Predicting and Solving the Dangers of Flood in Urban Basins Caused by Torrential Rainfalls: Based on Case Studies of Ansan Stream and Hwajeong Stream

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ABSTRACT: This research was conducted to examine and assess the vulnerability of Korean urban areas to heavy rainfalls and propose a viable solution in preventing floods. The target of this research was Ansan of Gyeonggi Province, an urban area with Ansan and Hwajeong Streams and big river basins.

To determine the status of Ansan's flood precaution, a simulation of heavy torrential rain was run on Ansan urban basins using the model CAMEL. The result was that Ansan is inadequately prepared for heavy rainfalls. Simulation showed that most of Ansan's downtown areas will flood during the heavy rain. From the simulation, a list of regions that are most vulnerable to flooding and attention has been compiled.

To prevent further flooding in Ansan, this research tested scenarios with different flood preventative measures. After comparing different scenarios, it was discovered that reducing the impervious surfaces and adjusting water content and hydraulic conductivity of the soil show a significant decrease in the level of flooding.

1. INTRODUCTION

One of recently arising environmental issues is significantly changed rainfall patterns. According to Korea Ministry of Environment, torrential rainfalls at a rate of 50mm/hour have been observed 111 times in year 2000, which is approximately a 14-fold increase since 1960. Such frequent heavy torrential rainfalls seem to be caused by global warming that increases the Earth's average temperature which in turn influences the rainfall patterns. Global warming creates unusual weather phenomenon, causing more frequent heavy rainfalls and water bombs that ultimately lead to flooding and unwanted casualties. Korea is especially vulnerable to the problems brought by changed rainfall patterns because the country has been facing a severe global warming due to a rapid industrialization of the country in last few decades (according to Korea Meteorological Agency, the average temperature in Korea has increased by 1.5 Celsius in the last century, which twice higher than the world's average temperature increases).

Humans have only been exacerbating the situation by destroying forests and natural environments for development projects. Development projects annihilate protected green-belt areas, an action that increases impervious surfaces and decreases cross-sectional areas of streams. This indicates that the same amount of rainfall as the past is capable of increasing surface runoff and water discharges that lead to higher probability of flooding.

In past two years, Korea experienced several severe floods in the populated areas of Seoul. In September 2010, a heavy rainfall of 198mm flooded the Guanghwamoon area, which has a design capacity of 120mm, just in three hours. In July 2011, Seoul once again experienced a heavy rainfall of 301.5mmjust in a day, the heaviest rainfall in a century, which flooded all areas of Seoul and caused mountain landslides that resulted in several human casualties.

Therefore, this report is dedicated to examine the vulnerabilities of the local cities against the torrential rainfalls during monsoon seasons and to find appropriate solutions to prevent flood disasters. This case study is based on a Korean city named Ansan, its two main streams called Ansan and Hwajeong Streams, and its urban watershed areas.

1.1 Methods of research

This research focuses on Ansan and Hwajeong Streams that flow through downtown of Ansan City to Shihwa Lake. Urban watersheds of Ansan and Hwajeong Streams are adequate subjects for the purpose of studying urban stream flooding cases because Ansan and Hwajeong Streams pass through highly populated residential and business areas of the city. Moreover, Ministry of Land Transports and Maritime Affairs of Korea already carries the model called CAMEL which is necessary for such urban watershed flooding research. Using already well-established and proven model will allow a more accurate and objective case studies

First step to this research is to investigate and evaluate how prepared Ansan City is for torrential heavy rainfalls that may result in a flood. CAMEL is used to simulate a case of an extreme rainfall to predict possible flooded regions and estimate the extent and depth of the flood in square kilometers to analyze its causes. After obtaining running this simulation, different flood scenarios will be created by decreasing impervious surfaces and improving soil characteristics to maximize infiltration capacity. Finally, those scenarios will be tested for efficiencies to find the best solution that minimizes the problems caused by flood.

1.2 Relevant research

As mentioned above, flood caused by heavy torrential rain has been one of the main environmental concerns in Korea. Many researches have conducted experiments and researches to analyze the causes and produce solutions. Some of the notable discoveries are as following.

In a research published in 1996, Kyuwoo Suh used an ILLUDAS model to analyze the effects of soil compaction in the areas around Dongsu Stream in Bupyung City, one of the recently developed areas. He concluded that soil compaction in the targeted area increases both impervious surfaces and surface runoff, which brings up peak discharge and total discharge and brings down peak hours. In a similar research conducted in 2003 by Dongkuk Jung around Noeun watershed in Daejeon region using a SWMM model, it was observed that urbanization increased peak discharges by 20% and decreased peak hours by 25 minutes.

Using the same SWMM model, Junghwa Choi analyzed the changes in hydrological environment caused by urbanization of Jokyung Stream in Junjoo region in 2009 and also came up with a similar conclusion. According to this research, urbanization diminished permeable areas by 55.7% and increased impervious surfaces by 33.4%, which dropped flood travel time by 53 minutes and raised peak discharges from $4.37m^3/s$ to $111.13m^3/s$.

In the most recent research conducted in 2011, Jiwoong Jang divided Kwangju City into impervious and permeable areas and analyzed water runoff per rainfall frequencies using a XP-SWMM model. He discovered that Yongbong business area with a lot of cemented surfaces has two to three times greater runoff than green areas around Jeonnam University park or Woosandong residential area.

Most researches mentioned above show limitations in that they only consider a simple relationship between urbanization and corresponding increase in impervious area when examining the causes of flooding. Therefore, in order to add complexities to previous researches, this research added more variables, such as water contents and hydraulic conductivity, along with impervious surfaces, to model real life situations more closely and to provide more practical solutions.

2. CASE STUDIES AND ANALYSIS MODELS

2.1 Objects of case studies

Ansan Stream starts from a joined boundary of Ansan Town and Anyang Town of Ansan and flows 1.4km south to join Jangha Stream. After that, Ansan Stream is also joined by one of small local streams called Jangsang Stream at a point 1.3km away from its intersection with Jangha stream. The stream keeps flowing south where it is once again joined by Bukok Stream from the left and Yangsang Stream from the right. The main Ansan Stream then passes through the center of the city and is joined by Hwajeong Stream at a point 0.7km before the river mouth to finish its journey at Shihwa Lake or West Sea. Size of the river watershed is $51.08km^2$ and the length of flow channel is 12.56km. To sum up, Ansan Stream flows through a total area of $51.08km^2$ that consists of 44% forest, 11% farmlands, 16.6% urban areas, and 29.2% rest, passing through 19 towns where a population of 449,060 resides in 161,429 households.

Hwajeong Stream, one of the main tributary streams of Ansan Stream, starts flowing from a valley in a mountain at a boundary of Sanhyun Town of Siheung City and Hwajeong Town of Ansan City. It is joined by a nameless stream on its way south; after passing through the center of Ansan City, it joins Ansan Stream at a point located 0.6km into the lower reaches of Ansan Stream. Mountains and farmlands are located in the upper region of Hwajeong Stream and Ansan downtown area is located in the lower reaches. In the lowest reach of the stream, Gojan New-town and high-rise apartment buildings are located. Hwajeong Stream watershed is considered as a typical urban watershed that consists of 54.1% urban areas, 35.7% forest, and 7.7% farmlands. The stream stretches from north to south, 7.75km long, running through eight towns in Ansan City where 161,330 people live in 60,569 households.

2.2 Soil distribution and uses

One of the important factors that determine the runoff percentage of rainfall is the soil type, which directly affects the infiltration capacities.

According to soil criteria described by National Institute of Agricultural Science and Technology that grades draining capacities of soils with A(excellent), B(good), C(little poor), and D(very poor), Ansan watershed area consists of 22% type A soil(11.18km^2), 44% type B soil (23.06km^2), 5% type C soil (2.81km^2), and 29% type D soil(14.93km^2).

Ansan Stream urban watershed consists mostly of forests that stretch over 22.90km^2 and takes up 44% of total land. Other land uses of urban watershed are 11.5% farmlands (5.99km^2), 16.6% urban areas and building sites (8.63km^2), and 27.8% rest (14.46km^2). Hwajeong Stream urban watershed is mostly used for urbanization and constructions, which accounts for 54% of the land uses, with the rest used as 35.7% forests (5.34km^2) and 7.7% farmlands (1.16km^2).

Examining the land usage of Ansan and Hwajeong Stream urban watershed shows that 1/3 of the urban watershed is urban areas, where the surfaces are mostly impervious to water. Therefore, if the city encounters a heavy torrential rainfall, the city is vulnerable to flooding because the land surfaces have low infiltration capacities and will allow a high runoff rate.

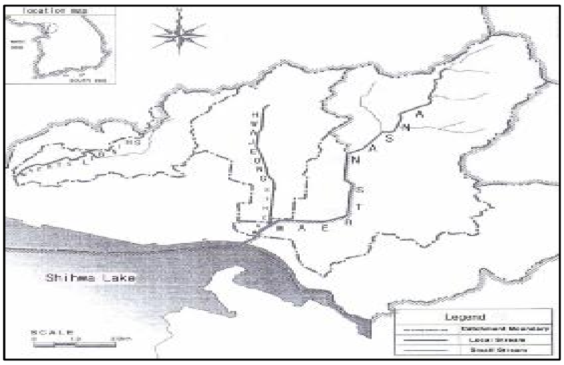


Fig.1 Ansan river system
(Source : Ansan Stream master plan, 2009)

Infiltration is when water is absorbed into soil from land surface by gravity and capillary action. Once water is in the soil, it moves in a transverse direction from the surface layer to create an intermediate flow or moves vertically to reach groundwater level. Such vertical flow, caused by gravity, is called percolation. Percolation and infiltration are closely related because without percolation, water cannot infiltrate the soil.

Infiltration capacity, the maximum infiltration rate which is measured in mm/hr or in/hr, is affected by several conditions, some of which are types of soil and state of the soil surface. Infiltration capacity is also determined by water content and hydraulic conductivity of the soil. Saturated Water Content refers to a quantity of water that a certain material holds, and is measured in a fraction scale from zero (completely dry) to one (completely saturated) scale. Hydraulic conductivity, or K, represents how easily water can move inside a material through cracks or capillary tubes. Hydraulic conductivity is determined by intrinsic permeability of the substance and the saturation state. K_{sst} is specifically for indicating hydraulic conductivity of a substance that is completely saturated.

2.3 Construction Methods for Improving Infiltration Capacity

Typical construction methods used to improve infiltration capacity to prevent flooding disasters are porous pavement, infiltration side gutter, infiltration barrel, infiltration trench.

a) Porous pavement

As mentioned above, porous pavement uses porous materials so that rainfall can penetrate the covered area through the filter layer to infiltrate the ground. Types of porous pavements vary according to its materials, some of which are asphalt, cement, or flat precast pavers. It is usually used to pave sidewalks, roads with light traffic, or parking lots. Its disadvantage is that it requires more frequent maintenance compared to other pavement techniques.

b) Infiltration side gutter

This method uses porous materials to fill the floor and the sides of the gutters and let the collected water infiltrate the ground through those gutters. It is usually used in combination with infiltration barrels in parks, parking lots, playgrounds, and roads. Its disadvantage is that sometimes substances other than water, such as garbage, soils, and sand flows into the gutter, which calls for extra care in maintenance.

c) Infiltration barrel

For this method, crushed stones are placed around permeable barrels and allow water to infiltrate the ground through the barrels. This method is usually appropriate for locations with small water collection. In case of high water collection, infiltration barrel alone does not suffice to reduce the water runoff, so it is installed together with infiltration trenches and other vehicles. The infiltration barrel consists of a body, filled crushed stone, permeable sheet, connection pipe, collection pipe, drain pipes, subsidiary facilities, and prevention clogging facilities.

d) Infiltration trench

This method fills a ditch with crushed stones and places infiltration barrel in the middle with perforated drain pipes to conduct infiltration. This is usually used for green belts or grounds with high permeable capabilities.

2.4 About the model

Due to the lack of an appropriate model that will follow the real-life conditions closely to produce the most accurate outputs, CAMEL (Chemicals from Agricultural Management and Erosion Losses), a distributed model that was first developed by Macaulay Institute in the United Kingdoms, was decided as the hydrological model for this research. CAMEL uses process-based formulas and allows modifications to simulate pipe network water runoff which were other essential criteria, as mentioned above, in determining the hydrological model to most accurately simulate urban watershed flooding. For this research, CAMEL 2.0, which has been modified to follow the domestic environment, was used.

CAMEL 2.0 is a distributed model that is designed to analyze the water flows on and under the land surface in river watersheds over a long period of time.

CAMEL 2.0 divides the target river watershed into individual 3-dimensional square prisms defined as cells. Cells are lined up in a grid to form the river watershed, and each cell can have at most eight adjacent cells. Top part of the cell is considered as the soil and bottom part is the aquifer. The stream is located on top of the cell and gradient of the stream is modeled by slope of the cells.

In order to run CAMEL 2.0, following variables have to be inputted: climate, topography, vegetation, soil, aquifer, and stream

3. RESULTS

3.1 Simulation overview

Factors that trigger flooding, peak flow and time to reach, are influenced heavily by infiltration which is dependent on the characteristics of soil. Considering these facts, four scenarios, as demonstrated in Tab.1 are simulated and tested. First scenario is created by changing the impervious surfaces in Ansan and Hawjeong urban watersheds to see how these changes affect flooding. Then, three other scenarios are created by tweaking the first scenario to improve the water content of soil and hydraulic conductivity to see what would be the best solution to minimize the flooding damages. To carry out a case-specific simulation, few more variables has to be added to the CAMEL model that was already calibrated and verified from prior researches. New variables are rainfall values, areas of impervious land surfaces, water content and hydraulic conductivity of the soil. Such additions are necessary so that a meticulous observation is conducted to seek the best possible solution to prevent flooding disasters.

Tab.1 Simulation scenarios

SCENARIO No.	land use	soil	
	ratio of impervious area	saturated water content (porosity)	saturated hydraulic conductivity (m/day)
1	50% decrease of urban impervious area	current condition	current condition
2		0.5	2
3		0.6	3
4		0.7	4

3.2. Simulation results

a) Flood Situations of Ansan and Hwajeong Watersheds during Extreme Rainfall

Given the current conditions and the assumption that Ansan experiences a rainfall at 96.6mm per hour, the flood situations in the urban watersheds of Ansan and Hwajeong Streams are as displayed in Tab.2.

Tab.2 Flooded areas of Ansan and Hwajeong watersheds during extreme rainfall

		non - flooded (ha)	flooded(ha)						
flood depth (m)		0	total flooded	0.00-0.05	0.05-0.10	0.10-0.50	0.50-1.00	1.00-2.00	> 2.00
elapsed time	30min	3307 (64.7%)	1801 (35.3%)	1743	26	27	5		
	60min	3295 (64.5%)	1813 (35.5%)	1582	156	41	22	8	4
	120min	3474 (68.0%)	1634 (32.0%)	1487	103	26	7	4	7

b) Flood Situations for Each Scenario

Flood simulation results for each scenarios are as displayed in Tab.3.

Tab.3 Flooded areas for each scenario(after 30, 60, 120 minutes rainfall)

			non - flooded (ha)	flooded(ha)					
flood depth(m)			0	0.00-0.05	0.05-0.10	0.10-0.50	0.50-1.00	1.00-2.00	> 2.00
area (ha)	current	30min	3307	1743	26	27	5		
		60min	3295	1582	156	41	22	8	4
		120min	3474	1487	103	26	7	4	7
	sce. 1	30min	3320	1737	18	28	5		
		60min	3300	1608	128	39	21	7	5
		120min	3500	1465	100	25	7	4	7
	sce. 2	30min	3342	1735	10	19	2		
		60min	3322	1689	39	34	15	6	3
		120min	3716	1336	25	14	9	4	4
	sce. 3	30min	3429	1660	6	11	2		

		60min	3380	1693	4	21	4	4	2
		120min	4100	995	2	5	3	2	1
	sce. 4	30min	3429	1661	7	9	2		
		60min	3427	1652	3	17	3	4	2
		120min	4268	831	1	5	1	2	

3.2. Analysis

a) Analyzing Flood in Current Conditions

Tab.2 and Tab.3 show that if it rains at a rate of 96.6mm per hour, Ansan downtown area and most of Ansan and Hwajeong Streams watershed will be flooded after 30 minutes of rain. At this point, flooding is very slight, water level reaching only up to 5cm in most areas. After 60 minutes of rain, flooding becomes more serious, with water level doubling up to a number between 5~10 cm. Fortunately, flooding is still contained in the same areas, but in some of these areas, cases of extreme flooding with the water level at 1m are observed. Based on these observations, Ansan urban watershed areas can be broadly categorized as a “dangerous” area that encounters flooding even in the early stage of rain and a “safe” area that remains relatively unharmed from flooding even after some time has passed. Damages brought by flood also show big fluctuations across different areas within the city.

After 120 minutes of rain, water starts to drain after reaching its peak point during sometimes in 60 minutes of rain. The overall flooded area decreases by 3.5% (1.79 km2) from 32.0% (16.34 km2) and water level also decreases slightly. However, the general flood situations have not been improved and damages caused by flooding continue to be visible.

From this simulation, six areas that seem to be most vulnerable to flood are selected.

1) Streams around Hwajeong Elementary School located in the upper region of Hwajeong Stream watershed: the area starts to flood with water levels reaching between 50cm and 1m even before the 30-minute window. After 60 minutes has passed, the flood damage approximately doubles.

2) Cross roads between Wallpi1 Bridge and Ansan Interchange near Ansan Stream: This is the point where Yangsan Stream joins Ansan Stream. After it starts raining, flooding starts from the streams around the Wallpi Bridge and inundates the upper streams. After the 60-minute point, flooding has affected Ansan Interchange and nearby residential areas as well.

3) The point where Hwajeong Stream meets Ansan Stream: Three towns in this area, Hosu, Choji, and Sa III, have shown water levels higher than 5 cm within the 60-minute time frame.

4) Hanyang University Station: This area, including its nearby residential towns, is not near one of the main streams in Ansan, but lacks proper drainage system. Some of the residential areas in this area have shown heavy flooding with water levels ranging from 10cm to 1m in the first 30-minute time frame.

5) Hwajeong Bridget #3 located in the upper region of Hwajeong Stream: Flooding spreads very quickly only after the 30-minute point, but overall, water level is observed to be lower than 5 cm.

6) Residential areas near 42nd Street of Boogok Town: This location is where two tributary streams merge together. Flooding is caused in the later period when the stream, incapable of holding all the water that flows from the upper streams, inundates. This area has relatively light flood damages compared to other areas.

From this simulation, it can be concluded that Ansan is not well-prepared for the extreme cases of torrential rains due to lack of proper drainage systems, pipe networks, and maintenance of local streams.

b) Comparing different scenarios

Results show that Scenario 1, where imperious surfaces have been decreased by 50%, is the worst scenario in which the flooded area only decreases by 0.05km^2 from 18.13km^2 (a 0.28% drop) after the 60-minute time frame where draining is supposed to occur. However, after altering water content and hydraulic conductivity of soil step- by-step in subsequent scenarios, the flooded area decreases as much as 1.32km^2, which is a 7.28% drop. Such improvement is represented visually by comparing Fig.2, Fig 3, and Fig 4.

Fig.2 Flood simulation results under Scenario 1 conditions

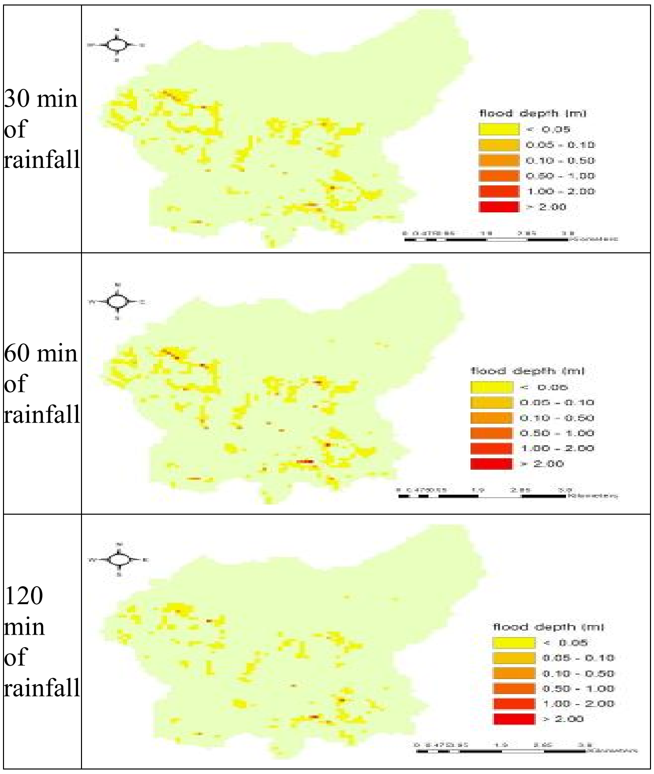


Fig.3 Flood simulation results under Scenario 4 conditions

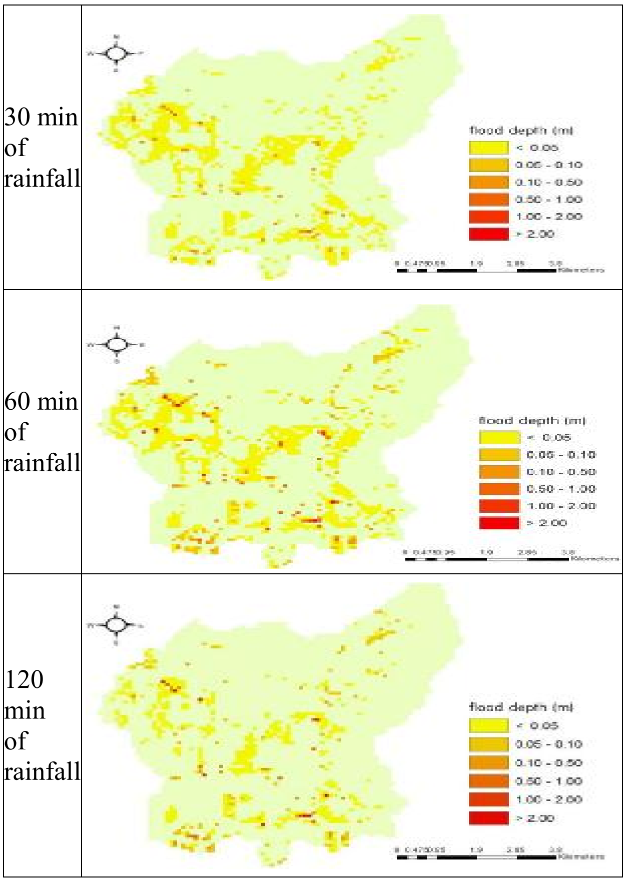
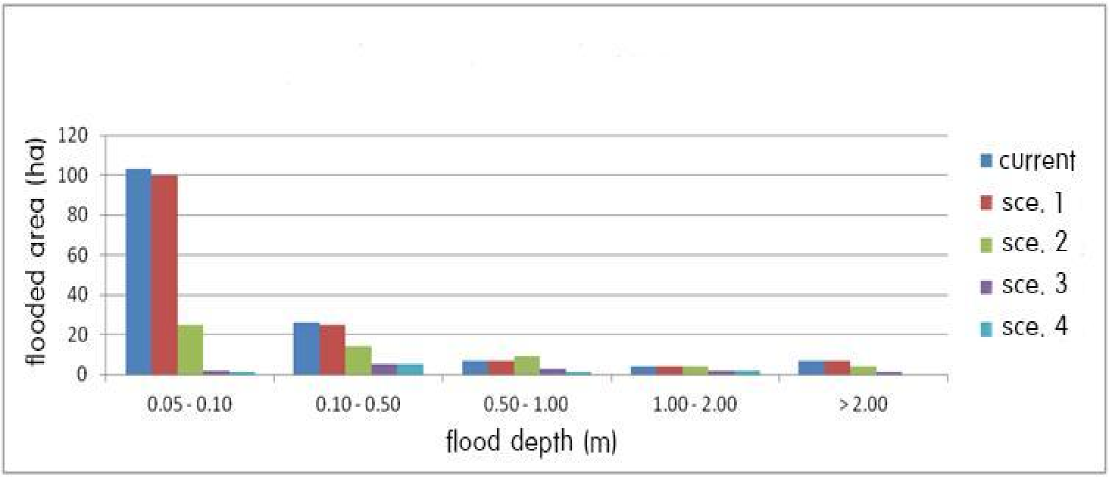


Fig.4 Flooded areas for each scenario (after 120 minutes)



b) Improvements to Prevent Flooding

Simulation results show that flooding damages can be minimized by improving the values of water content and hydraulic contents. However, a complete control over flooding is impossible because of several extraneous factors.

In other previous researches on containing flood damages, decreasing impervious areas proved to be very effective. However, the same theory cannot be applied to Ansan's case because the simulation showed that the changes in flooded areas due to decreasing impervious areas are minimal. The result is affected by the topographical characteristics of Ansan. Ansan Stream has its tributary streams concentrated in its upper region. However, the process of decreasing impervious surfaces is usually conducted in the lower regions of streams, which is of little help in the case of Ansan. Simulation results show that improving the characteristics of soils to have higher water content and higher hydraulic conductivity also have only limited effect in minimizing the flooding disasters. Lastly, Ansan is not equipped with proper pipe networks and drainage systems to handle the high amount of water flow in the case of torrential rains.

Therefore, in order to prevent flooding in Ansan Stream watershed, solutions should be customized. The plan to decrease impervious surfaces by increasing water content and hydraulic conductivity of the soil should be conducted along with upgrading the city's drainage system and pipe network.

Even though this simulation is modeled for an extreme case, given the recent flooding incidents, it should be understood that such extreme cases are becoming more common. Therefore, it is important for the city to anticipate and plan for even the most extreme outliers in terms of preparing for natural disasters.

4. CONCLUSION

This research concentrates on finding solutions to flooding problems that is occurring more and more frequently in local cities of Korea by doing a case study on Ansan and Hwajeong Stream. The research is conducted using a simulation model called CAMEL that allows an objective examination of the targeted flooded areas, of the depth and scope of floods, and their causes to devise an appropriate solution. Four different flooding scenarios are created in order to test the efficiency of the plans to decrease impervious surfaces and improve infiltration, a strategy based on the theoretical problem-solving of this situation.

Assuming a rainfall at a rate of 96.6mm/hr and using CAMEL to simulate the situation, it is shown that 35.3% (18.01 km2) of Ansan and Hwajeong Stream urban watersheds are flooded within the 30 minutes. In this stage, 97.1% (17.43 km2) of the flooded areas show water level lower than 5cm. After 60 minutes, the flooded area remains approximately the same as before. However, areas showing water level lower than 5cm decreased to 87.3%(15.82km2) whereas areas showing water level between 5 and 10cm expanded to 1.56km2. Overall, the water levels rise and even places with extremely high water levels above 1m begin to appear. After 120 minutes, which is 60 minutes after raining has stopped, water starts to drain out but there are only slight improvements in flooding. Through this simulation, it was possible to extract six areas within Ansan that are especially vulnerable to flooding and require special attention, which happened to be areas near joined streams or with bad drainage systems.

In order to come up with a solution to prevent flooding, different scenarios with controlling variables of impervious surfaces, water content and hydraulic conductivity of soil to improve infiltration are tested and compared. However, those solutions only demonstrate slight improvements because of the topographical characteristics of Ansan that counteract the solutions. As a result, what Ansan requires other than improving infiltration capacity of the soils is upgraded artificial draining systems focused especially on the vulnerable areas with improved capacities and larger pipe networks. Further research will be required to come up with more detailed and customized plans in determining how to improve the current systems.

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