Article

A Study on Runoff Analysis in Ungauged Basins Using Satellite Image Information

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Abstract: This study was designed to assess the reliability of geographic information using satellite image information in ungauged basins. For this, this study constructed geographic information using actual gauged data and satellite information data and conducted runoff analysis through S-RAT, a rainfall–runoff model, and performed the comparison and analysis of geographic information and runoff data. For actual gauged data, the gauged geographic information of the Water Resources Management Information System (WAMIS) was collected, and for satellite information, the image information of moderate-resolution imaging spectroradiometer (MODIS) observation sensor loaded on Terra Satellite was collected. As analysis areas, three basins where mountains occupy more than 80% and another three basins where urban areas occupy more than 7% in the Han River basin were selected. According to the analysis result, the gauged information and satellite image information showed great difference in runoff, maximum 50% in peak flood and maximum 17% in total flood, in the rivers with many urban areas, while the runoff difference in the rivers with many mountains showed maximum 13% in peak flood and 4% in total flood. What showed the greatest difference in image information was land use, and it turned out that the MODIS satellite recognized the urban rivers as cities for more than maximum 60% compared to WAMIS-gauged data. Meanwhile, in the forest area, the MODIS satellite image showed error of less than 5% of the WAMIS-gauged data, which indicates that it has higher applicability in Mountain Rivers.

Keywords: Ungauged Basin, MODIS, Satellite Image, S-RAT

1. Introduction

1.1. Research Background and Purpose

The Republic of Korea is the only divided nation in the world. It was liberated from Japan in 1945, but it was again divided into South Korea and North Korea based on the 38th parallel of latitude after the Korean War in 1950. The two sides remain under an armistice today. Therefore, the South can never carry out gauging activity in the North region. However, the analysis/assessment of the North Korean water resources is considered vital in preparation for unification in the future. Currently, North Korea is highly vulnerable to natural disasters related to climate change because its forest ecosystem was damaged because of long-term food and energy shortage. To prepare for large-scale natural disasters predicted in North Korea and to efficiently cope with climate change, the systematic and scientific use of water resource information is crucial. To analyze the natural disasters in North Korea, actual gauged geographic and hydrological data are necessary. However, the North Korean region is an ungauged region, and it is difficult to collect geographic and hydrological data in the location. Consequently, to analyze/assess the water resources in North Korea, an ungauged region, it is necessary to use geographic information extracted from a satellite image, not from gauged data.

The ungauged region refers to a location where gauging has not been conducted because of financial, political, social, and technical reasons that make the gauging inefficient or impossible, or a location where the topography has changed because of climate change or existing information has changed because of the development and damage of waterside by the humans. Accordingly, North Korea is classified as an ungauged region (Kang, 2015)[1].

It was impossible to carry out a hydrological analysis in an ungauged basin with no gauged information. However, it was now made possible to collect the geographic information, such as digital elevation model (DEM), Land Cover, and soil of the whole world, from a satellite image that can substitute geographic information systems (GISs), and the hydrological prediction of the ungauged basin was also made possible using such information. However, to properly deal with the problem of lack and shortage of data in an ungauged basin, a good understanding of hydrological characteristics in the basin is necessary, and a reliability analysis must be conducted using a model that can reflect the basin characteristics.

To assess the reliability of the satellite image information in an ungauged basin, this study randomly selected six basins from major rivers in the Han River basin in South Korea and conducted rainfall-runoff analysis using gauged data and satellite image information. In the selected basins, the gauged geographic information of the Water Resources Management Information System (WAMIS) of Korea was collected, and for satellite image information, the image information of the MODIS observation sensor provided by the Food and Agriculture Organization of the United Nations (FAO) and the Consultative Group on International Agricultural Research - Consortium for Spatial Information (CGIAR-CSI) was collected. Using the collected information, DEM, landuse, and soil map were constructed. In addition, to analyze the reliability of the constructed gauged geographic information and satellite image information, a runoff analysis was conducted using the Spatial Runoff Assessment Analysis Tool (S-RAT) rainfall-runoff model.

1.2. Literatures Review

For hydrological prediction in an ungauged region, hydrological theories, and models, and empirical methods have been mostly used so far. The research trend in hydrological analysis is as follows: Moon (2014)[2] attempted to find a method of localizing the characteristics of a gauged basin and rainfall-runoff model parameters so that they can be applied to an ungauged basin with no rainfall and inflow data; Suh (2014)[3] attempted the prediction of a hydrological curve based on the current understanding and knowledge of the river network and showed the possibility of hydrological curve prediction in an ungauged basin using a stochastic network model through the application in the Chungju Dam basin; Kang et al. (2013)[4] improved the components of a tank model and localized the parameters to simulate the runoff of the upper basin of the reservoir, an ungauged basin, and assessed the applicability of the model; M. Hrachowitz et al. (2013)[5] predicted the ungauged basin with reduced uncertainty by improving the capacity of a hydrological model and improved the reliability of the prediction in ungauged basins by developing a new and innovative model that represents temporal and spatial variables in a hydrological process; J. Parajka et al. (2013)[6] conducted research to predict and compare the runoff levels in ungauged basins, and Lance E. Besaw et al. (2010)[7] conducted research to predict the basin flow through an artificial neural network in an ungauged basin; Chung et al. (2012)[8] assumed Geumho point, the upper point of the Deungchon water level observatory that is the flood prediction point in Geumho River, as an ungauged basin and studied on the applicability of the flow estimation method using a specific discharge method and a regional regression method, the flow estimation methods in ungauged basins, and SWAT, a rainfall-runoff model; Kim et al. (2012)[9] suggested a reasonable alternative to the limit of the deterministic runoff modeling method by analyzing the statistical characteristics of runoff result in ungauged basins considering the uncertainty of the parameters; and Choi et al. (2010)[10] assessed the possibility of localization of the models in small river basins where flow gauging is not conducted in the same water system by supplementing the models for runoff points and estimating the flow in upper river points using GRM (Grid-based Rainfall-runoff Model), a physics-based distributed model. To analyze the current situation and forecast of water resources in North Korea, Ahn et al. (2010)[11] estimated the potential water resources in each North Korean region using the Kajiyama equation, a simple empirical flood equation, using rainfall information of a North Korean rainfall observatory. Lee (2009)[12] estimated the runoff curve index using the Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) model in ungauged basins. Kim et al. (2008)[13] carried out flood runoff simulation and compared the results targeting the Imjin River basin, about two-thirds of which is an ungauged region, using the physics-based VfloTM model and ModClark model, a quasidistributed hydrological model. Stein Beldring et al. (2005)[14] researched on the potentiality of the prediction method using previous experience with and hydrological actions in ungauged basins in North European countries, and M. Sivapalan et al. (2003)[15] researched on the estimation of prediction uncertainty in ungauged basins and future development directions.

Recently, however, hydrologists have started to believe that the hydrological theories, models, and empirical methods are unsuitable for hydrological prediction in ungauged basins (M. Hrachowitz et al., 2013)[16]. With the development of science, satellite image technology has also rapidly developed with satellite observation currently being conducted all over the world. Accordingly, the applicability of satellite image information in ungauged regions is considered very high. The research trend using satellite image information in ungauged regions is as follows: Lee et al. (2014)[17] estimated the air temperature using the ground surface temperature of the MODIS sensor and vertical temperature information in the region with no gauged value using remote sensing (RS) information, estimated the amount of evapotranspiration, and verified the hydrological drought assessment and monitoring method. Chae (2004)[18] introduced various RS images that can be used to generate various hydrological factors in ungauged basins such as future possible areas or limitations of RS imaging. Lee et al. (2003)[19] compared the calculation effective rainfall and observation effective rainfall using the runoff curve number (CN) estimated from a statistical approach to satellite image land cover classification items and studied on its applicability. Kim et al. (1999)[20] studied on the applicability of the use of satellite image information as a GIS spatial information to estimate the Soil Conservation Science (SCS) CN value.

1.3. Mothodology

This study intended to analyze the reliability of the satellite image information for hydrological analysis in the ungauged basins. To analyze the reliability of the satellite image information in ungauged basins, it is necessary to apply in the gauged basins. Thus, this study divided the river basins in South Korea into gauged and ungauged basins and collected geographic information constructed by WAMIS for gauged basins and collected geographic information observed by MODIS satellite image sensor for ungauged basins. The collected information was used to construct geographic information, such as DEM, landuse, and soil map, for each study basin by unifying the resolution, coordinate system, and classification system through the reclassification process of South Korea. The reliability of the geographic information constructed with satellite image information was analyzed by comparing/analyzing the flood discharge and by using it as input data for S-RAT, a distributed runoff model. Fig. 1 shows the research flow.

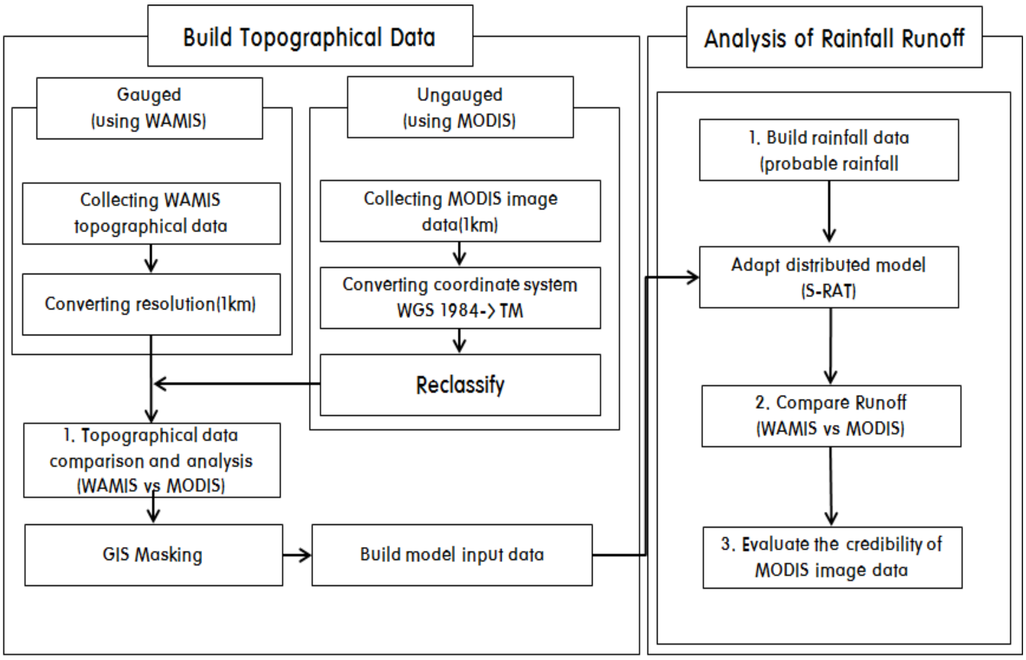

Figure 1. Research Flowchart

2. Application

2.1. Description of Pilot Basin

Fig. 2 shows North Korean basins (upper right), which un-gauged basin and gauged Han River basins (lower right). As shown in Table 1, North Korea can be divided into 8 representative basins, and, currently, the rainfall data of 27 rainfall observatories can be collected through the World Meteorologic Organization (WMO). However, because there is no gauged geographic data, such as DEM, landuse, and soil map, necessary for rainfall-runoff analysis, geographic information created from satellite images is used. Accordingly, the reliability of the satellite image information should be assessed first, and for rainfall-runoff analysis using satellite image information, a region with gauged geographic information is necessary. Therefore, this study selected the study basins from major rivers that are the nearest from North Korean region, in Han River water system among the South Korean water systems, the Han River basin is the greatest river basin in Korea covering 36-28-19 to 38-30-05 latitude and 126-30-59 to 128-59-56 longitude with 23,292.80 ㎢ (except the Imjin River basin) of basin area, 483.00 km of flow extension, 48.20 km of average basin width, and 1.95 of basin shape factor, located at the center of Korean peninsula; it covers about 23% of the whole area (99,253.80 ㎢, as of 2001, Statistics Korea) south of the ceasefire line. Its basin shape is a multitype basin, a mixture of a dendritic basin and a fan-shaped basin. The Han River basin includes 1 special city, 1 metropolitan city, and 5 provinces, such as Seoul Metropolitan City, Incheon Metropolitan City, Gyeonggi-do Province, Gangwon-do Province, Chungcheongnam-do Province, Chungcheongbuk-do Province, and Gyeongsangbuk-do Province, and it is composed of 13 national rivers, such as Han River, Anyangcheon, Jungnangcheon, Gyeongancheon , Seom River, Dalcheon, Bukhan River, and Soyang River, and about 600 local rivers (Hydrological Survey Center, 2014)[21]. This study randomly selected six basins from national and local rivers as divided into urban areas and forest areas.

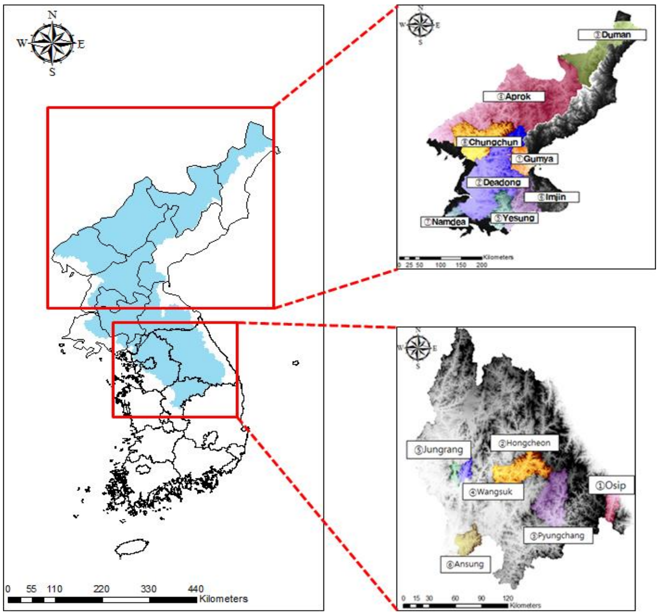

Figure 2. Dependency of the critical Marangoni number on the heating rate for floating half zones (5 cSt silicone oil) of different scales with V/V0 = 1.0 in the microgravity conditions.

Table 1. Overview of Study Basin

Class	Basin	Area(km²)	Circumference(km)	Average width(km)	Average altitude(m)
North Korea	Gumya	3371	252	15.2	449
	Deadong	19,377	796	35.7	334
	Duman	9,551	695	60.1	959
	Aprok	31,705	1,129	6.9	1004
	Yesung	3,935	321	20.9	166
	Imjin	5,183	407	10	408
	Namdea	731	111	11.8	100
	Chungchun	9370	460	44	353
South Korea	Samcheock Osip	394.72	185.08	19.59	404.7
	Hongcheon	1,566.05	248.52	14.43	366.67
	Pyungchang	1,773.39	244.64	11.87	592.02
	Wangsuk	247.46	82.58	9.5	157.76
	Jungrang	204.59	83.02	7.85	93.98
	Ansung	1,658.66	239.76	27.72	69.54

2.2. Construction of Input Data

The geographic information necessary for a rainfall-runoff model is composed of DEM, landuse, and soil map. The satellite image information is received in raster form, and it is reclassified according to the Korean classification system. Afterward, the reclassified geographic information goes through the masking process to be suitable for basin scale to construct final geographic information such as DEM, landuse, and soil map.

2.2.1. Construction of Digital Elevation Model(DEM)

For DEM construction, MODIS image information with 1 km global resolution was received from Consultative Group on International Agricultural Research - Consortium for Spatial

Information (CGIAR-CSI) in raster form. The coordinate system was the WGS 1984 coordinate system, which was converted into the TM (Tokyo Transverse Mercator) coordinate system, a Korean coordinate system, and it was used as geographic information after the masking process in river basin form in study regions. Fig. 3 shows GIS-based 1 km global DEM data using satellite image information.

Figure 3. Global-Scale DEM Using Satellite Image Information

2.2.2. Landuse

The land cover extracted and provided from satellite images is composed of 18 classes (Table 2). It was converted into the TM coordinate system like DEM and reclassified into 8 class systems to be suitable for domestic terrains such as water, urbanization, bare ground, wet ground, grassland, forest, paddy, and field (Table 3).

Table 2. Thermophysical properties of 5 cSt silicone oil

Class	Contents	Class	Contents
0	Water	9	Savannas
1	Evergreen neeleleaf forest	10	Grasslands
2	Evergreen broadleaf forest	11	Permanent wetlands
3	Deciduous needleleaf forest	12	Croplands
4	Deciduous broadleaf forest	13	Urban and built-up
5	Mixed forests	14	Cropland/natural vegetation mosaic
6	Closed shrublands	15	Permanent snow and ice
7	Open shrublands	16	Barren or sparsely vegetated
8	Woody savannas	17	Unclassified

Table 3. Land Cover Classification on Korean Standard

Class	Contents	MODIS Land Cover Reclassify
1	Water	0, 15
2	Urbanization	13
3	Bare ground	16
4	Wet ground	11
5	Grassland	8, 9, 10
6	Forest	1, 2, 3, 4, 5, 6, 7
7	Paddy	12
8	Field	14

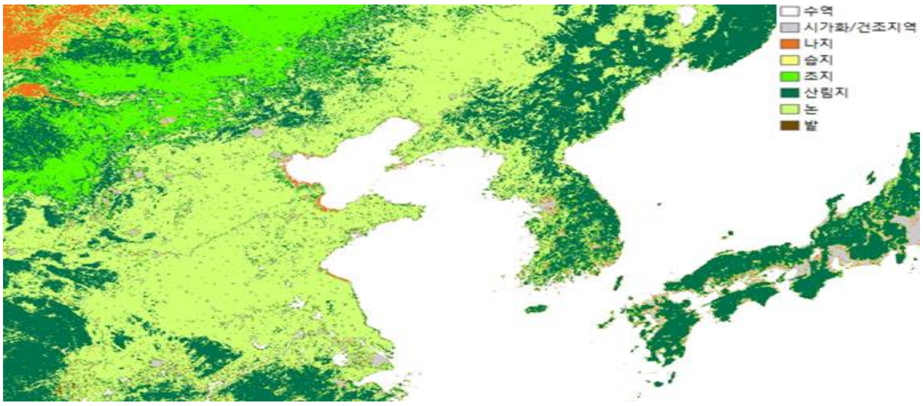

Figure 4. Conversion of Satellite Image Information into 8-Classification Land Cover

2.2.3. Soil Map

The Hydrologic Soil Group (HSG) is classified into four groups according to soil characteristics and infiltration rate: Groups A, B, C, and D (Table 4). The soil map extracted from the satellite image has 16 classifications, and it goes through reclassification process of four HSGs according to each soil characteristic (Table 5). Fig. 5 shows reclassified four soil groups. The SCS CN value, the runoff coefficient, is calculated using reclassified landuse and soil map.

Table 4. Characteristics of Soils Assigned to Soil Groups(McCuen, 1998)[23]

Characteristics of Soils	Minimum Infiltration Rate(mm/hr)	HSG(Hydrologic Soil Group)
Deep sand, deep loess, aggregated silts	7.62–11.43	A
Shallow loess, sandy loam	3.81–7.62	B
Clay loams, shallow sandy loam, soils low in organic content, soils usually high in clay	1.27–3.81	C
Soils that swell significantly when wet, heavy plastic clays, certain saline soils	0–1.27	D

Table 5. Reclassified Soil Groups from TERRASTAT Database to Hydrological Soil Group(HSG)(Han, 2010)[22]

ID	Soil Description	HSG	ID	Soil Description	HSG
10	Coarse-textured soils (loamy)	C	31	Organic soils	C
12	Coarse-textured soils (sandy clay)	C	32	Coarse textured soils (sandy)	A
13	Medium-textured soils (loamy)	C	34	Fine-textured soils (clay)	D
14	Fine-textured soils (clay)	D	40	Fine-textured soils (silt)	D
20	Coarse-textured soils (sand)	A	41	Organic soils	D
21	Organic soils	C	42	Coarse-textured soils (sandy)	D
23	Medium-textured soils (loamy)	A	43	Medium-textured soils (loamy)	D

24	Fine-textured soils (clay)	D	99	Glaciers, Rocks, Shifting Sand, No Data
30	Silt loam	B	97	Water

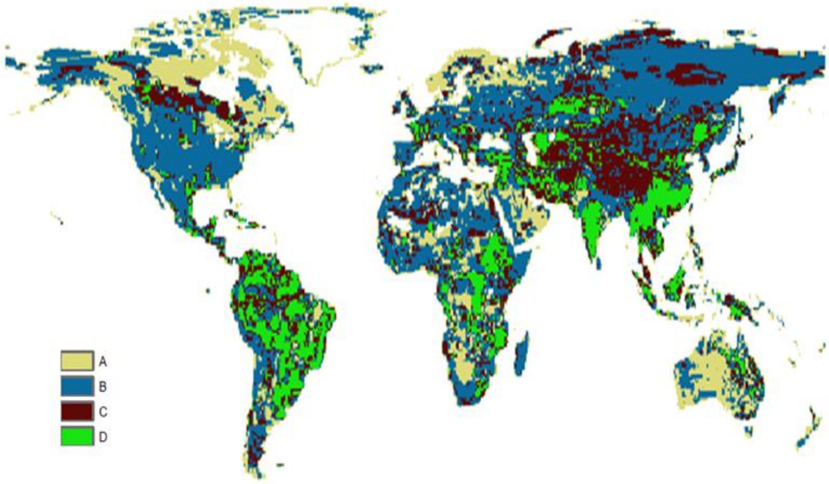

Figure 5. Reclassified Soil Data

2.3. Application of Rainfall-Runoff Model

The geographic information provided from WAMIS and the image information extracted from MODIS images were constructed in GIS-based geographic information, and rainfall-runoff simulation was conducted using these two types of geographic information. The input data, except geographic data, was evenly applied. Thus, the additional parameter calibration of the rainfall-runoff model was omitted.

2.3.1. Comparison of Geographic Data Analysis Between MODIS and WAMIS

Fig. 6 shows the comparison of average elevation based on DEM of WAMIS and MODIS. There is no great difference in average elevation of the two geographic data. Fig. 7 shows the landuse distribution of MAMIS and MODIS. In non-urban areas, such as Osip, Pyungchang, and Hongcheon Rivers, the difference between the urban area and the paddy field area was around 10%, and there was no great difference in the forest area. However, in urban rivers, such as Wangsuk, Jungrang, and Ansung Rivers, the great difference between the impermeable urban area and the paddy field area was identified in MODIS image information. Such result appeared more accurately in the HSG as shown in Fig. 8. In Wangsuk, Jungrang, and Ansung Rivers, the hydrologic soil group extracted from MODIS image information mostly turned out to be Group D. Consequently, it causes the runoff increase because of the increase in the impermeable layer.

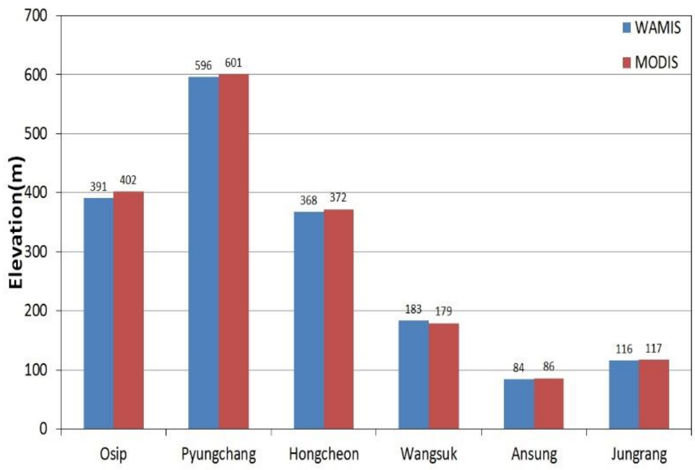

Figure 6. Average Elevation of Study Basins(WAMIS vs MODIS)

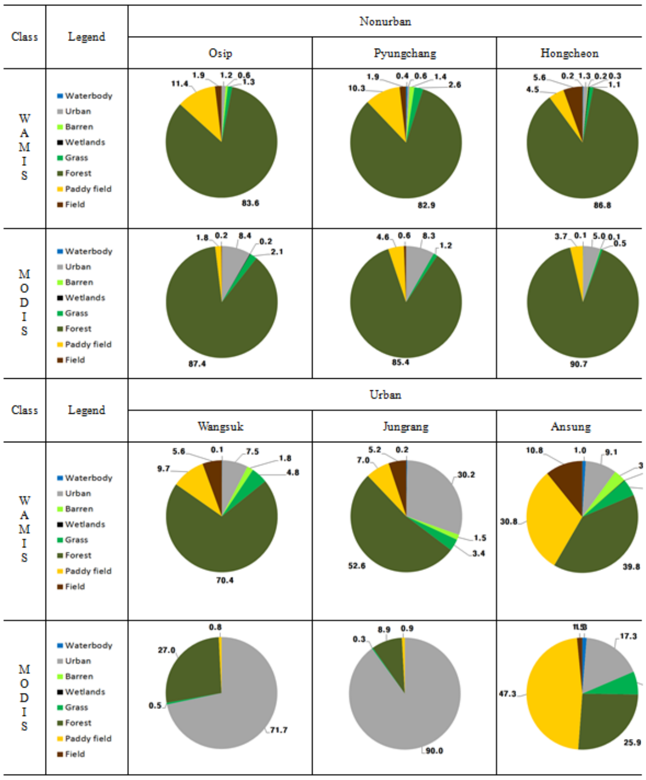

Figure 7. Ratio of landuse in Study Basins(WAMIS vs MODIS)

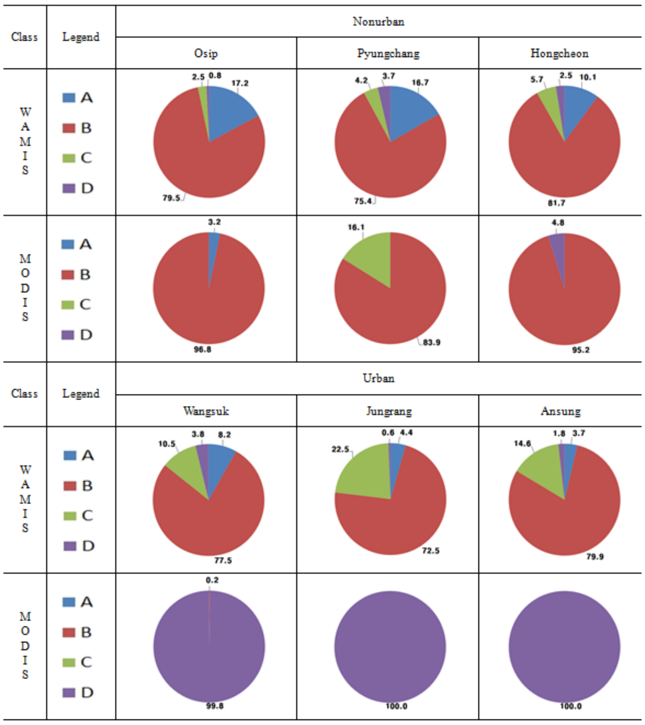

Figure 8. Hydrologic Soil Group of Study Basins(WAMIS vs MODIS)

2.3.2. Rainfall-Runoff Model(S-RAT)

The Spatial Runoff Assessment Tool (S-RAT) model is a distributed model developed by Kangwon National University that can simulate the resolution and time interval in various spaces. The S-RAT model can concurrently satisfy the convenience of data construction in a lumped hydrological model and spatial runoff analysis ability in a distributed hydrological model, and it is a conceptual-distributed hydrological model that can use grid-based radar rainfall data.

The S-RAT model receives input data, such as DEM, landuse, and Soil, of the study basin in ESRI-ASCII form and generates a geographic parameter from DEM. It also creates runoff simulation data of the simulation point by performing runoff and tracing calculation using the CN value of each grid, temperature data, Soil, and landuse. Fig. 9 shows the conceptual map of the S-RAT model.

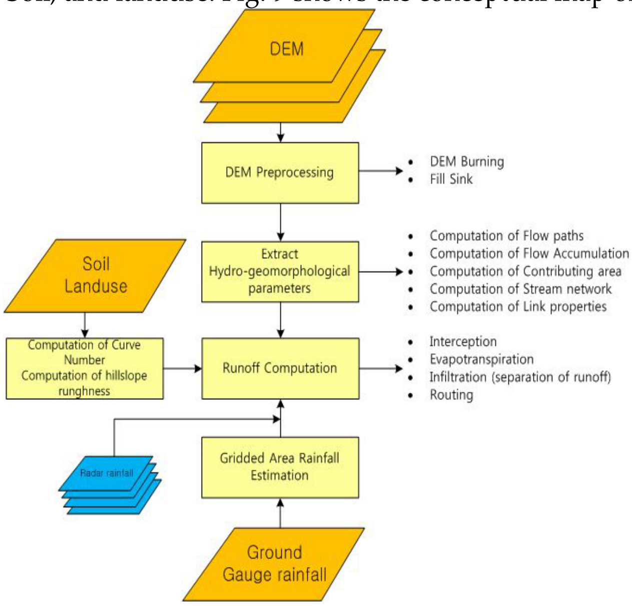

Figure 9. Conceptual Map of S-RAT Model(Kim, 2010)[24]

To estimate the flow direction of each grid, the D-8 direction method was used (Band 1986, Tarboton 1997)[23], and the flow direction and slope were estimated using this method. In the D-8 method, the drainage area increases one by one along the course of the flow vector, and the value of the drainage area is piled up on each grid. Fig. 10 shows the conceptual map of the D-8 method.

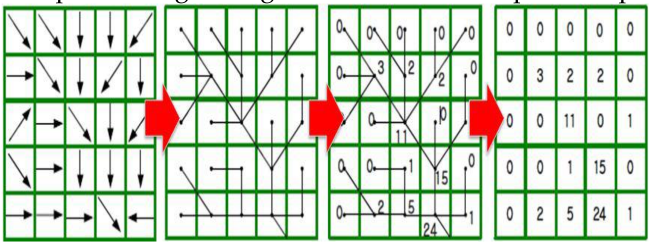

Figure 10. Conceptual Map of D-8 Direction Method (Kim, 2010)[24]

If runoff course is identified using the elevation of each grid like Fig. 10, the runoff volume of each grid can be calculated. The runoff simuation method using S-RAT is as follows.

1. Calculation of Areal Rainfall of Each Grid

To consider the spatial variability of the rainfall in the basin, the S-RAT model generates the rainfall value of each grid using the Thiessen method and inverse distance weighting method. It also uses the radar rainfall as grid like the GIS data.

2. Calculation of Evapotranspiration

Evapotranspiration is calculated using the radiation method (Doorenbos et al., 1984)[24].

$$E_p[t,(i,j)] = a + bT[t,(i,j)]N(i)W_{ta(i)} \tag{1}$$

Here, a and b are regression coefficients in the radiation method, N(i) $\mathrm{N(i)}$ is the monthly average maximum sunshine hours, and $W_{ta(i)}$ is a correction factor for each elevation.

3. Infiltration and Runoff

The S-RAT model calculates infiltration and direct runoff of each grid using SCS Curve Number (CN) method. For this calculation, it receives Soil and landuse as input data to generate the CN value grid data.

$$S(i,j) = 254(\frac{100}{CN(i,j)} - 1) \tag{2}$$

$$\frac{dF[t,(i,j)]}{dt} = -\frac{F[t,(i,j)]}{H_s} - E[t,(i,j)] + P[t,(i,j)]\{1 - \frac{F[t,(i,j)]}{HS(i,j)}\} \tag{3}$$

Here, $S(i,j)$means potential q'ty, $CN(i,j)$CN value for each grid, $F[t,(i,j)]$infiltration ability of infiltration storage tank, H_s dimensionless constant, $E[t,(i,j)]$ potential evapotranspiration, $P[t,(i,j)]$ (mm) precipitation, and $HS(i,j)$means the capacity of infiltration storage tank.

2.3.3. Application of S-RAT Model

Fig. 11 shows the result of additional input data construction using DEM, landuse, and Soil Map, which are geographic data of WAMIS and MODIS. If such data as DEM, landuse, and Soil Map are put into S-RAT, a rainfall-runoff model, such data as Stream Network, Roughness, and CN are automatically constructed.

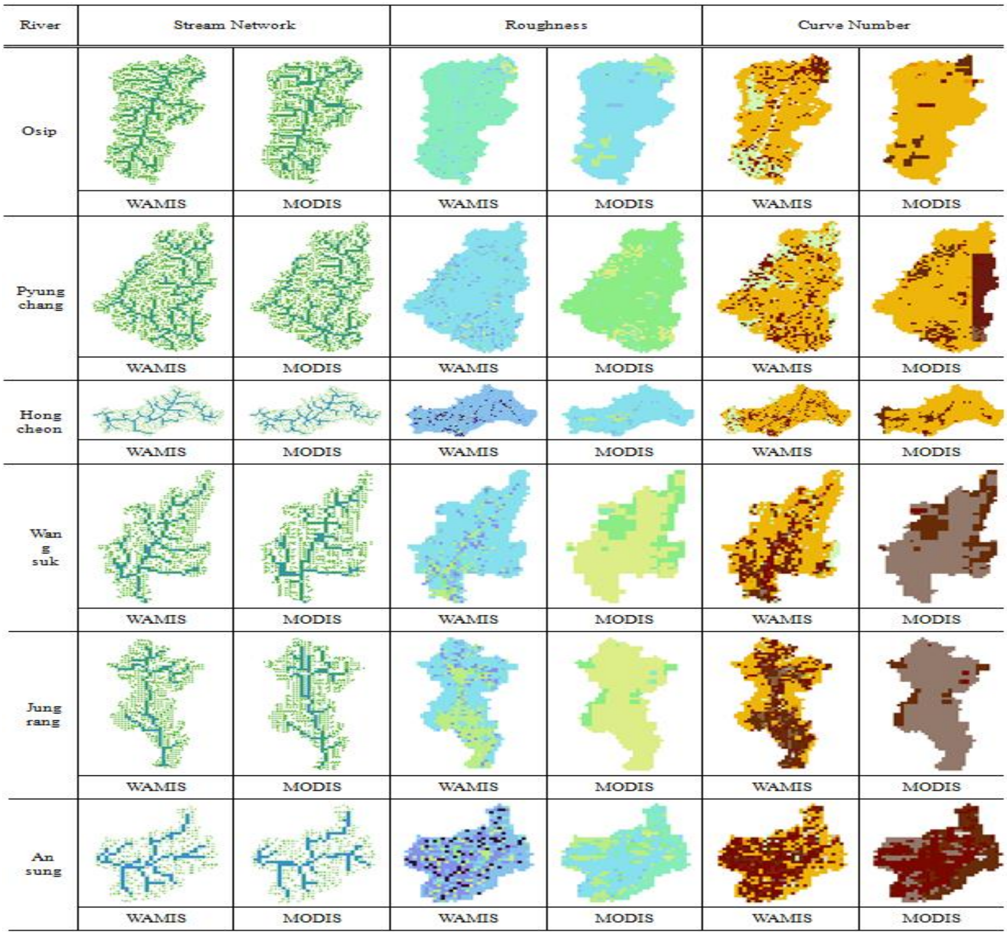

Figure 11. Construction of S-RAT Input Data

This study converted the geographic data provided from WAMIS and image data extracted from the observation sensor of an artificial satellite into GIS-based geographic data, conducted flood runoff simulation for six Han River basins using S-RAT, a distributed hydrological model, and compared/analyzed the results. The result of flood calculation is shown in Fig. 12 and Table 6. The ratio of the results calculated with WAMIS and MODIS geographic data of mountainous rivers, such as Osip, Pyungchang, and Hongcheon Rivers, showed very similar values, CN 1.03–1.05, peak flood 0.87–1.04, and total flood 0.96–1.01. In urban rivers, such as Wangsuk, Jungrang, and Ansung Rivers, CN was 1.12–1.28, peak flood was 1.10–1.50, and total flood was 1.14–1.17, with some points showing more than 50% of difference.

Table 6. Flood Calculation Result in Study Basins

Class	CN(Average)			Q(Peak, m^3/s)			Q(sum, m^3)		
	Wamis	Modis	Ratio	Wamis	Modis	Ratio	Wamis	Modis	Ratio
Osip	66	69	1.05	2,630	2,742	1.04	91,527	92,602	1.01
Pyungchang	67	71	1.06	7,408	6,469	0.87	396,010	378,638	0.96
Hongcheon	68	70	1.03	4,550	4,365	0.96	327,956	322,087	0.98
Wangsuk	71	90	1.28	2,207	2,419	1.10	78,032	89,907	1.15
Jungrang	75	91	1.21	1,119	1,678	1.50	67,963	79,185	1.17
Ansung	74	83	1.12	2,307	2,940	1.27	159,904	182,329	1.14

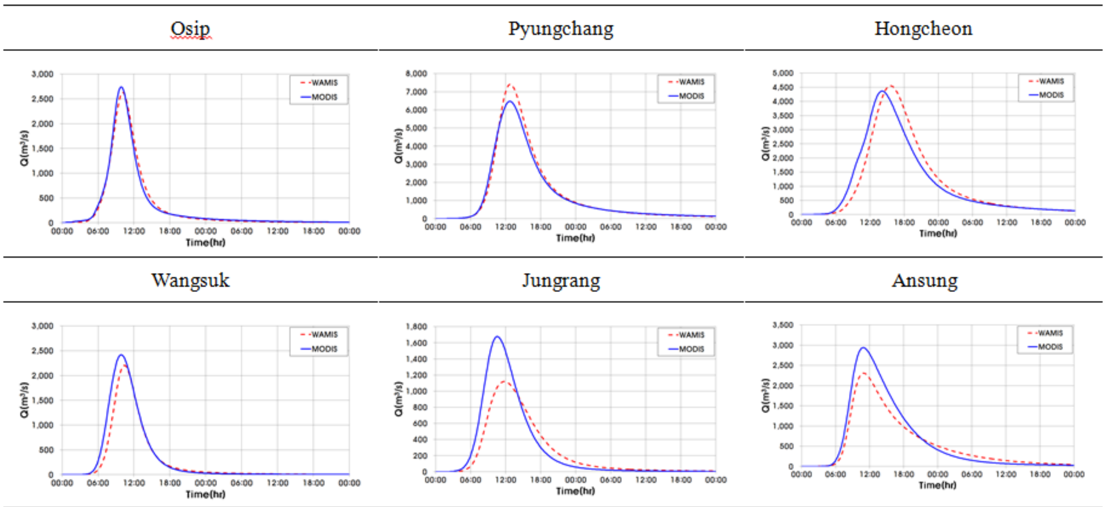

Figure 12. Result of Flood Estimation in Study Basins

The landuse is considered as the greatest factor. As shown in Fig. 7 and Table 7, the ratio of urban area in mountainous rivers, such as Osip, Pyungchang, and Hongcheon Rivers, shows a small value of maximum 1.3% while the ratio of urban area in urban rivers, such as Wangsuk, Jungrang, and Ansung Rivers, shows higher values from minimum 7.5% to maximum 30%. The greater difference appears in satellite image information. Because it recognizes the forest area in urban rivers as urban area for about 50%, the runoff can increase because of urban areas with many impermeable layers.

Table 7. Thermophysical properties of 5 cSt silicone oil

Class	Urban		Forest		Paddy Field	
	Wamis	Modis	Wamis	Modis	Wamis	Modis
Osip	1.2	8.4	83.6	87.4	11.4	1.8
Pyungchang	0.6	8.3	82.9	85.4	10.3	4.6
Hongcheon	1.3	5.0	86.8	90.7	4.5	3.7
Wangsuk	7.5	71.7	70.4	27.0	9.7	0.8
Jungrang	30.2	90.0	52.6	8.9	7.0	0.9
Ansung	9.1	17.3	39.8	25.9	30.8	47.3

3. Conclusion and Discussions

This study attempted to assess the reliability of geographic information using satellite image information in ungauged basins. For this, this study constructed geographic information using actual gauged data and satellite information data and conducted runoff analysis by applying it to S-RAT, a rainfall-runoff model. As analysis areas, three basins where mountains occupy more than 80% and another three basins where urban areas occupy more than 7% in the Han River basin were selected. According to the analysis result, the gauged information and satellite image information showed great difference in runoff, maximum 50% in peak flood and maximum 17% in total flood, in the rivers with many urban areas while the runoff difference in the rivers with many mountains showed maximum 13% in peak flood and 4% in total flood. What showed the greatest difference in image information was landuse, and it turned out that the MODIS satellite recognized the forest area in urban rivers as urban area for more than maximum 60% compared to WAMIS gauged data, while in forest area, MODIS satellite image showed the error less than 5% of the WAMIS gauged data, which indicates that it has higher applicability in mountainous rivers.

This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation as well as the experimental conclusions that can be drawn.

Author Contributions: B.S. Kim developed the original idea of this study, revised the manuscript and supervised the research project. S.H. Lee analyzed the data and draft preparation under the supervision of the corresponding author. D.H. Kang worked with B to revise the paper and draw conclusions.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix B

All appendix sections must be cited in the main text. In the appendixes, Figures, Tables, etc. should be labeled starting with 'A', e.g., Figure A1, Figure A2, etc.

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