Hydrological Radar Network Simulation Model Considering Effective Flood Management and Control

Shin, Hyun-Suk
Assistant Prof., Dept. of Civil. Engrg., Pusan National University, Pusan, Korea

Yoon, Kang Hoon
Senior Researcher, Korea Institute of Construction and Technology, Kyungki Province, Korea

ABSTRACT: Weather Radar have played an important role in both precipitation observation and hydrological operations over several countries and evaluated its efficient and necessities for the developed flood management and control. This paper describe the factors influencing the design the hydrological radar network in Korea and develop Hydrological Radar Network Simulation Model (HRNSM) based on GIS and UI system. Moreover, the methodologies for geographical and hydrological feasibility analysis for radar network were provided in detail manner.

1 INTRODUCTION

Rainfall radar is intended to measure quantitatively the rainfall intensity by using radar. The main advantage of using radar for precipitation estimation is that the measurements can be performed over large spatial area with fairly high temporal and spatial resolution and spatial coverage. In addition, using radar rainfall information can predict the movement of local storm area that can help to improve the flood control efficiency. Therefore the radar rainfall information may be very valuable for several aspects related with flood control such as mountain and urban flash flood control, erosion control, quantitative precipitation forecasting, optimal dam operation, and flood warning system. The weather radar networks have been constructed in several countries such as NEXRAD in USA, Radar Raingage Network in Japan, Weather Radar Network in Germany, etc, and have been evaluated as one of necessary equipments to improve rainfall forecasting and also flood control tasks.

In Korean system, the Water Resources Bureau, Ministry of Construction and Transportation have been charged on the responsibility for the dam operation for flood-control as well as appropriate flood warning activity including providing accurate flood-related information. In most years, flooding at rivers, mountains, and urban areas have caused more deaths and economic damages than any other meteorological disaster in Korea, which indicate the necessity of more advanced flood control system. Therefore, the optimal design of hydrological radar network considering and concentrating on the purpose of both flood control and management have been of important for hydrologists and flood managers, instead of meteorological-purposed radar network.

In this study, we concentrate on solving two questions. One is "what is the definition and concepts of optimal hydrological radar networks considering the flood control over Korea", and another is " how we can develop the automatic and computational radar simulator to design Hydrological Radar Simulation Model (HRSM)".

2. HYDROLOGICAL RADAR FOR FLOOD CONTROL AND MANAGEMENT

For the purpose of flood control and management, the Korean government established the Korean Flood Monitoring and Warning System (KFMWS) for five major rivers such as Han River

Nackdong River, Keum River, Sumjin River, and Youngsan River since 1987, and expanded the system for the flood control of several secondary rivers recendly. Figure 1. (a) shows the local flood control offices of KFMWS and (b) show the main flood control screen installed in Nackdong Flood Control Office. Moreover (c) describe the details of the system in terms of subsystems such as data analysis, flood control, and flood warning etc. The current system has been concentrated mainly on the control of river flood. Now a day, it is tend that the major reason of flood damages over Korea have been caused by local heavy storm, mud flow intrusion and flash flood in both urban and regional scale. Figure 2 shows the concept of the future KFMWS including rainfall radar network and other local flood schemes.

Table 1. Description of Ground Rainfall Gauge Networks in South Korea (1999 Year)

Rivers	MOCT			KOWACO			KMA	KAA	TOTAL		
	TM	SR	Total	TM	SR	Total	SR	SR	TM	SR	Total
HR	50	55	105	50	0	50	11	0	100	66	166
NR	66	50	116	40	0	40	13	1	106	64	170
KR	27	26	53	26	0	26	7	5	53	38	91
SR	13	5	18	10	0	10	4	-	23	9	32
YR	14	0	14	0	0	0	2	-	14	2	16
Others	31	33	64	0	0	0	36	3	31	72	103
Total	201	169	370	126	0	126	73	9	327	251	578

c.f) HR : Han River, NR : Nackdong River, KR : Keum River, SR : Sumjin River, YR : Youngsan River
MOCT : Ministry of Construction and Transportation,
KOWACO : Korea Water Resources Cooperation,
KMA : Korea Meteorological Agency, KAA : Korea Agricultural Agency,
TM : Telemetering Rain Gauge, SR : Self-Recording Rain Gauge

The KMOCT has been installing ground-telemetering (TM) rain gage networks over the country for many years. Table 1 describes the current status of the ground rain gages in terms of operational agencies and watersheds in Korea. The total number of TM rain gages which are used for KFMWS is about 327 and the density of TM rain gage is about 271 km^2 per one gage as indicated in Table 2. This shows that it is still difficult to obtain the accurate real-time rainfall information based on the current system and also most impossible to capture the rainfall movement and spatial variation, which result in the weak feature for flood control specially for local mountainous and urban area. In these difficulties, the design of rainfall or hydrological radar system has been needed to observe the accurate rainfall and help the real-time operational flood control.

Table 2. TM Rainfall Gauge Density Operated by MOCT and KOWACO

	Total Number of gauges	Number of TM gauges (1)	Watershed Area (km2) (2)	TM Density (2) / (1) (km2)
HR	166	100	26018 (34473)	260.2
NR	170	106	23817	225
KR	91	53	9810	185
SR	32	23	4897	213
YR	16	14	3371	240
Others	103	31	20832	672
Korea	578	327	88748	271

The current weather-oriented radar sites can be described as multi-purposed weather observation, site location near the coast with the aim of covering marine area, large mesh grid, and CAPPI observation etc. Otherwise, the hydrological radar network should consider object-oriented (rainfall and flood related observation) observation, coverage over the object watershed and river including mountain and urban area, and higher spatial resolution and shorter operation time interval. Therefore, we define the following primary guideline for the design of hydrological radar network, which may consider Korean situation of geography and flood situation.

(1) HRN should cover effectively the overall Korean and also flood control watersheds.
(2) Because of high variation of Korean geography, the effective radar range should be considered in both meteorological and hydrological aspects.
(3) For the safe flood control, HRN should consider the effective overlapping scenarios in the system.
(4) HRN should consider the effective coverage of major cities and the flood-damaged region.
(5) The radar hardware should be considered in terms of both accurate rainfall estimation and flood control.
(6) The proposed site should be possible to install suitable facilities such as road, building, and electric power etc.

Considering above items to design HRN may be very difficult job in terms of geographical variability and situation. Therefore, we decided to develop Hydrological Radar Network Simulation Model (HRNSM), which can link and implement complex meteorological, geographical, and hydrological information in a system and can simulate various scenarios for HRN in Korea.

3. DEVELOPMENT OF HRNSM

Before coding and modeling the proposed Hydrological Radar Network Simulation Model (HRNSM), the factors to be considered in radar network modeling are defined as described in Table 3. The major factors are categorized in three items such as geographical factor, flood management factor, and site feasibility factor, and each factor is also described in several elements. Because of the main purpose of radar networking which is flood control, several aspects such as population (flood death), economic density, historical flood damage area, and meteorological heavy storm region should be considered in model design, as well as geographical factors such as horizon, scan schedule, site location and height, blockage, watershed occupation, etc.

Moreover, each factor should be double-checked in design process as shown in Figure 3. At first, one may select arbitrary networks with several radars, and then geophysical factors are checked to meet the network purpose. If the geophysical analysis is satisfied, the flood management feasibility of the network is checked. Finally, based on the real site investigation, the site feasibility including road vicinity and electric power possibility are considered to finalize the optimal radar network for flood control. In doing this, we used GIS technique to construct several base maps such as DEM, Watershed boundary map, major mountain location, population density, economic density, flood damage density, and flood rainfall index map in spatial modeling process as shown in Figure 4.

Finally, we developed HRNSM including most of above items and necessities, and summarized the schematic structure of HRNSM as in Table 4. HRNSN is divided in three major screens such as main analysis screen (MAS), geographical feasibility analysis screen (GFAS) and flood management feasibility analysis screen(FMFS). In main screen, the detail information of the proposed radar network such as location, radar range, beam trajectory angel, and antenna information is provided in either manual or graphical ways. Table 4. and Figure 5. (a) show MAS and its sample output. Then, the radar simulation will be performed and the related primary results such as radar network scheme, radar overlapping, and radar blockage map are displayed in main screen. Then, one should get in GFAS step. Several results such as radar beam simulation map, radar beam profile (propagation) map, radar occultation result table (blockage %), radar watershed coverage result table, radar overlapping percentage result map are made for both each installed radar and radar network as in Figure 5 (b).

Table 3. Factors Influencing Hydrological Radar Network Design

MAJOR FACTORS	ELEMENTS	DATA NEEDED
Geographical Factor	Radar Horizonal Coverage Ground Clutter Occultation (Blockage)	DEM
	Watershed Occupation	Watershed boundary map River network map
Flood Management Factor	Population Density Index	Population density map
	Economic Density Index	Regional facility price map
	Flood Damage Index	Regional historical flood damage cost map
	Probabilistic Flood Rainfall Index	Flood rainfall map with 100 yr return period
Site Feasibility Factor	Road vicinity Civil work	By site investigation
	Electric and electronic Interference	Investigation of other electric facilities at site

After finishing GFAS step, one can check the results of flood management feasibility analysis (FMFA) as shown in Figure 5. (c) and (d). In FMFA step, the maps and computational results of four flood indices such as population density index (%), economic density index (%), flood damage severity index (%), flood rainfall index (%), and flood management feasibility index (%) are calculated for each radar in each watershed basis as well as overall Korea. This result may help to decide the feasibility of radar networking in terms of flood management and control. As described in Figure 3., GFA and FMFA steps are performed iteratively to meet the optimal goal of radar network design. Actually, the radar network scheme including the numbers and locations, the radar types, the operational radar ranges, observation schedules may depend on various situations considering hydrometeorological aspects as well as country budget. Therefore, the possible network scenarios should be evaluated and compared to make a decision of optimal hydrological radar network in a country.

3. CONCLUSIONS

In this paper, we concentrated on explaining the necessities of hydrological radar network in Korea for improving the quality flood control and management and the efficiency of real-time flood warning system. Then, in engineering aspects, the factors considered in the process of hydrological radar network design were defined in the features of three analyses; geographical feasibility analysis, flood management feasibility analysis, and cite feasibility analysis. Among them, geographical and flood feasibility analyses were implemented on the radar simulation model called Hydrological Radar Network Simulation Model (HRNSM) and explained in detail manner in the contents.

There is no escape to perform the radar simulations using HRNSM for various scenarios and suggest an optimal hydrological radar network in Korean Peninsular in future study. To do this, more preliminary studies considering geographical, meteorological, and hydrological features of Korea should be accompanied to make a appropriate decision of Korean Hydrological Radar Network.

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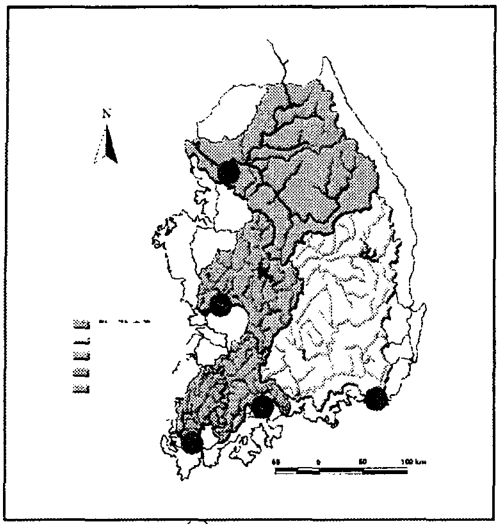
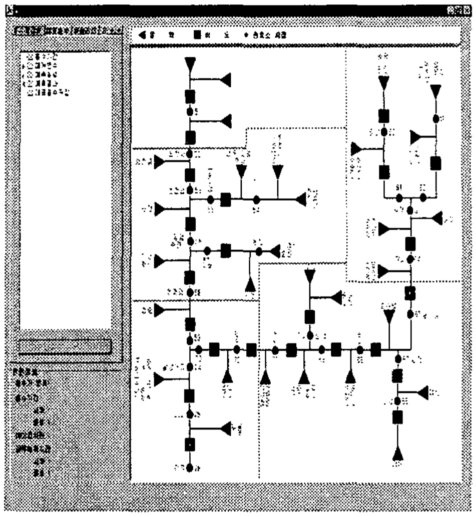
Table 4. Schematic Structure of Hydrological Radar Network Simulation Model (HRNSM)

	Items	Details	Others
Main Screen	Radar Location Information	Longitude	Direct Input
		Latitude	
		Radar Range (Radius, Km)	
		Site Elevation (E.L. m)	
		Antenna Height (m)	
		Antenna Elevation (E.L. m)	
		Antenna Angel (degree)	
	Multiple Radar Simulation		
	Geographical Analysis (GA)		Icon to GA
	Flood Management		Icon to FMFA
	Feasibility Analysis (FMFA)		
	GIS Map Information	DEM (Color Image)	Base map
		Governmental Division Boundary	
		Watershed Boundary	
		Major Mountains	
		Major Cities	
GA Screen	Solo Radar Simulation Map	Radar Range	Color Base
		Radar Simulation Line	Black Line
		Blockage Area	Shadow
	Radar Beam Propagation Map	Land Profile	Black Area
		Radar Beam Propagation Line	Black Line
	Radar Site Specification	Longitude	* Simulation
	(Pointed Site)	Latitude	for each site
		Radar Range (Radius, Km)	
		Site Elevation (E.L. m)	
		Antenna Height (m)	
		Antenna Elevation (E.L. m)	
		Antenna Angel (degree)	
	Radar Occultation (Blockage %)		
	Radar Watershed Coverage		
FMFA Screen	Flood Index Maps	Population Density Index (PDI) Map	
		Economic Price Density Index (EPDI) Map	*Results are made
		Flood Damage Cost Index (FDCI) Map	for
		Flood Rainfall Index (FRI) Map	(1) each Index
		PDI Figure and Table	(2) each Radar site
	FMFA Result	EPDI Figure and Table	(3) each Basin
	Han River	FDCI Figure and Table	(4) overall Korea
	Nackdong River	FRI Figure and Table	
	Keum River	Flood Management Feasibility Index	
	Youngsan River	(FMFI) Figure and Table	
	Sumjin River		
	Overall South Korea		



(a)



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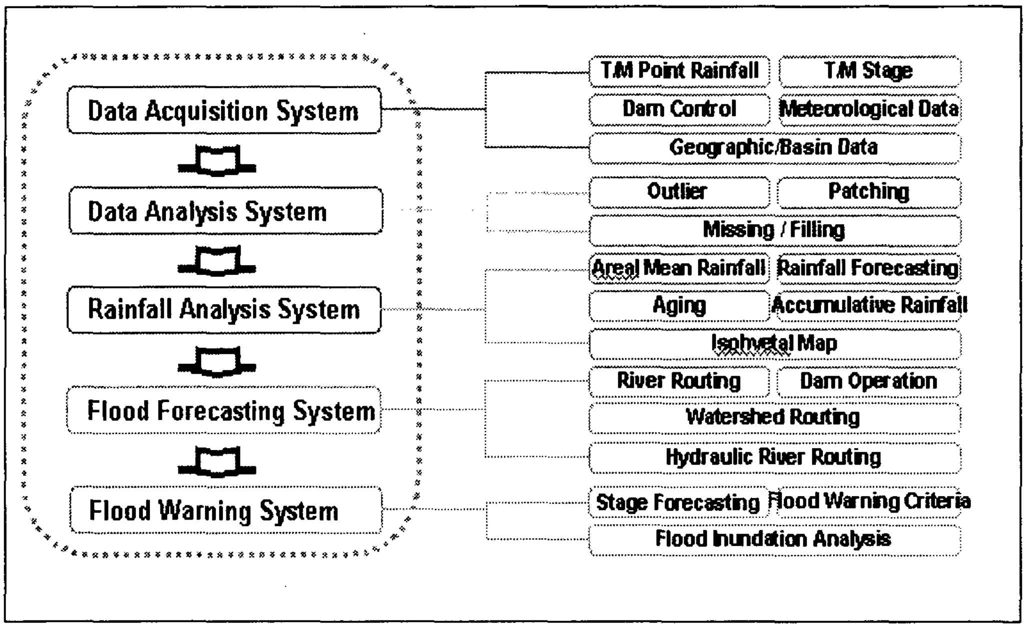

(c)

Figure 1. Korea Flood Monitoring and Warning System (KFMWS)
(a) Five Divisions of Flood Warning Agencies, (b) Main System Screen of KFMWS
(c) Detail Subsystems in KFMWS

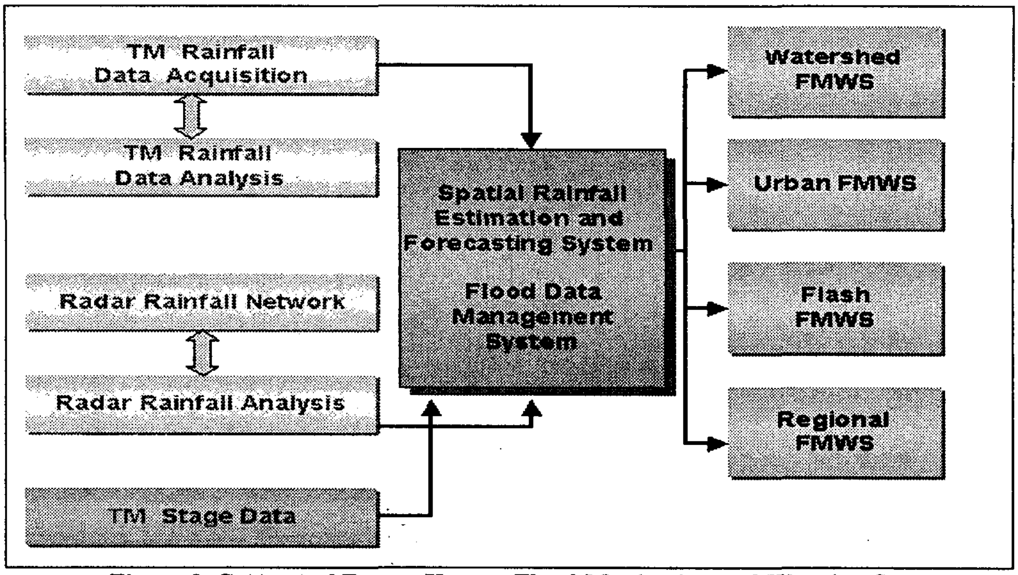

Figure 2. Concept of Future Korean Flood Monitoring and Warning System Based on Hydrological Radar Networks

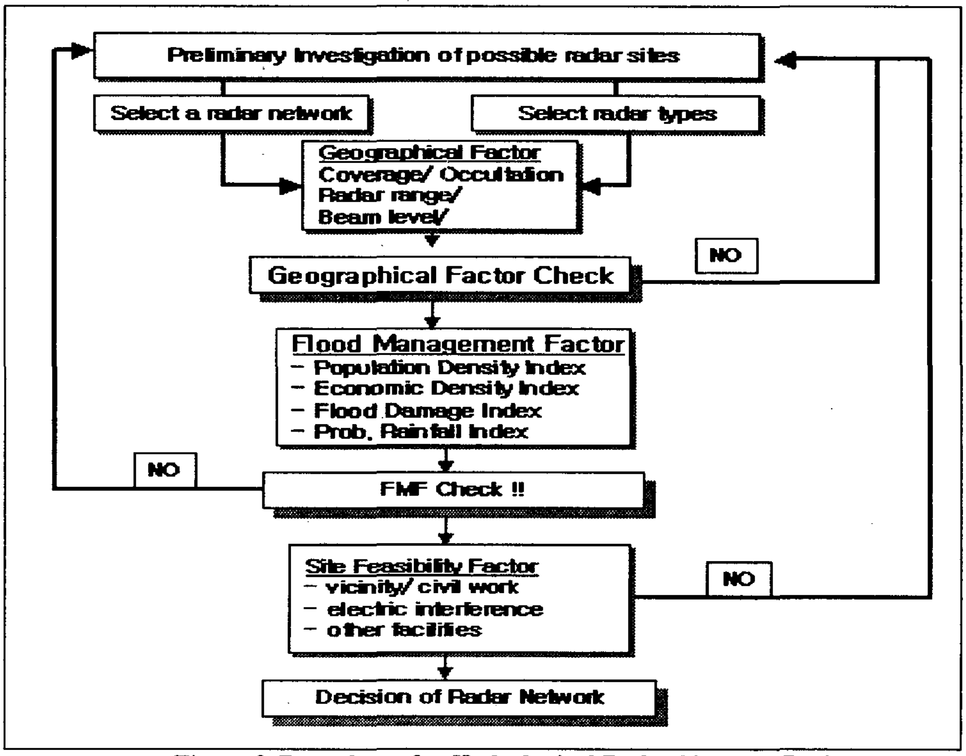

Figure 3. Procedures for Hydrological Radar Network Design

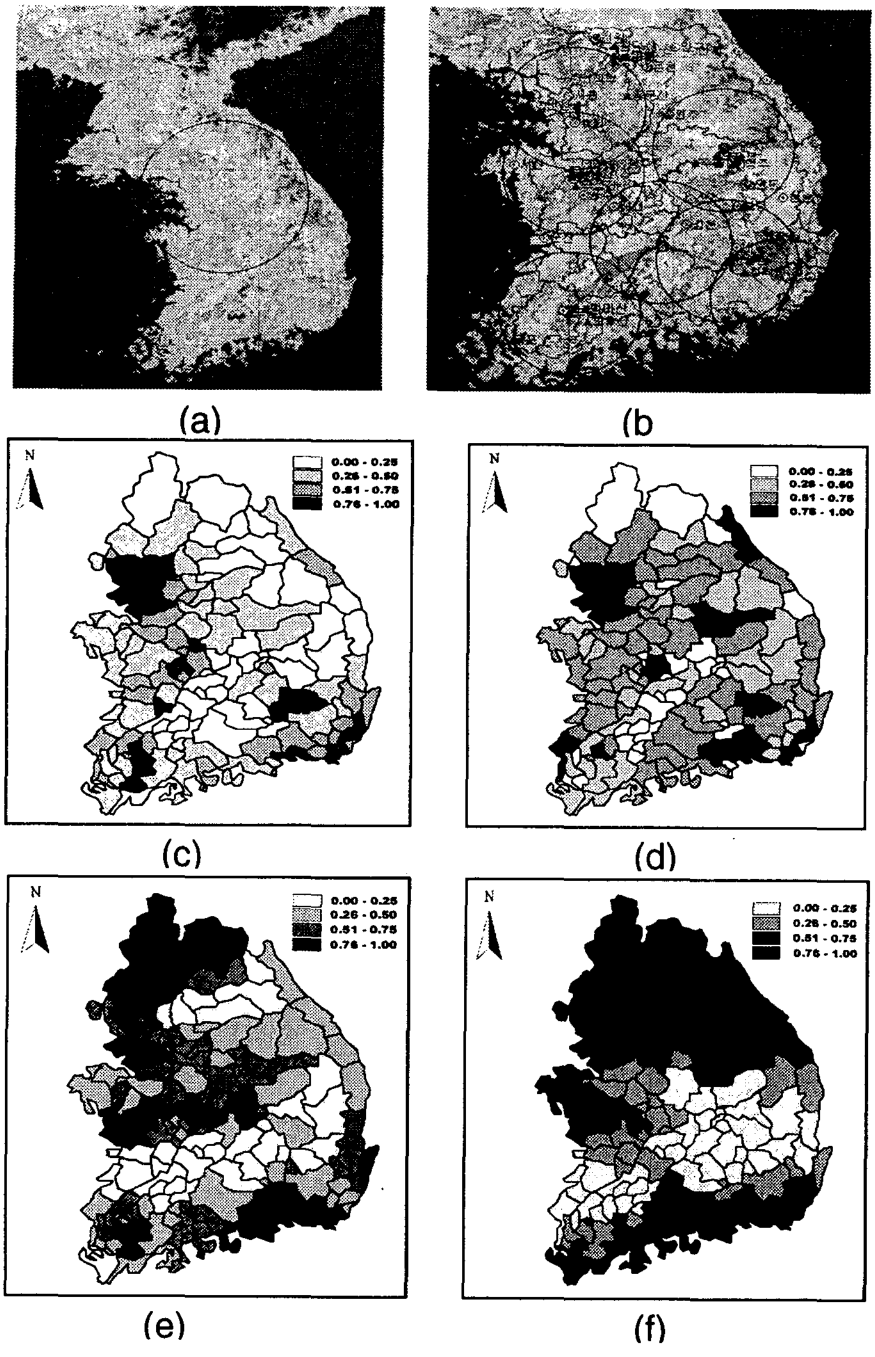

Figure 4. GIS Base Maps for Radar Network Analysis Simulator (RNAS)
(a) Digital Elevation Map (DEM), (b) Watershed divide and major locations
(c) Population Density Index Map, (d) Economic Density Index Map
(e) Flood Damage Index Map, (f) Flood Rainfall Index Map

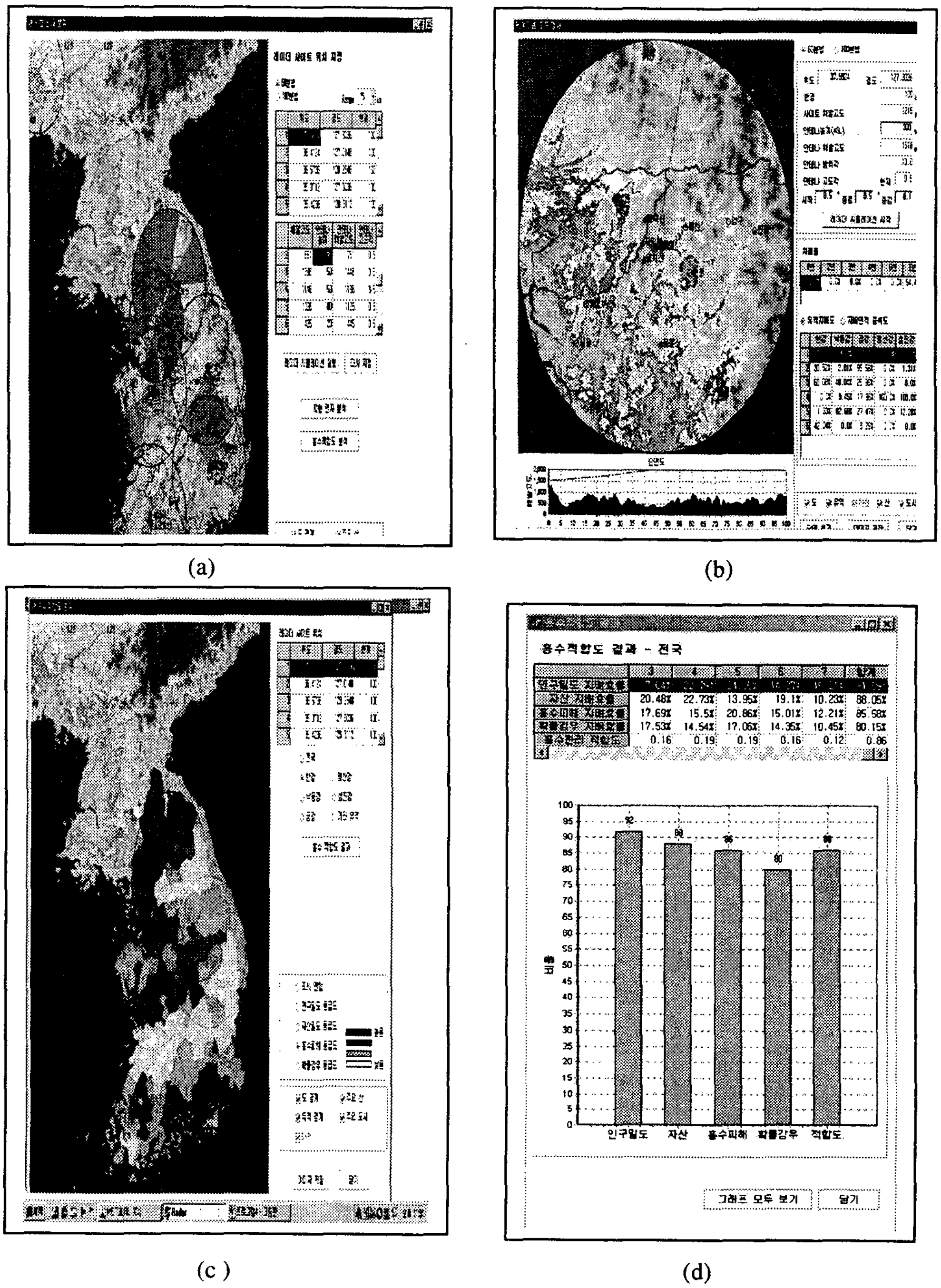

Figure 5. Description of Hydrological Radar Network Simulation Model (HRNSM)
(a) HRNSM Main screen, (b) GA Screen, (c) FMFA Screen, (d) FMFA result example