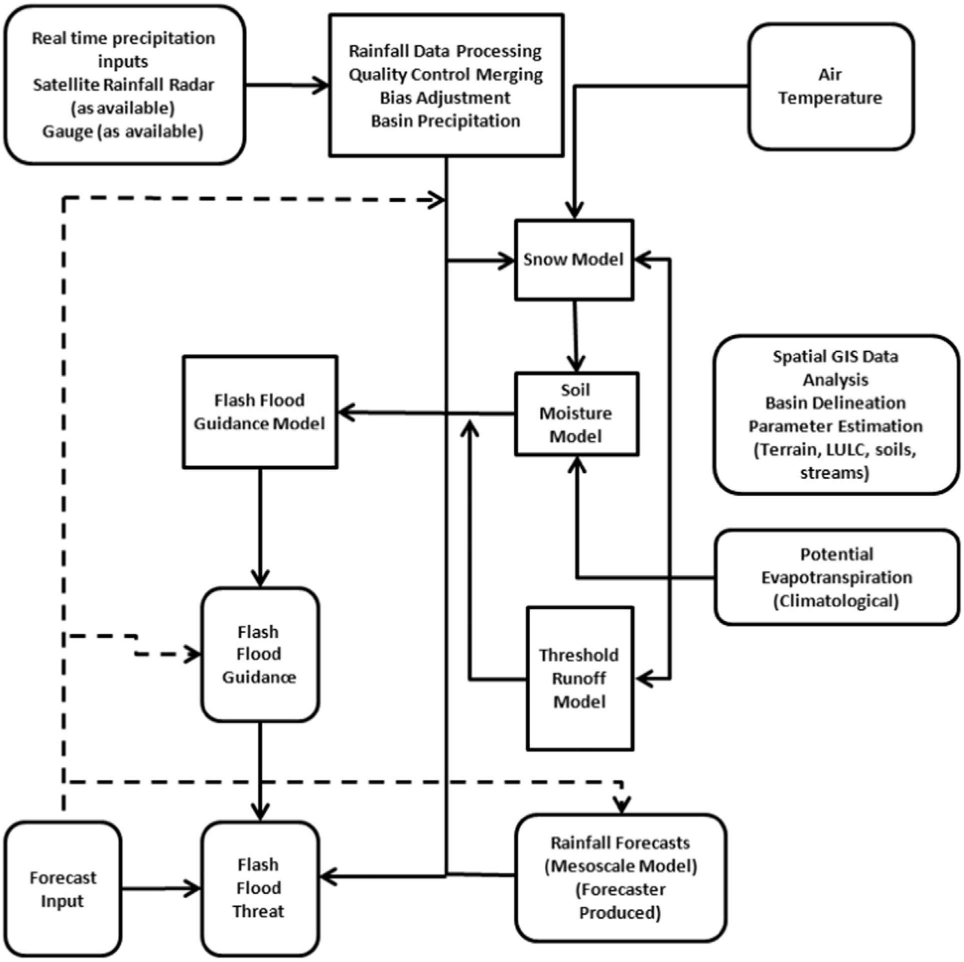


Fig. 1. FFG System configuration [2].

(HEC-HMS/HEC-1) input file format to forecast the runoff. Server-Socket-Client programming tools were used to deliver future predicted water level in the form of flood warning message to the people who has registered for flood alert application.

Following the introduction, the remaining parts of this paper are organized as follows. Section 2.1 presents the geological location of the study area. Section 2.2 introduces the methodologies adopted to determine the characteristics of watershed and estimation of areal rainfall. Section 2.3 presents the methods used to determine the parameters of HEC-HMS model. Section 2.4 discusses about the statistical criteria used for the calibration and validation of the model. Section 2.5 presents the structure of EFWS. Section 2.6 presents the overall procedure adopted in this study. Section 3 presents the results of sensitivity analysis, calibration and validation of the hydrologic model, designing of hydro-meteorological database and client-server program. Finally, the summary and conclusion is given in Section 4.

2. Material and methods

2.1. Study area

Mushim stream watershed is the sub-basin of Miho stream covering the upper side of Geum river basin and is located in Cheongju city at 127°28′E and 36°38′N containing the area of 163.5 km^2. Its topography consists mostly on hills and upland area consisted mostly on forest. It includes one water level station and four rainfall stations with two Cheongju rainfall stations [Cheongju 1 administered by Ministry of Land, Infrastructure and Transportation (MoLIT) and Cheongju 2 is administered by Korea Meteorological Administration (KMA)], Gadeok and Munui. Fig. 2 showed the location of Mushim stream on the standard watershed map of South Korea, location of rainfall stations and water level stations.

2.2. Application of HEC-GeoHMS

Hydrologic Engineering Center Geospatial Hydrologic Modeling system (HEC-GeoHMS) version 1.1 used before using HEC-HMS to calculate the initial parameters required for calibration and validation of HEC-HMS model. HEC-GeoHMS, the GIS extension coupled with ESRI's Arcview GIS program used as geospatial toolkit for hydrologists to compute the watershed characteristics and able to create input files required to run HEC-HMS model [15]. Primary hydrologic parameters derived through HEC-GeoHMS depend upon the array of elevation values so called Digital Elevation Model (DEM) (30 m×30 m). Before the delineation of the watershed DEM should be preprocessed to satisfy the surface drainage pattern. DEM preprocessing involves modifying the elevation data to be more consistent with the real stream. The detailed description is given in [15]. DEM data is downloaded from the website: www.wamis.go.kr. Major quantitative assessments of basic topographic configuration include slope, longest flow path, drainage lines, stream network. Watershed was delineated into several interconnected sub-basins using the grid based physical characteristics of stream and sub-basins shown in Fig. 3.

Forecast quality of hydrologic model depends largely upon the availability of rainfall data, parameter optimization and preprocessing methodology. For the pre-processing of rainfall data thiessen polygon method was selected because it assigns the relative weights to each gauge according to surrounded area of that gauge. Thiessen polygon

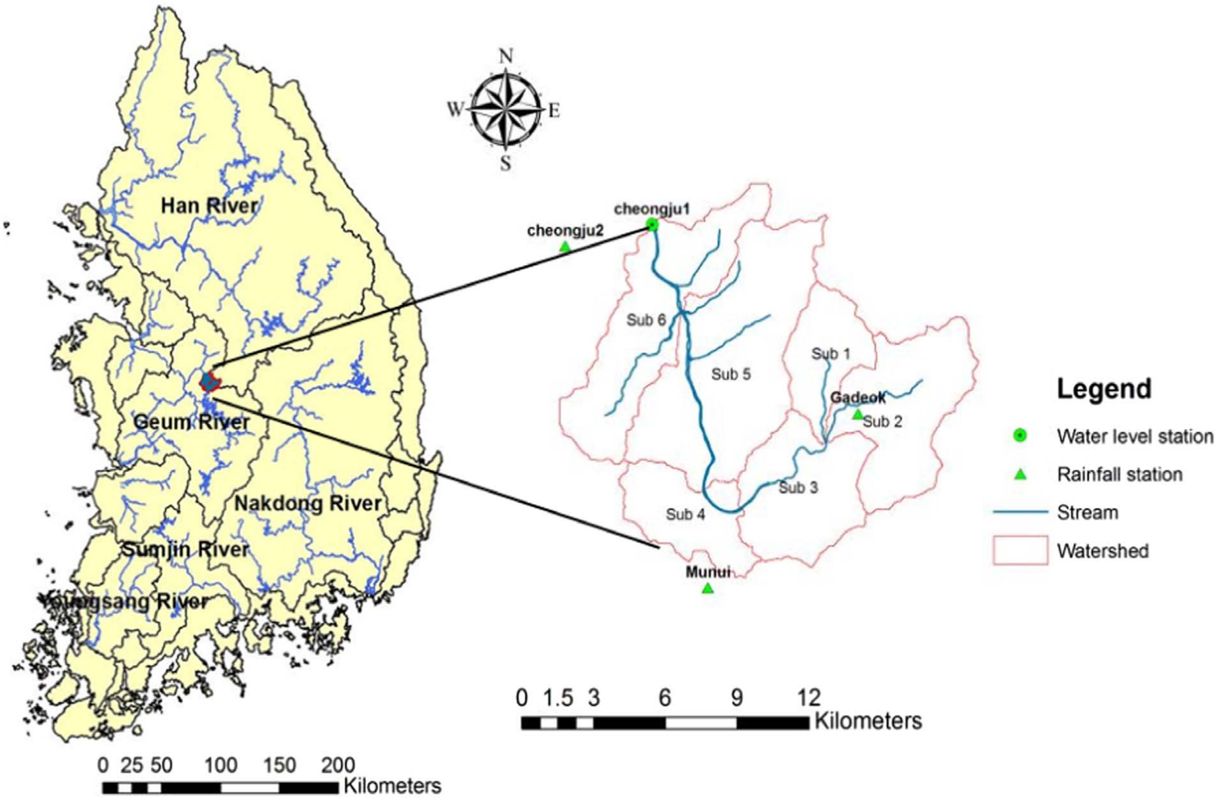


Fig. 2. Location of Mushim stream watershed.

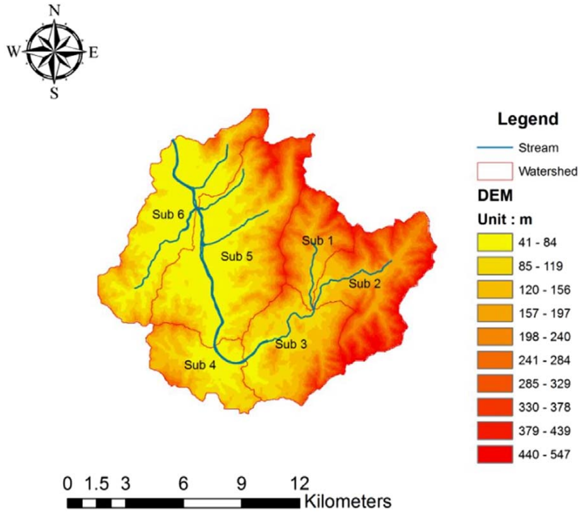


Fig. 3. Sub-basin delineation of Mushim stream watershed.

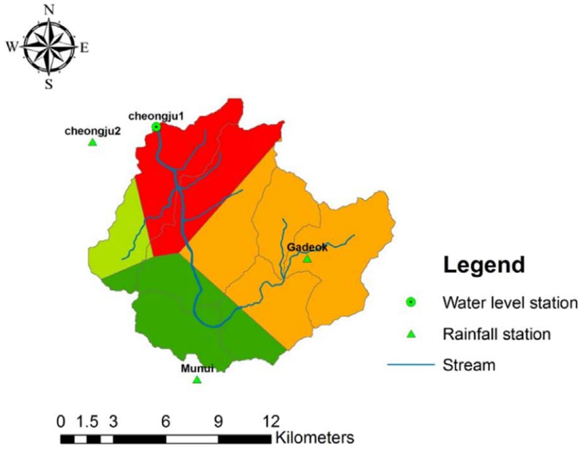


Fig. 4. Thiessen polygon method for Mushim stream watershed.

method is suitable for the larger watersheds having the area of more than 25.9 km^2 and where the gauges are less dense and non-uniformly distributed [16,17].

In our study Gadeok contains the maximum gauge weight as compared to other rainfall stations shown in Fig. 4 and Table 1 below.

HEC-HMS is an event based hydrological model that is able to simulate each rainfall events separately. HEC-HMS is able to compute runoff hydrographs for each sub-basin and also evaluates infiltration losses, transforms precipitation into runoff hydrographs, and routes hydrographs through open channel routing for each rainfall event. HEC-HMS model used hourly data of major rainfall events especially during major flood season (Jun–Aug) for multi-year simulation. To run the model observed discharge values corresponding to rainfall events were computed through rating curve approach for Cheongju water level station. Three years (2010–2012) hourly rainfall data recorded at four rainfall stations (Munui, Cheongju2, Gadeok and Cheongju1) used for calibration (2010–2011) and validation (2012) of the model shown in Table 2. Among total seventeen rainfall events six rainfall events were selected for development of hydrologic model. The summary of selected rainfall events is shown in Table 2.

2.3. Determination of parameters

The initial parameters needed for the calibration of HEC-HMS model are Time of Concentration (T_c), Storage-Coefficient (R), basin lag (t_p), Muskingum (K), Curve Number (CN), initial abstraction (Ia) and recession constant(RC). Initial parameters were calculated mostly by using the mathematical methods available in hydrologic text books. Initial values of parameters that are subject to automated calibration are required to start an optimization process. Generally T_c is calculated

Table 1
Watershed characteristics and thiessen rain gauge for each sub-basin.

Sub-basin	Area (km^2)	Slope (%)	Stream length (km)	Weight of rain gage (%)			
				Munui	Gadeok	Cheongju1	Cheongju2
Sub 1	13.6	25.12	5.7	–	100	–	–
Sub 2	27.7	28.74	8.2	–	100	–	–
Sub 3	24.1	17.21	5.7	33.72	66.28	–	–
Sub 4	15.5	12.33	2.1	100	–	–	–
Sub 5	48.9	16.48	8.7	19.93	38.36	41.15	0.56
Sub 6	33.7	11.25	10.8	6.54	–	62.51	30.95

Table 2
Selected rainfall events for this study.

Event ID	Starting time (dd/mm/yyyy, hh:mm)	Ending time (dd/mm/yyyy, hh:mm)	Duration (h)	Rainfall depth (mm)	MaximumIntensity (mm/h)
Calibration					
150810	15/08/2010, 00:00	16/08/2010, 04:00	28	70.6	27.4
100910	10/09/2010, 18:00	12/09/2010, 14:00	44	124	37.5
100711	10/07/2011, 00:00	11/07/2011, 21:00	45	97.6	14.7
090811	09/08/2011, 00:00	11/08/2011, 10:00	58	59.2	10.3
Validation					
150812	15/08/2012, 14:00	17/08/2012, 02:00	36	153.7	45.2
300812	30/08/2012, 01:00	30/08/2012, 21:00	20	94.3	10.5

Table 3
Formulas for calculation of T_c [17].

Formulas	Type	Application condition
Kirpich	$T_c=3.976\frac{L^{0.77}}{S^{0.385}}$	Suitable for agriculture farmland
Rziha	$T_c=0.833\frac{L}{S^{0.6}}$	Suitable for the river having upstream slope (S≥1/200)
Kraven (I)	$T_c=0.444\frac{L}{S^{0.515}}$	Suitable for the river having downstream slope (S < 1/200)
Kraven (II)	$T_c=16.667\frac{L}{V}$	Flow velocity vs. streamflow (S < 1/200: V=2.1 m/s, 1/200≤S≤1/100: V=3.0 m/s, S=1/100: V=3.5 m/s)

Table 4
Formulas used for calculation of storage coefficient [17].

Item	Type	Application condition
Russel	$K=\alpha T_c$	α: Urban area (1.1–2.1) Nature area (1.5–2.8) Forest area (8.0–12.0)
Sabol	$K = \frac{T_c}{1.46 - 0.0867\frac{L^2}{A}}$	–

by using TR-55 method. In TR-55 method T_c is defined as the ratio of flow length to flow velocity [18] however, in Korea because of the lack of reliability and availability of hydrological data, Kraven, Sabol, Rziha are the methods recommended by the guideline of flood estimation in Korea [3,17]. Each of the three equations used in calculation of T_c require the longest watercourse length in the watershed L, the average slope of that watercourse S and a coefficient representing the type of ground cover, A is the area of the watershed and α represent the developed catchment (Tables 3 and 4).

Other loss parameter is Ia includes losses related to soil and land cover parameters such as depression, vegetation interception, evaporation and infiltration [16]. Runoff started after the meeting of Ia and its value varies from storm to storm and watershed to watershed. Peaking coefficient was calculated using trial and error method of calibration. The model was calibrated by applying two different transform methods (Clark's and Snyder's unit hydrograph) in order to choose the better simulation approach for the Mushim stream watershed.

There are existing parameters calibration approaches such as parameter estimation (PEST) [19]. The PEST suite provides methods for exploration of pre- and post-calibration parameter uncertainty which do not require an assumption of model linearity. Initially model was calibrated using the automatic calibration technique of HEC-HMS. However, while adopting those approaches it is important to remember that all model input parameters must be kept within a realistic uncertainty ranges and that automatic procedure can hardly substitute for actual physical knowledge of the watershed. So we decided to adopt the sensitivity analysis method to know the realistic uncertainty ranges of the parameters by evaluating statistical significance. Modeler is able to judge the realistic ranges of the parameters by applying the physical knowledge of the watershed.

For CN method excess rainfall computed in HEC-HMS on hourly time step, divide the watersheds into natural small sub-basins and characterize by its focus on land management, soil properties and topographical characteristics. Runoff value increased with the increase in CN as its value 100 means all precipitation falling is participating in direct runoff. CN is recommended because it is empirical data supported, considers the LULC type and conditions (poor, fair and good), four hydrological soil groups and flexible method for the calculation of runoff. CN approach is used to assess the excess precipitation that was further divided into other components of rainfall-runoff processes such as initial abstraction, infiltration, baseflow, channel routing, soil moisture condition and evaporation. For a storm the direct runoff is P_e is excess precipitation, which is less than or equal to depth of total precipitation P; the depth of water retained when runoff begins F_a, is less than or equal to the maximum value of S, so potential runoff is $P - I_a$ [16]. The basis of the curve number method is the empirical relationship between the retention (rainfall not converted into runoff) and runoff properties of the watershed and the rainfall. The hypothesis of the U.S. Department of Agriculture Soil Conservation Service (USDA-SCS) CN method is that the ratio of actual retention in the watershed to the potential maximum retention is the same as the ratio of actual direct runoff to the potential maximum runoff [16].

$$\frac{F_a}{S} = \frac{P_e}{P - I_a} \tag{1}$$

From the continuity principle

$$P = P_e + I_a + F_a \tag{2}$$

Combining Eqs. (1) and (2) to solve P_e

$$P_e=\frac{(P-I_a)^2}{P-I_a+S} \tag{3}$$

Eq. (3) is the basic equation used for computing the depth of excess rainfall from a storm according to SCS method.

Results of recent studies showed that I_a value of $0.05S$ is better able to predict runoff as compared to the conventional value of $0.2S$ by SCS method [20,21]. In this study modified value of I_a is used and the empirical relationship is described as follows:

$$I_a=0.05S \tag{4}$$

On this basis

$$P_e=\frac{(P-0.05S)^2}{P+0.95S}\quad \text{for } P>0.05S \tag{5}$$

[22] Derived the relationship that is able to convert 0.20 based CN to 0.05 based CN using the rainfall data from 307 watersheds.

$$S_{0.05}=1.33S_{0.20}^{1.15} \tag{6}$$

Eq. (6) shows the relationship between $S_{0.05}$ and $S_{0.20}$. The basic definition of CN according to SCS method is CN = 1000/(10 + S), substituting the above value of $S_{0.05}$ to CN and simplifying gives

$$CN_{0.05}=\frac{100}{1.879\left[\frac{100}{CN_{0.20}}-1\right]^{1.15}+1} \tag{7}$$

A comparison between standard and modified Ia/S values showed that modified Ia/S value improved the agreement between measured and predicted direct runoff to a high degree [21]. Since CN value is the major parameter of hydrologic model to estimate the direct runoff, the modified method of CN calculation helped to improve the predictability of rainfall-runoff model in this study.

Soil data was used to characterize the parameters that deals with the hydrologic processes occur between earth and atmosphere such as infiltration rate and soil storage capacity. Soil map usually classified in four hydrological soil groups (A, B, C, D) based on infiltration rate of soil shown in Fig. 5 and Table 5. But soil group D does not exist because most of area consisted on forests and landscape having relatively higher infiltration rate.

Water Resource Management Information System (WAMIS) database served as basis of soil and land cover imageries data for the year 2000; available from: www.wamis.go.kr. WAMIS provide spatial and hydrologic data for water resource planning, management and monitoring. Land cover data is from the Landsat 7 (Enhanced Thematic Mapper), and having the resolution of 30×30. Land cover data of satellite imagery has unique code assigned to every pixel representing the spatial class of features such as field, paddy field, forest, meadow, wetland, fallow, residential districts and water shown in Fig. 6.

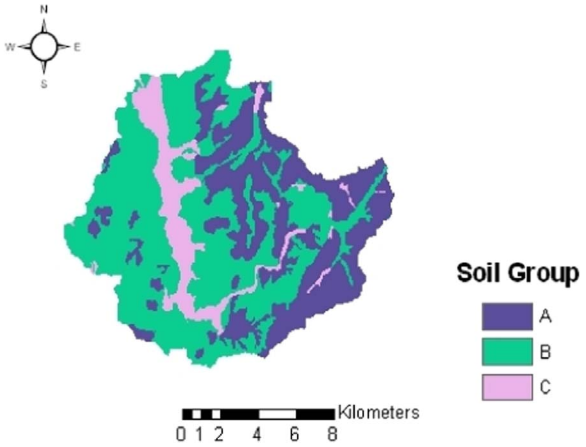


Fig. 5. Hydrologic soil group of Mushim stream.

Table 5
SCS soil groups and infiltration rates [7].

Soil group	Description	Infiltration loss rate (cm/h)
A	Deep sand, deep loss, aggregated silts	0.762–1.143
B	Shallow loess, sandy loam	0.381–0.762
C	Clay loams, shallow sandy loam, soils low in organic content, and soils usually high in clay	0.127–0.381
D	Soils that swell significantly when wet, heavy plastic clays, and certain saline soils	0.00–0.127

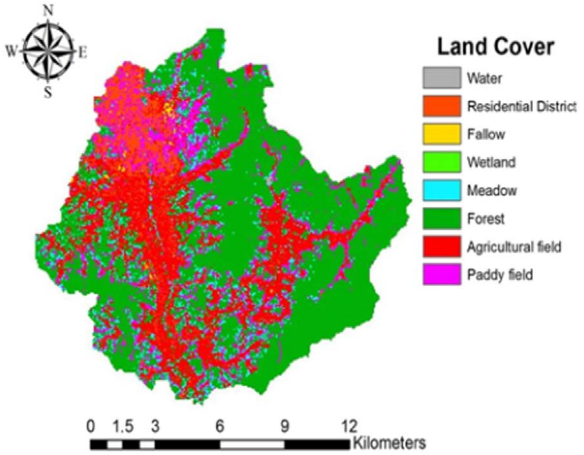


Fig. 6. 2000 year land use map of Mushim stream watershed.

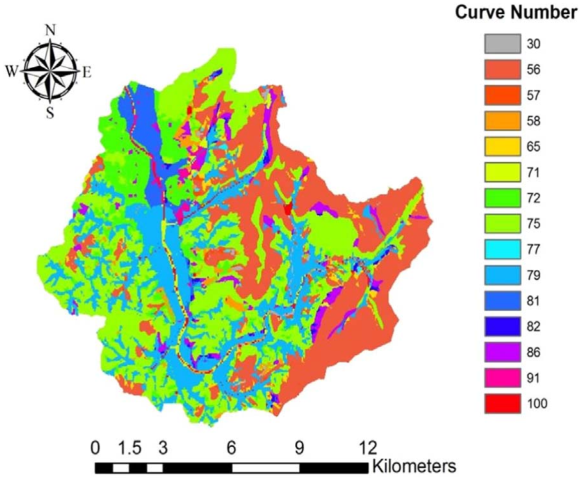


Fig. 7. Curve number map of Mushim stream watershed.

HEC-GeoHMS tool uses the spatial data layers of soil, land cover and topography to compute the hydrologic parameters of the watershed in two ways. Firstly, primary parameters that is the function of soil and topographical characteristics such as area, slope, soil group etc., derived from original data and used directly in rainfall-runoff model. Secondly, primary computed parameters used in conjunction with CN look-up table to drive the secondary watershed parameters such as CN, I_a, S etc., that are not available in original data (Fig. 7).

2.4. Statistical evaluation of model

Selection of basic performance criteria considered as a key element

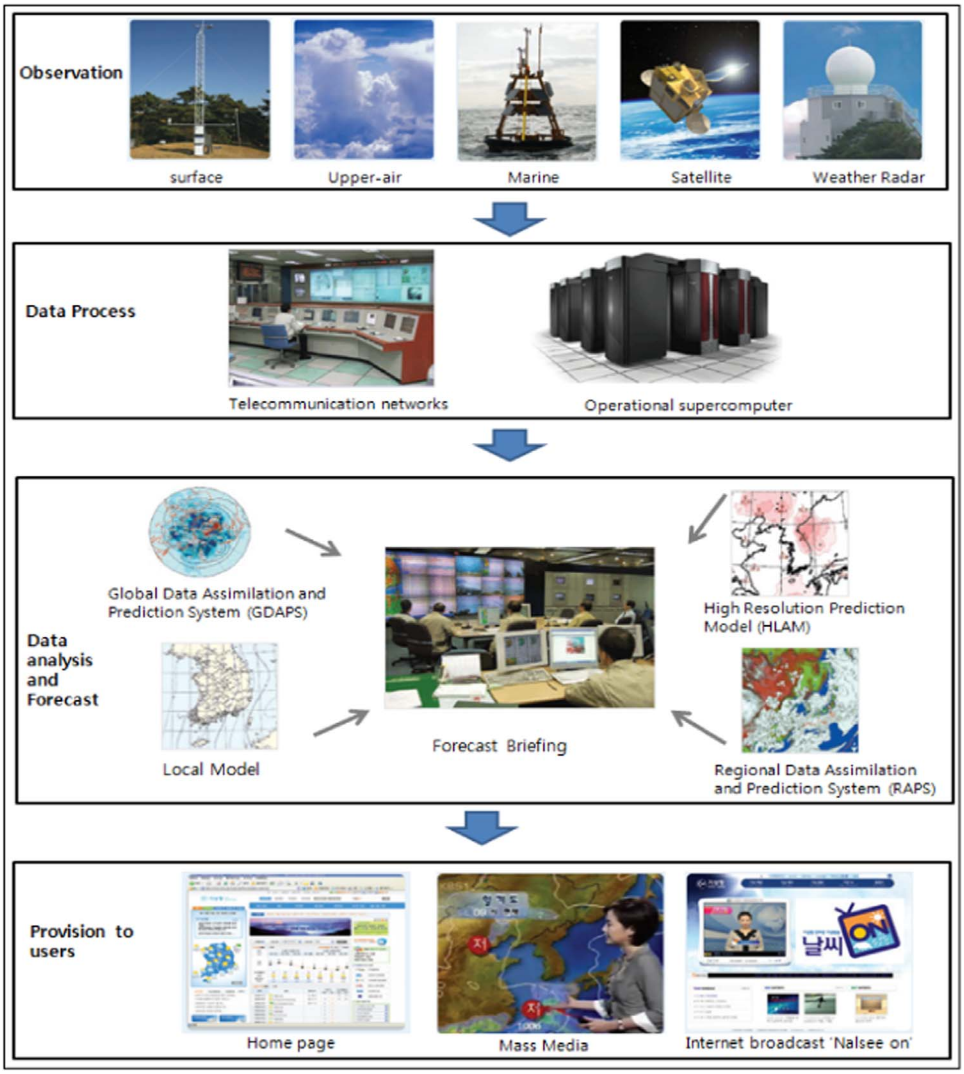


Fig. 8. Weather forecast process.

Table 6
Environment of flood alert application.

Server	
Operating system	Window 2003 Server
Database (DB)	MySql 5.6
Development tool	Microsoft Visual Studio Express 2012
Development language	C#, Asp.net 3.5
Client	
Operating system	Android series
OS version	Froyo 2.2 or higher
Database (DB)	Sqlite 3.0
Development tool	eclipse 4.3.1
Development language	Java

to handle problems such as the systematic divergence between modeled and observed values, and provide visual analysis to detect over-prediction bias, or under-prediction bias [23]. The observed baseline flow used for statistical evaluation of the model is derived from the rating curve approach. In order to ensure the stability of calibration and validation of the model baseline flow remain same during the statistical evaluation of the model. Nash-Sutcliffe Efficiency (NSE) index is potentially reliable statistic for assessing the goodness-of-fit of hydrologic model [24]. Implementation of NSE index for a wide variety of model types indicates its diversity as goodness-of-fit statistic [24]. Ref. [25] used this index for the calibration and validation of the parameters of lumped conceptual model. In this study NSE index used to analyzed goodness-of-fit between observed and simulated values shown in Eq. (8) below.

$$NSE{=}1-\frac{\sum_{i=1}^{N}(Q_{obs,i}-Q_{sim,i})^2}{\sum_{i=1}^{N}(Q_{obs,i}-\bar{Q}_{obs})^2} \tag{8}$$

$Q_{obs,i}$, $Q_{sim,i}$ are the i th observed and simulated discharges; $\bar{Q}_{obs}$=mean observed discharge; NSE value 1 indicates the perfect prediction of model. NSE method was selected because it is more sensitive to peak flows.

In addition model performance was evaluated using the Normalized Objective Function (NOF) shown in Eq. (9) [26]. NOF value 0 indicates perfect a prediction of the model. Percentage Error in Peak (PEP) [27] was also used for quantitative evaluation of the model.

$$NOF{=}\frac{1}{\bar{Q}_{obs}}\sqrt{\frac{1}{n}\sum_{i=1}^{n}(Q_{obs,i}-Q_{sim,i})^2} \tag{9}$$

$$PEP{=}\left(1-\frac{Q_{psim}}{Q_{pobs}}\right)\times 100 \tag{10}$$

Where PEP is the percentage error in peak, Q_{psim} is simulated peak discharge (m^3/s), Q_{Pobs} is observed peak discharge (m^3/s). Negative value indicates that the model has predicted more than observed values and vice versa.

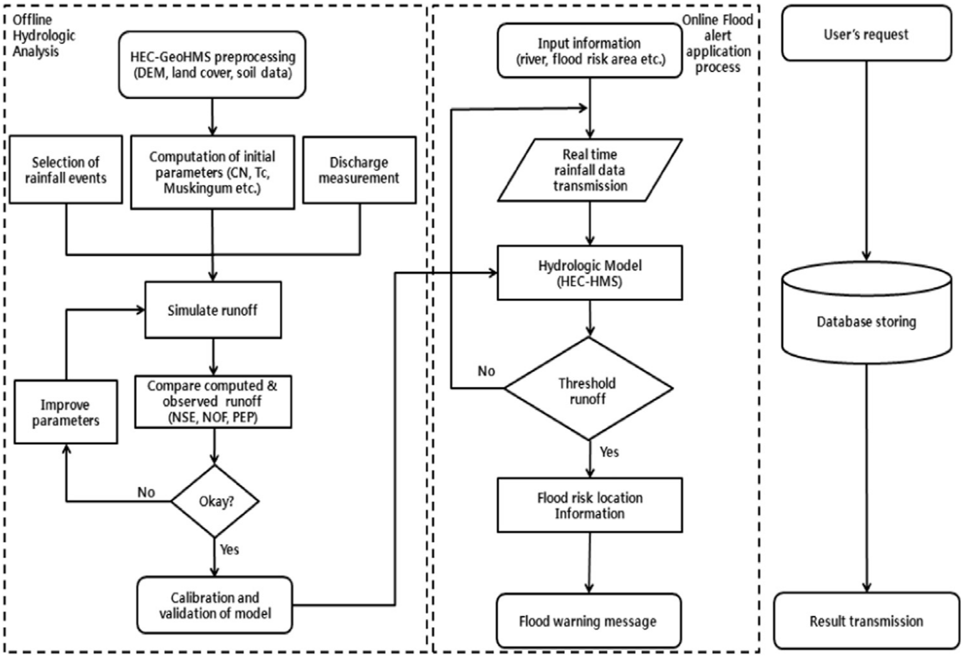


Fig. 9. Offline and online process of flood alert application development.

Table 7
Calibrated parameters for both Clark and Snyder unit hydrograph method.

Method	Clark unit hydrograph		Loss model		Base flow	Snyder unit hydrogphra
Sub-basin	Time of concentration (T_C)	Storage coefficient (R)	Initial abstraction (I_a)	Curve number (CN)	Recession constant	Lag time t_p (h)
Sub 1	0.5	6	1.2	66.90	0.06	0.3
Sub 2	0.6	6	1.2	65.48	0.15	0.12
Sub 3	0.5	4.67	0.2	71.51	0.05	0.6
Sub 4	0.2	3.93	0.2	76.59	0.06	0.54
Sub 5	1	3.87	0.2	63.88	0.26	0.3
Sub 6	0.9	3.71	0.1	76.28	0.14	0.36
Routing						
Reach no	Muskingum K (h)		Muskingum (X)			
1	0.31		0.2			
2	0.12		0.2			
3	0.47		0.2			
4	0.21		0.2			

2.5. System structure

In this study, we developed flood alert mobile application to provide timely and correct information for dangerous flash flood conditions, so that appropriate actions could be taken in advance to reduce the potentially affected risks. After the offline calibration and validation of the model then next step is the putting that hydrologic estimated parameters into real time KMA rainfall forecasting system to give warning to end users. For this system employs the use of advance sensing technology in performing real-time flash flood monitoring. Flood alert application is composed of three major components; 1) automated rain gauges for collection of rainfall and water level data, 2) processing and transmitting modules for transferring measured data to database and application server, 3) database and application server for allowing the users to view real-time water level condition and also able to send warning message to the users. Automated rain gauges installed by KMA served as basis for collection of water related information; available from: http://www.kma.go.kr. Water data is then further inputted in weather forecast Numerical Weather Prediction (NWP) models as preliminary information.

The current NWP system of the KMA shown in Fig. 8, mainly consist of the following models, Global Data Assimilation and Prediction System (GDAPS), Regional Data Assimilation and Prediction System (RDAPS), Local Data Assimilation and Prediction System (LDPS), Korea Weather and Research Forecasting model (KWRF), Korea Local Analysis and Prediction System (KLAPS) and various application systems derived from such systems. The specification of each model is as follows.

GDAPS consists of 25 km of horizontal resolution and it is used for 10day forecast and 72-h forecast with 2 h 25 min observation data cut-off [28]. GDAPS is used for short-range weather forecasts, weekly forecast as well as for the provision of lateral boundary conditions of the two short-range regional NWP systems for the East Asia domain. RDAPS and KWRF have the horizontal resolution of 12 km and 10 km respectively, and both are operated 4 times daily for 72 h forecast. LDPS is made up of 1.5 km horizontal resolution, runs 4 times daily to produce 24-h forecast with 3-hourly cycle. KLAPS consist of 5 km horizontal resolution and has been improved and operated for the public service of very short-range forecast. KLAPS is a local very short-range forecasting system runs every hour analyzing weather conditions around the Korean peninsula [28].

The NWP applies the physical formulas and dynamics, and

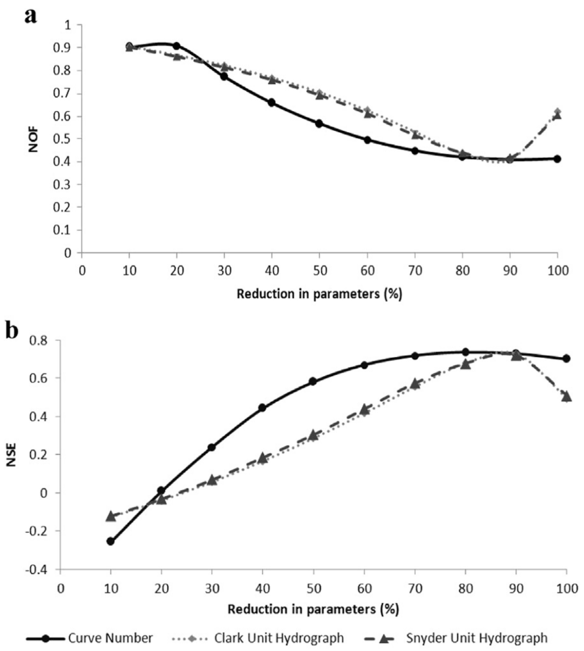


Fig. 10. Percentage reductions in parameters of Snyder's unit hydrograph method, Clark's nit hydrograph method and curve number, and corresponding sensitivity of a) NOF b) NSE.

Table 8
Statistical evaluation of calibrated Clark's unit hydrograph.

Event ID	Observed peak flow (m^3/s)	Simulated peak flow (m^3/s)	Runoff volume (mm)	Clark's unit hydrograph		
				NOF	NSE	PEP
150810	197.800	180.80	32.37	0.423	0.687	8.600
100910	194.100	215.60	72.91	0.535	0.675	−10.000
100711	131.100	109.10	48.65	0.413	0.387	−0.069
090811	111.000	100.10	26.97	0.384	0.822	9.900
150812	395.000	478.00	99.00	0.382	0.910	−21.000
300812	209.000	202.60	50.28	0.326	0.898	3.300

Table 9
Statistical evaluation of calibrated Snyder's unit hydrograph method.

Event ID	Observed peak flow (m^3/s)	Simulated peak flow (m^3/s)	Runoff volume (mm)	Snyder's unit hydrograph		
				NOF	NSE	PEP
150810	197.800	219.9	33.98	0.423	0.687	−11.173
100910	194.100	259.5	75.92	0.535	0.675	−33.694
100711	131.100	118.6	49.63	0.413	0.387	9.535
090811	111.000	117.6	27.36	0.432	0.775	−5.946
150812	395.000	584.9	101.49	0.382	0.910	−14.067
300812	209.000	238.4	51.8	0.326	0.898	4.414

monitors the atmospheric changes. Then data passed through the short range weather forecasts (every three hours interval) using NWP model. Finally weather forecasts are provided by various media to be easily available by the customers. The system is entirely automated with the real time short-range weather forecast precipitation data from KMA received and saved in hydro-meteorological database to give warning to end users. The detailed processing of weather forecasting in KMA is given in Fig. 8 below. The database is designed in such a way that it is capable of refine data according to time and region. Screening of KMA data is required because we need to collect only short range weather forecasts for the study area. The real time forecasted rainfall data from public portal in KMA should be transformed and saved in to database for flood alert mobile application. The current version of the flood alert application is implemented using PHP and JAVA as the web application and MySQL 5.6 as its relational database. Microsoft Visual Studio Express 2012 in C#, Asp.net 3.5 used for designing of server. Further detailed environment of Server-Client-Database system is given in Table 6.

2.6. *Study process*

In this study flood alert application was developed for the Mushim stream watershed to provide real time water level situation of the river and give early warning message to the people. These are the online and offline steps followed for the development of this application and the detailed development process is given in Fig. 9.

2.6.1. *Offline hydrologic analysis*

1. Preprocessing of DEM (30×30) by making it depression-less to develop hydrologically-correct DEM using Arc Hydro Tool 9 (GIS extension).
2. Watershed and subwatersheds was delineated after computation of flow direction, flow accumulation, and stream networks grids using HEC-GeoHMS 1.1 and Arc Hydro Tool 9. Hydrological parameters required for the calibration of HEC-HMS 3.4 were calculated using the grid based physical characteristics of stream and sub-basins.
3. CN value was computed by preprocessing and overlay analysis of land cover map, soil map, and DEM data in HEC-GeoHMS 1.1.
4. The physical parameters of the watershed (area, slope etc.) derived by HEC-GeoHMS 1.1 were imported in HEC-HMS for the further calibration and validation purposes.
5. Preprocessing of rainfall data after the calculation of areal rainfall using the Thiessen Polygon method, stream flow was computed using the rating curve for the year 2010, 2011 and 2012 at Cheongju rainfall station.
6. Model parameters were calibrated and validated for Snyder's and Clark's unit hydrograph method using three statistical evaluation criteria such as NSE, NOF and PEP.

2.6.2. *Online flood alert application*

1. Designing of Database (DB) by MySql 5.6 and server using Microsoft Visual Studio Express 2012 in C#. Asp.net 3.5 used for storing of the real time monitored and short-range weather forecasted rainfall data from the KMA. Data is then converted into input file format of calibrated hydro- meteorological Model (HEC-HMS 3.4) to predict the future water level.
2. Designing of android mobile application (Client program) using android application development tools (ADT, SDK and eclipse 4.3.1) in Java and connecting it with the server using socket to deliver flood alert message to customers at flood risk areas located at Mushim stream.

3. Results

3.1. *Calibration and validation of model*

In this study HEC-HMS model was calibrated and validated using the streamflow data collected at the outlet of the watershed. Model calibration is performed considering the geographic and hydrological characteristics of stream channel and watershed. Hydrologic characteristic continuously changes depending on gain and loss process. Soil moisture gains are from snow melt and rainfall while losses are from evaporation, runoff and infiltration. These loss and gain parameters are the main inputs of hydrologic model to compute the runoff. The main purpose of calibration and validation of the model is to decide the threshold runoff and simulate the runoff considering the changes in soil moisture (loss and gain) due to recent precipitation or snowmelts.

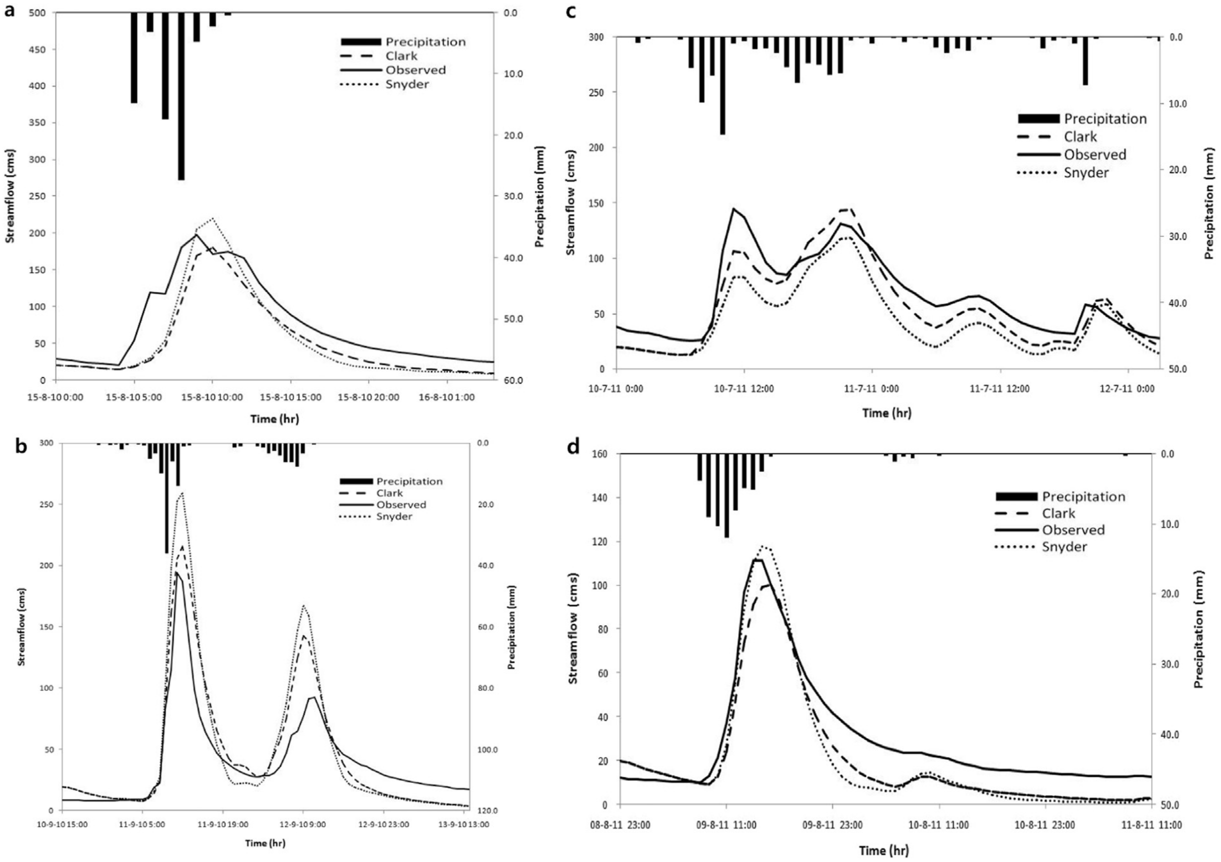


Fig. 11. Calibrated and observed hydrograph for Mushim stream watershed: a) 15th August 2010 b) 10th September 2010 c) 10th July 2011 d) 09th August 2011.

When calibrated model become the part of server-client based flood alert application then it is able to update real time soil moisture estimates.

Calibration processes was undertaken for HEC-HMS model to the Cheongju water level station that act as outlet for subsequent model run. WAMIS database served as basis to collect major rainfall events data from 2010 to 2012 for calibration and validation purpose. Major selected rainfall events lies between the May to September because Korea faced major flash floods during that period of the year.

Before the calibration of model sensitivity analysis was performed to enhance the forecast quality of hydrologic parameters that are further used to compute the runoff. Sensitivity analysis also helps to choose the suitable direct runoff method between Clark and Snyder's unit hydrograph. At 90% reduction in parameters both NOF and NSE showed the least value of objective function. Sensitivity analysis on the basis of two statistical evaluation criteria showed that CN=69.29, T_c=0.72, S=4.49 and t_p=0.35 can be used for further calibration of model. The final calibrated parameters according for each sub-basin is given in Table 7. NOF and NSE statistical evaluation criteria served as basis to perform sensitivity analysis between CN, Clark and Snyder unit hydrograph methods. Sensitivity analysis showed that with the every 10% reduction in CN value, the NOF and NSE values approached to their ideal conditions (0 and 1 respectively) shown in Fig. 10.

Mean values of NOF and NSE for six rainfall events corresponding to the different parameters for CN, Clark and Snyder's unit hydrograph is shown in Fig. 10. Hence NOF showed negative correlation and NSE showed the positive correlation with the every 10% reduction in parameters.

In case of Clark's and Snyder's unit hydrograph NOF value varies from 0.326 to 0.535 during the rainfall events of 30th August 2012 and 10th September 2010 respectively which shows the agreement between simulated and observed discharges are within acceptable limit. In Clark's unit hydrograph, the lowest value of PEP was – 21 during 15th August 2012 rainfall event and highest value is 9.9 during 9th August 2011, which showed variation of peak value is within acceptable limit. In Snyder's unit hydrograph, PEP ranges from 9.5 during 10th July 2011 to – 33.6 during 10th September 2010 rainfall event. Hence with a total of four rainfall events having the value less than zero showed the over-prediction bias of model.

During the calibration average of NSE and NOF for the Clark's unit hydrograph was 0.729 and 0.41 respectively (Table 8) and in case of Snyder's unit hydrograph these values are 0.722 and 0.42 respectively (Table 9). PEP also showed that the Clark's unit hydrograph fits better as compared to Snyder's unit hydrograph (Figs. 11 and 12).

Hence on the basis of three statistical evaluation criteria it is concluded that Clark's unit hydrograph method is a suitable transform method for the Mushim stream as compared to other Snyder's unit hydrograph method as it cause the over-prediction bias of flood with a relatively greater value of objective function.

Main goal of calibration of hydrologic model is to increase the forecast quality of real time flood. Hydrologic model play key role to increase flood warning (lead) time in flood alert application. With the increased lead time government official and the people can get enough time to reduce damage and to protect lives. Secondly, hydrologic model helps to decide runoff/stage threshold after inspecting the incoming rainfall and water level data from the KMA. Flood alert application identifies flood threats in an area when runoff/stage exceeds the defined Threshold value for that area.

3.2. Development of hydro-meteorological database

After the calibration and validation of the model then next step is the putting that hydrologic estimated parameters into real time flood forecasting system. The real time rainfall and water level data from the

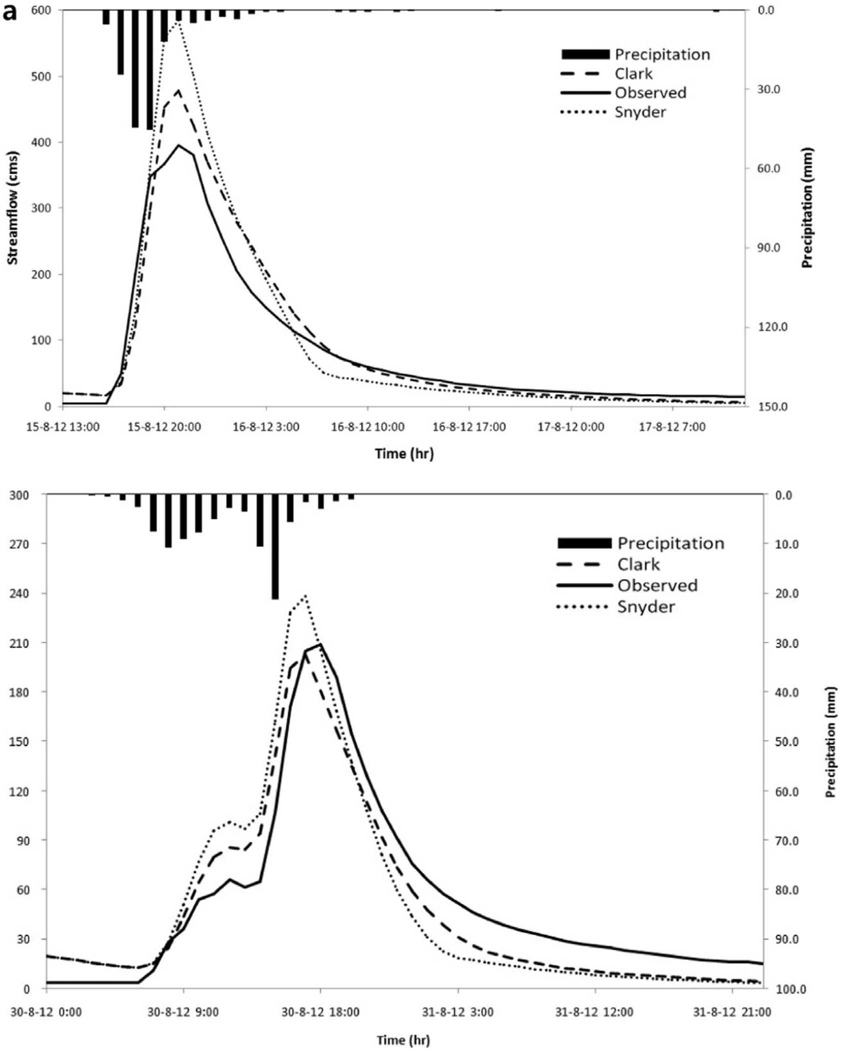


Fig. 12. Validated and observed hydrograph for Mushim stream watershed: a) 15th August 2012 b) 30th August 2012.

Table 10
Code values and categories of rainfall data.

Categories	Character string display	GRID stored value
Less than 0.1 mm	0 mm none	0
More than 0.1 mm less than 1 mm	Less than 1 mm	1
More than 1 mm less than 5 mm	1–4 mm	5
More than 5 mm less than 10 mm	5–9 mm	10
More than 10 mm less than 20 mm	10–19 mm	20
More than 20 mm less than 40 mm	20–39 mm	40
More than 40 mm less than 70 mm	40–69 mm	70
More than 70 mm	More than 70 mm	100

KMA stored in database for subsequent analysis, reporting and visualization. Flood threat recognition is accomplished after comparison of forecasted rainfall data to threshold. Threshold can be the elevation at which water will flow out of banks of the river and damage the property of the people or can be runoff.

Flood alert application automated in such a way that the software automatically detect and compare the incoming data from KMA to the threshold rules of flood risk recognition. For designing of database real time forecasted data from KMA should be refined according to time and region.

Refinement is needed because KMA has several kinds of weather forecasts such as short-, medium-, and long-range weather forecasts. In case of short-range weather forecasts all meteorological parameters (rainfall, temperature, wind, etc) are published, eight times in a day at three hours interval. Medium range forecasts published twice a day at twelve hours interval.

Long-range weather forecasts published three times a month. Only short-range weather forecasts are used for the development of flood alert application because; 1) unpredictable degree of uncertainty at long-range weather forecasts with longer lead time renders the results unreliable and therefore not useful for decision-making [29]; 2) it reflects the higher variation in rainfall fields due to the higher grid resolution. For this flood alert application KMA public data portal is highly usable because it provides the local forecasts with improved quality and forecast quality of the meteorological data.

In process of rainfall forecasting each rainfall category is stored in the form of grid and each grid represent the range of rainfall Table 10.

Total three steps are involved for the real time rainfall data to transfer from KMA to database of flood alert application. File structure, spatial distribution analysis of rainfall data and review of the input file format of hydro-meteorological models. To get the local forecasted data first we need to send the request message then response message will come, showing whether request can be fulfilled or not. Request message include the date, time and X, Y coordinates of the place whose forecasted data is required. Response message will be received

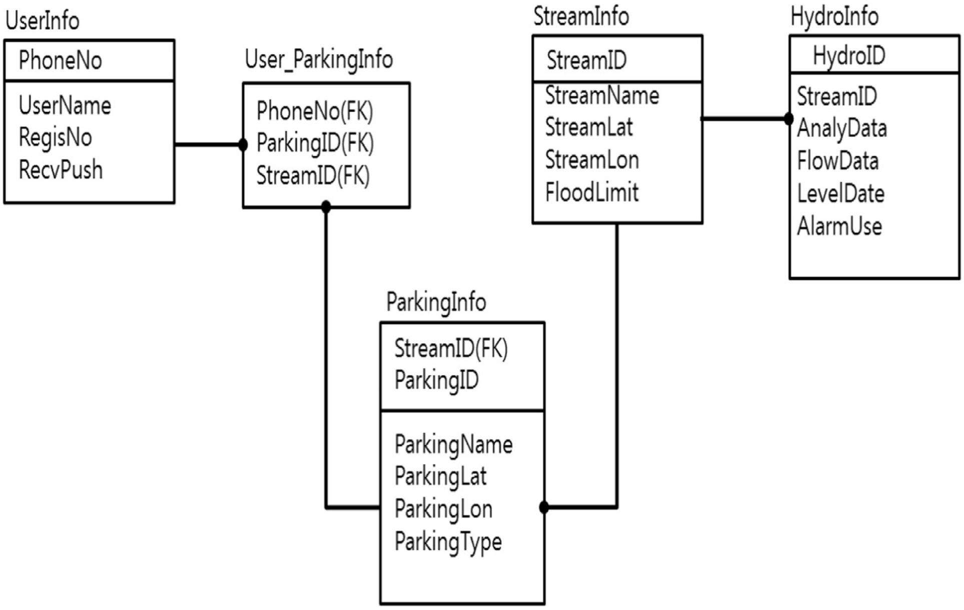


Fig. 13. Designing flow chart of data database.

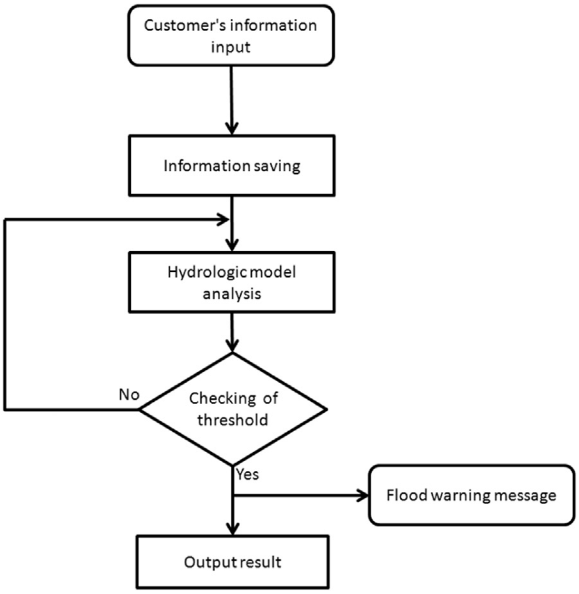


Fig. 14. Flow chart of client program.

on the basis of request message for the forecast (Figs. 13–17).

To get the real time information from the database the user has to enter the personal information such as user phone number, name etc., location information such as parking lot, stream etc., the place where user want to know the flood condition or level of flood risk. Then user is able to check the present and upcoming 3 h water level situation at these particular points of the stream (Fig. 18). Flood warning is provided to the user in two ways; 1) green, brown and red colors showing safe, caution and warning situation respectively (Figs. 17 and 18); 2) directly by sending the message to the users. Flow chart for the designing of database is given in Fig. 13 below.

3.3. Designing of client-server program

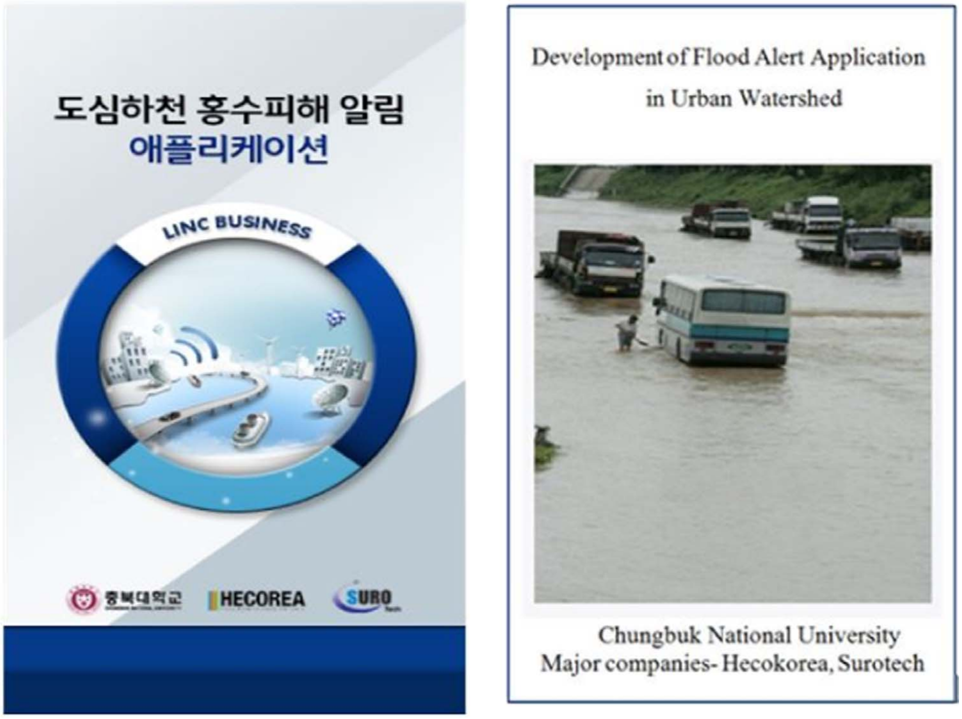
A client is a part of client-server model its operation relies on sending a request to another computer program. Server waits for potential clients to initiate connections that they may accept. Client and server connected via inter-process communication techniques. After getting the command from the customer to the client program then client program send that command to the server and server analyze the command after connecting with the database. Client program is constructed using Java programming environment. The programming tools such as Software Development Kit (SDK) and Java Development Kit (JDK) are used in eclipse 4.3.1 to develop android OS based client program. Fig. 14 showed the flow chart for the client program which saves the basic information of customers using the server and also used to deliver warning message.

Google Cloud Messaging (GCM) service for android used to send data from server to android application running on the target device of user and can also receive data from user using the same connection. GCM does not provide any built-in user interface but just simply transfer message received strait to the android application. It required the higher version of android 2.2 or google play store application or emulator running Android 2.2 with Google APIs. The newly developed Korean version and old developed English version of flood alert application both are shown in Figs. 15–18.

Membership page is designed for registration of new customers (Fig. 16). This will appear only for the first time entry then after this membership page will not appear during the opening of this flood alert application. So it is programmed in such a way that name, phone no, river, car park etc., were saved in DB once in a time.

Flood hazard map are made on the basis of android development method of Google map application named as Google Maps APIs. The three colors at the top shows the safe, caution, and warning situation in the map. So its color changed according the water level situation (Fig. 17). After the selection of appropriate location and name of the flood risk location then customers are able to check the water level situation from present to upcoming 3 h that whether it's safe, caution, or warning (Fig. 18). Warning and caution water level is decided according to threshold value of predicted water level. Threshold value is the maximum predicted water level after which the communities living in Mushim stream watershed are vulnerable to flood hazard. In this study threshold water level elevation used for the caution is 37.41 m and for the warning is 39.81 m. It gives the present and maximum predicted water level by applying the flood routing technique on the real-time rainfall forecasted data from the KMA. Basic customer's information can be adjusted using the setting option at the top right.

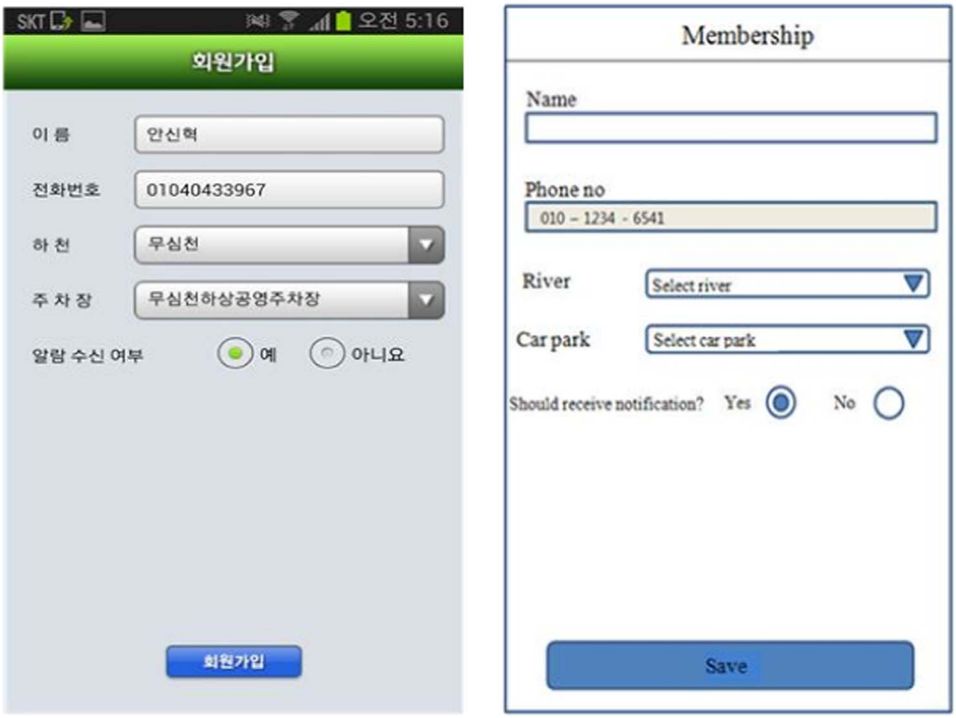
The flood alert application is developed under the joint project


도심하천 홍수피해 알림
애플리케이션

Development of Flood Alert Application
in Urban Watershed

Chungbuk National University
Major companies- Hecokorea, Surotech

Fig. 15. Main starting screens of flood alert application in Korean and English.



회원가입

이 름	안신혁
전화번호	01040433967
하 천	무심천
주 차 장	무심천하상공영주차장
알람 수신 여부	● 예 ○ 아니요

Membership

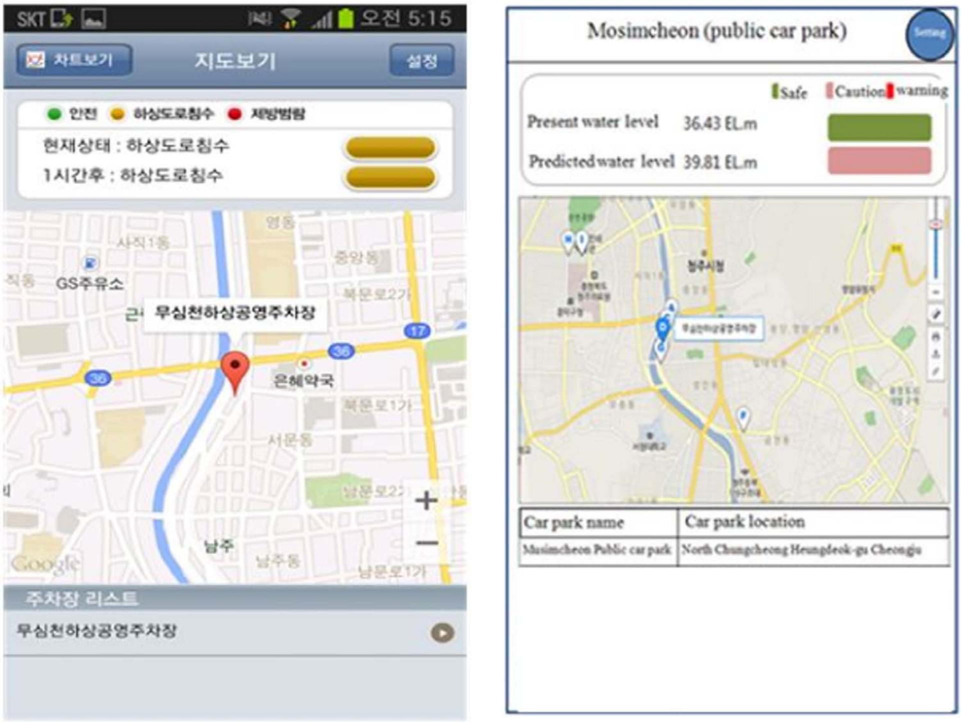
Name	
Phone no	010 – 1234 - 6541
River	Select river
Car park	Select car park
Should receive notification?	Yes ● No ○

Fig. 16. Membership window of application in Korean and English.

between Chungbuk National University and Surotech Cooperation Limited, Seoul (www.surotech.com). It is controlled and managed in Cheongju city. People can download that application directly from the Android Google Play Store. Output of this application is the prediction of water level from present to upcoming 3 h on basis of simulated discharge from the hydrologic model and also deliver warning message to the users.

4. Summary and conclusions

This paper attempted to develop the flood alert application to protect the property of the people living in Mushim stream watershed from flash flood disasters. Flood alert application is a flood disaster mitigation measure and gives flood warning based on river stage observation and rate of rise. It aims at providing early warning flood information for floods with lead-times up to 3 h by combining deterministic and probabilistic weather information. Flood alert appli-



현재상태 : 하상도로침수
1시간후 : 하상도로침수

주차장 리스트
무심천하상공영주차장

Mosimcheon (public car park)

Present water level 36.43 EL.m
Predicted water level 39.81 EL.m

Car park name	Car park location
Musimcheon Public car park	North Chungcheong Heungdeok-gu Cheongju

Fig. 17. Flood risk area locations map in Korean and English. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

현재상태 : 하상도로침수
1시간후 : 하상도로침수

주차장 리스트
무심천하상공영주차장

Mosimcheon (public car park)

Present water level 36.43 EL.m
Predicted water level 39.81 EL.m

Car park name	Location of car park
Musimcheon Public car park	North Chungcheong Heungdeok-gu Cheongju

Fig. 18. Real-time water level situation graph in Korean and English. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

cation development process passed through several stages, starting from the scientific feasibility study, followed by the need of the end-users, and finally the development of system and visualization.

Semi-distributed HEC-HMS rainfall-runoff model used for flood forecasting, play a key role to decide the lead time and runoff/stage threshold value in flood alert application. Therefore study also focused on stabilizing the calibration approach of HEC-HMS model by conducting sensitivity analysis of the hydrologic parameters. Model input parameters were computed using GIS tool in conjunction with topographic, soil data and classified land cover satellite imagery of the Mushim stream watershed. Model was calibrated and validated using both Clark's and Snyder's unit hydrograph to find the suitable direct runoff method that is able to simulate the hydrologic response reliably over the study area. To get real time rainfall data, short-range weather forecasts from KMA are refined according to time and region, and fed to the model. Hydro-meteorological database and server-client based program designed for subsequent analysis, reporting and visualization of flood condition by comparing the forecast data to threshold values to derive flood warnings. The predicted water level is analyzed and visualized through concise and easy to understand way with the indication of warning situations.

Sensitivity analysis performed on the basis of three statistical evaluation criteria showed that the HEC-HMS hydrologic model is more sensitive to the CN value over the study area. During the calibration process it is noted that Clark unit hydrograph is better able to simulate the flows with lesser value of objective function than the Snyder unit hydrograph method.

In flood alert application the coupling of prediction model increases the lead time but also faced the problem of uncertainty in the forecast. The errors in forecast quality may be because of uncertainty in hydrological data, potential data errors, improper optimization of parameters of the hydrological model and model mechanics (limitations in spatial and temporal resolution, etc.).

In future it is recommended to improve our hydro-meteorological database so that it could save the real time values to run the system retrospectively with the real archived forecast values to evaluate the flood alert warnings using well known verification scores (e.g., contingency scores such as Probability of Detection, Success Ratio, Critical Success Index). The KMA meteorological forecasts should be improved with shorter interval (less than 3 h) in order to maintain enough warning lead time for the very short and intense flash flood events.

In future, flood alert application expected to incorporate new weather forecast data (temperature, evaporation etc), particularly ensemble predictions with higher resolution and longer lead time with addition of more user friendly function according to user's feedback. In upcoming years it is expected to expand the technological infrastructure of flood alert application over the whole Korea with the improved meteorological forecasting from KMA.

Acknowledgment

This research was supported by a Grant (16RDRP-B066173-03) from Regional Development Research Program funded by Ministry of Land, Infrastructure and Transport of Korean Government.

References

[1] The University Corporation for Atmospheric Research, Flash flood early warning system reference guide, 2010. ⟨http://www.meted.ucar.edu/communities/hazwarnsys/ffewsrg/FF_EWS.pdf⟩.
[2] H.Division, Black Sea and Middle East Flash Flood Guidance System User Guide Head of Hydrometeorology Division, (n.d.).
[3] J. Joo, T. Kjeldsen, H.-J. Kim, H. Lee, A comparison of two event-based flood models (ReFH-rainfall runoff model and HEC-HMS) at two Korean catchments, Bukil and Jeungpyeong, KSCE J. Civ. Eng. 18 (2014) 330–343. http://dx.doi.org/10.1007/s12205-013-0348-3.
[4] H.L.H.Chang, E.Kim, G.Jeon, M.Azam, The change of flood according to dividing sub-basin at Mu-sim river, J. Inst. Constr. Technol., vol. 34, 2015, pp. 99–104. ⟨http://www.papersearch.net/view/detail.asp?Detail_key=46508316⟩ (accessed 07.11.16).
[5] P.C.D. Milly, R.T. Wetherald, K.A. Dunne, T.L. Delworth, Increasing risk of great floods in a changing climate, Nature 415 (2002) 514–517. http://dx.doi.org/10.1038/415514a.
[6] N.M. Dang, M.S. Babel, H.T. Luong, Evaluation of food risk parameters in the Day river flood diversion area, Red river delta, Vietnam, Nat. Hazards 56 (2011) 169–194. http://dx.doi.org/10.1007/s11069-010-9558-x.
[7] H. HMS, Hydrologic modeling system HEC-HMS technical reference manual, US Army Corps Eng. (2000) 155 (doi: CDP-74B).
[8] a.D. Feldman, HEC-1 flood hydrograph package, Comput. Models Watershed Hydrol. (1995) 119–150.
[9] D. Halwatura, M.M.M. Najim, Application of the HEC-HMS model for runoff simulation in a tropical catchment, Environ. Model. Softw. 46 (2013) 155–162. http://dx.doi.org/10.1016/j.envsoft.2013.03.006.
[10] H.L. Zhang, Y.J. Wang, Y.Q. Wang, D.X. Li, X.K. Wang, Quantitative comparison of semi- and fully-distributed hydrologic models in simulating flood hydrographs on a mountain watershed in southwest China, J. Hydrodyn. 25 (2013) 877–885. http://dx.doi.org/10.1016/S1001-6058(13)60436-9.
[11] S.-M. Kim, S.-J. Kim, S.-M. Kim, A comparative study of unit hydrograph models for flood runoff estimation for the streamflow stations in Namgang-Dam watershed, J. Korean Soc. Agric. Eng. 54 (2012) 65–74. http://dx.doi.org/10.5389/KSAE.2012.54.3.065.
[12] 2000-Thesis-Gayl-A-New-Real-time-Weather-Monitoring-and Flood Warning-Approach pdf.pdf, (n.d.).
[13] J. Thielen, J. Bartholmes, M.-H. Ramos, A. de Roo, The European flood alert system – Part 1: concept and development, Hydrol. Earth Syst. Sci. Discuss. 5 (2008) 257–287. http://dx.doi.org/10.5194/hessd-5-257-2008.
[14] D.-H. Bae, J.-H. Kim, Development of Korea flash flood guidance system: (I) theory and system design, J. Korean Soc. Civ. Eng. 27 (2007) 237–243.
[15] US Army Corps of Engineers (USACE-HEC), HEC-GeoHMS User's Manual, 2003, p. 281.
[16] V. Te Chow, D.R. Maidment, L.W. Mays, V.T. Chow, D.R. Maidment, L.W. Mays, Applied Hydrology, McGraw-Hill, New York, 1988.
[17] MLTM, The Estimation Method of Design Floods in Korea, Ministry of Land, Transport and Maritime Affairs, Sejong, Korea, 2012, (In Korean).
[18] NRCS, Urban Hydrology for Small Watersheds TR-55, USDA Natural Resource Conservation Service Conservation Engeneering Division Technical Release 55, 1986, p. 164.
[19] J. Doherty, Calibration and uncertainty analysis for complex environmental models, Water. Numer. Comput. (2015) ⟨https://scholar.google.com/scholar?cluster=12402867331864438764 & hl=en & oi=scholarr⟩.
[20] K.J. Lim, B.A. Engel, S. Muthukrishnan, J. Harbor, effects of initial abstraction and urbanization on estimated runoff using cn technology, J. Am. Water Resour. Assoc. 42 (2006) 629–643. http://dx.doi.org/10.1111/j.1752-1688.2006.tb04481.x.
[21] Z.-H. Shi, L.-D. Chen, N.-F. Fang, D.-F. Qin, C.-F. Cai, Research on the SCS-CN Initial Abstraction Ratio Using Rainfall-runoff Event Analysis in the Three Gorges Area, China, CATENA. 77, 2009, pp. 1–7. doi: http://dx.doi.org/10.1016/j.catena.2008.11.006http://dx.doi.org/10.1016/j.catena.2008.11.006.
[22] D.E.Woodward, R.H.Hawkins, R.Jiang, A.T.Hjelmfelt, Jr., J.A.Van Mullem, Q.D. Quan, Runoff curve number method: examination of the initial abstraction ratio, in: Proceedings of the World Water & Environmental Resources Congress 2003, American Society of Civil Engineers, Reston, VA, 2003, pp. 1–10. doi: ⟨http://dx.doi.org/10.1061/40685(2003)308http://dx.doi.org/10.1061/40685(2003)308⟩.
[23] N.D. Bennett, B.F.W. Croke, G. Guariso, J.H.A. Guillaume, S.H. Hamilton, A.J. Jakeman, S. Marsili-Libelli, L.T.H. Newham, J.P. Norton, C. Perrin, S.A. Pierce, B. Robson, R. Seppelt, A.A. Voinov, B.D. Fath, V. Andreassian, Characterising performance of environmental models, Environ. Model. Softw. 40 (2013) 1–20. http://dx.doi.org/10.1016/j.envsoft.2012.09.011.
[24] R.H. McCuen, Z. Knight, A.G. Cutter, Evaluation of the Nash–Sutcliffe efficiency index, J. Hydrol. Eng. 11 (2006) 597–602. http://dx.doi.org/10.1061/(ASCE)1084-0699(2006)11:6(597).
[25] R. Merz, G. Blöschl, Regionalisation of catchment model parameters, J. Hydrol. 287 (2004) 95–123. http://dx.doi.org/10.1016/j.jhydrol.2003.09.028.
[26] R. Ibbitt, T. O'Donnell, Designing Conceptual Catchment Models for Automatic Fitting Methods, IAHS Publication, UK, 1971 (accessed 11.07.16) ⟨http://hydrologie.org/redbooks/a100/101004.pdf⟩.
[27] A. Adib, M. Salarijazi, M. Shooshtari, Comparison between characteristics of geomorphoclimatic instantaneous unit hydrograph be produced by GcIUH based Clark model and Clark IUH model, J. Mar. (2011) ⟨http://www.airitilibrary.com/Publication/alDetailedMesh?docid=10232796-201104-201105130010-201105130010-201-209⟩ (accessed 11.07.16).
[28] Korea Meteorological Administration (KMA), Annual Report 2011, 2011. ⟨http://web.kma.go.kr/download_01/Annual_Report_2011.pdf⟩.
[29] D. Demeritt, H. Cloke, F. Pappenberger, J. Thielen, J. Bartholmes, M.-H. Ramos, Ensemble predictions and perceptions of risk, uncertainty, and error in flood forecasting, Environ. Hazards 7 (2007) 115–127. http://dx.doi.org/10.1016/j.envhaz.2007.05.001.