A Simulation-based Modeling Approach to Adapt Social-Ecological Green Infrastructure System for Resilient Urban Flood Management

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This research was supported by the Core Research Institute Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Education.
Grant number: NRF-2021R1A6A1A10045235

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01. Introduction

- 1.1. Background
  - 1.1.1. Study Site
  - 1.1.2. Problems
  - 1.1.3. Possible Solutions
- 1.2. Objectives
- 1.3. Research Questions

01. Introduction

1.1. Background

1.1.1. Study Site

Site : Yeoksam-dong, Gangnam-gu, Seoul.
Area : 3.50 ㎢
Average Slope : 39.6m
Population : 71,559 (2023.02)
Population Density : 20,445.43 / ㎢
Competent Administrative Dong : Yeoksam 1-dong, Yeoksam 2-dong

Figure 1: Study Site- Yeoksam-dong Area

01. Introduction

1.1. Background

1.1.2. Statement of the Problem

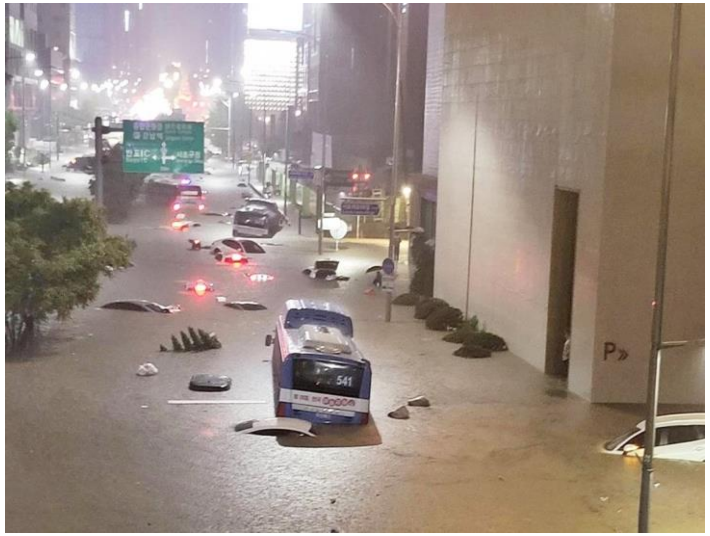
- **Heavy Flash Flood**
- **Sewage Overflow**
- **Property Damage**
- **Human Death**

01. Introduction

1.1. Background

1.1.2. Statement of the Problem

Source: https://www.donga.com/news/Society/article/all/20220809/114868488/1



Source: https://autopostkorea.com/95199/

Source: https://autopostkorea.com/95199/

Figure 2: Gangnam District Flooding (2022/08/08)

01. Introduction

1.1. Background

1.1.2. Statement of the Problem

- What are the reasons for this problems?

I. Climate Change

II. Seoul's Drainage System

III. Urban Planning of Gangnam district

So

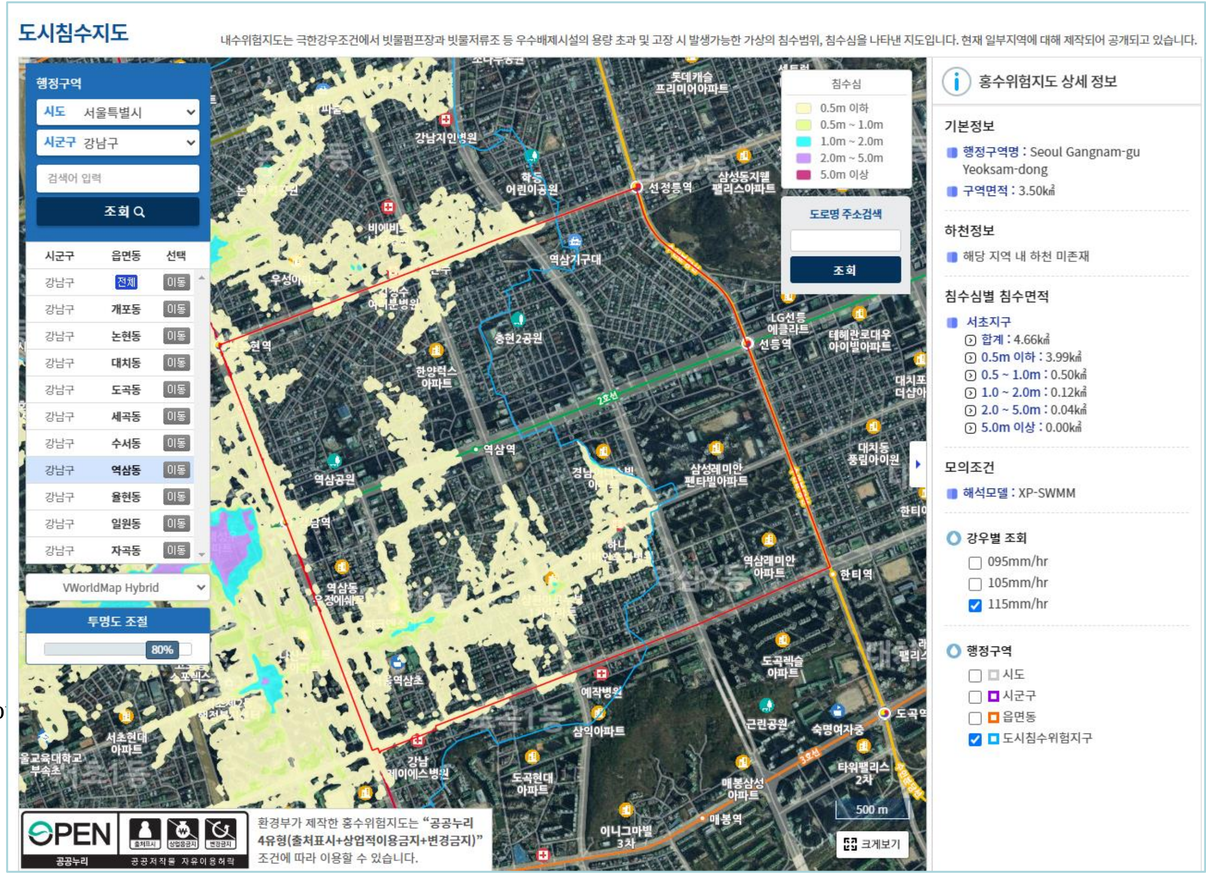


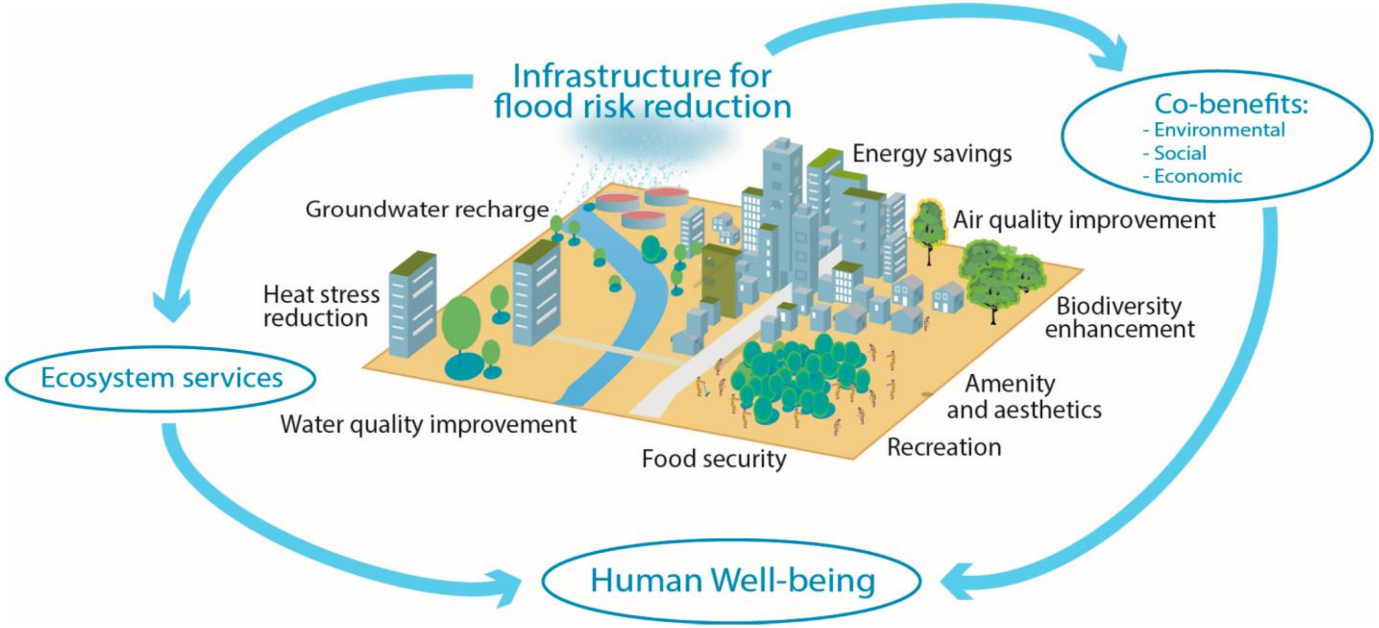
Figure 3: Flood Risk Map of Yeoksam-dong Area

01. Introduction

1.1. Background

1.1.3. Solution

- What can be the solutions for this problems?
  - **Green Infrastructure (GI) Planning**



Source: Tzoulas et al., 2007; Haines-Young, R., & Potschin, M. 2010

Figure 4: Links between green infrastructure for flood risk reduction, ecosystem services, human well-being, and co-benefits

01. Introduction

1.2. Objectives

I. To evaluate and propose the best combination of Green Infrastructure scenarios for resilient urban flood control in the Yeoksam-dong area in the Gangnam district.

1.3. Research Questions

I. What is the current condition of flood control in the Yeoksam-dong area?

II. What GI scenarios can be proposed for improving the flood control in the study area?

III. What are the practical implications of the study's findings for the implementation of GI in other urban areas facing similar stormwater management issues?

01. Introduction

Research Framework

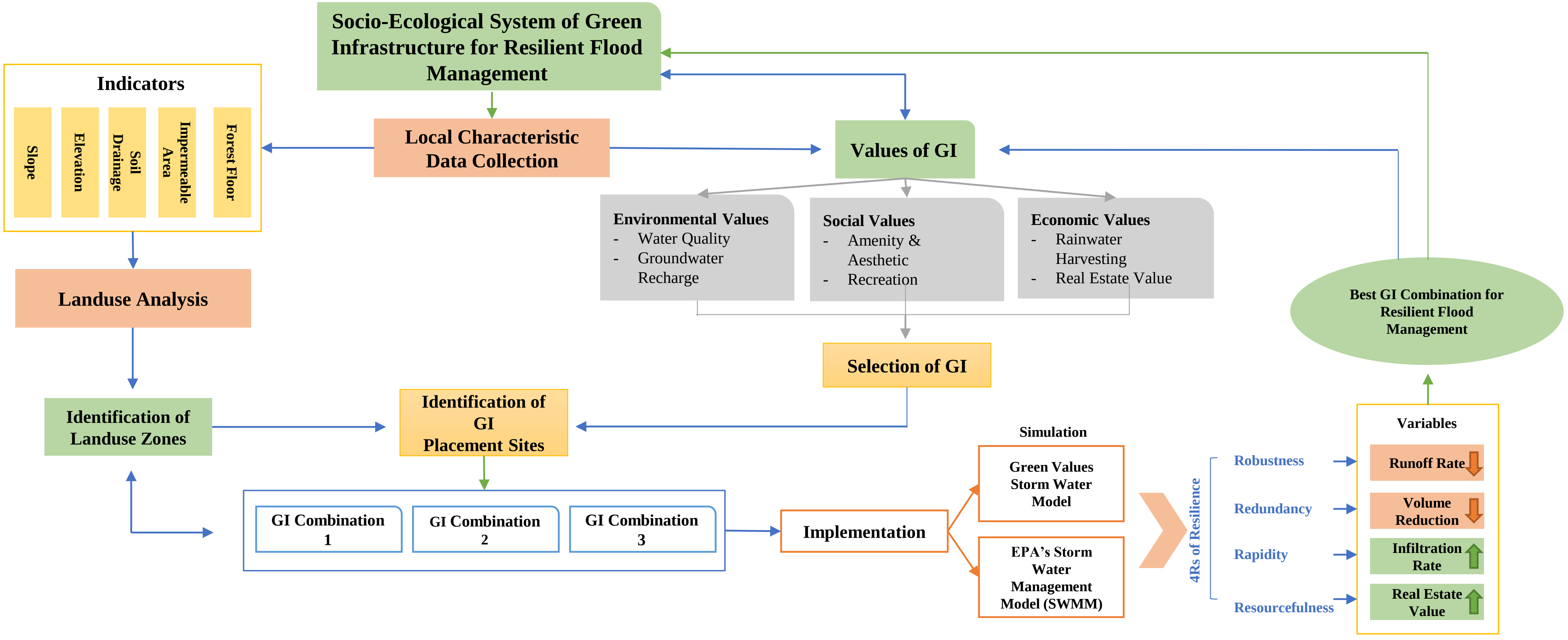


Figure 5: Research Framework

02. Research Methodology

- 2.1. Research Flow
- 2.2. Study Area
- 2.3. Research Steps
  - 2.3.1. Landuse Analysis
  - 2.3.2. GI Planning Scenarios
  - 2.3.3. Simulation

02. Research Methodology

2.1. Research Flow

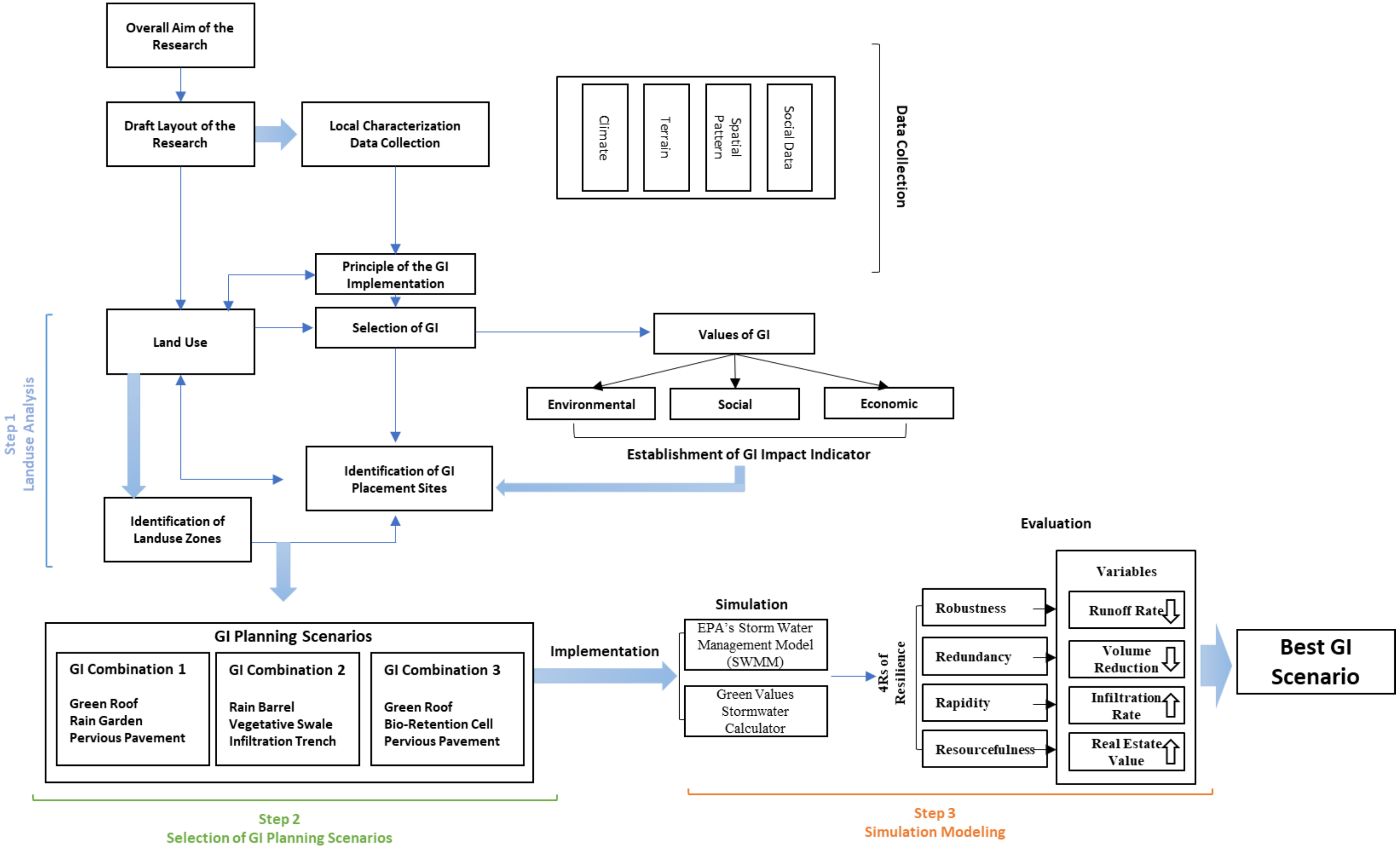


Figure 6: Research Flow

02. Research Methodology

2.2. Study Area

Data Collection:

- Local characterization data of the study area were collected.
- 5 indicators were used.

Slope
Elevation
Soil Drainage
Impermeable Area
Forest Floor

- Rainfall, temperature, landuse and other hydrological data of the study area were also collected.
- Direct site visit, existing works in the study area, literature review and spatial analysis were used to collect the data

02. Research Methodology

2.3. Research Steps

2.3.1. Step 1: Landuse Analysis

- A Landuse analysis was conducted to identify the specific Landuse zones in the Yeoksam-dong area in the Gangnam district.
- Direct site visit and spatial analysis by QGIS was used for evaluating the landuses in the site.

02. Research Methodology

2.3. Research Steps

2.3.1. Step 1: Landuse Analysis

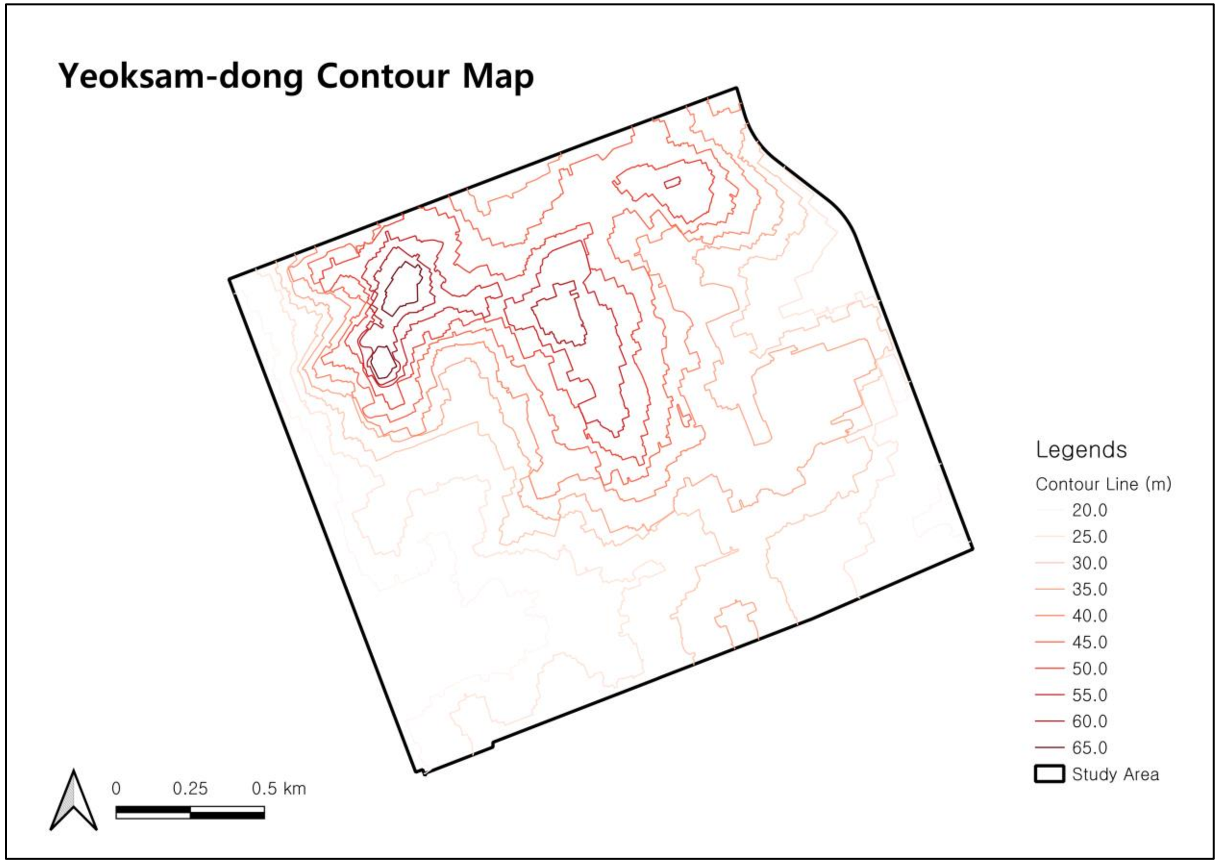


Figure 7: Yeoksam-dong Contour Map

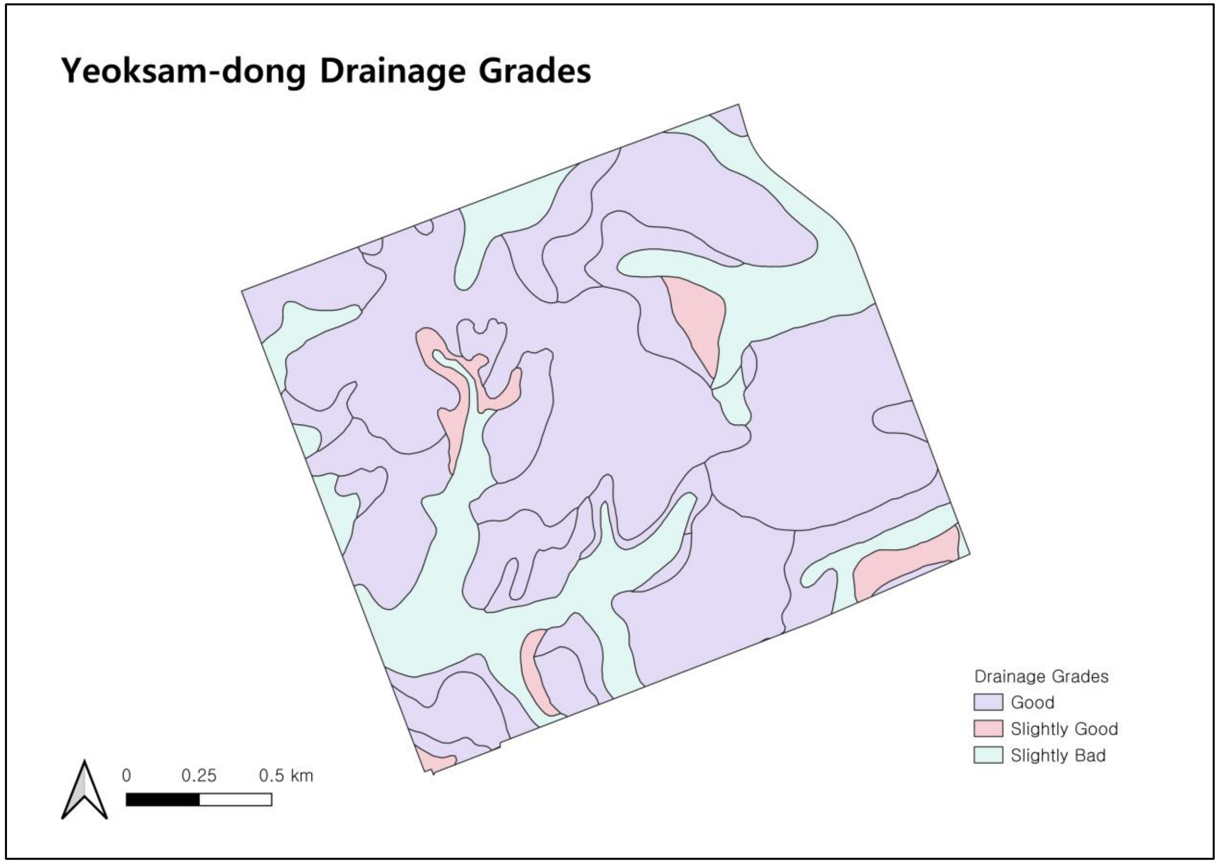


Figure 8: Yeoksam-dong Drainage Grade Map

02. Research Methodology

2.3. Research Steps

2.3.1. Step 1: Landuse Analysis

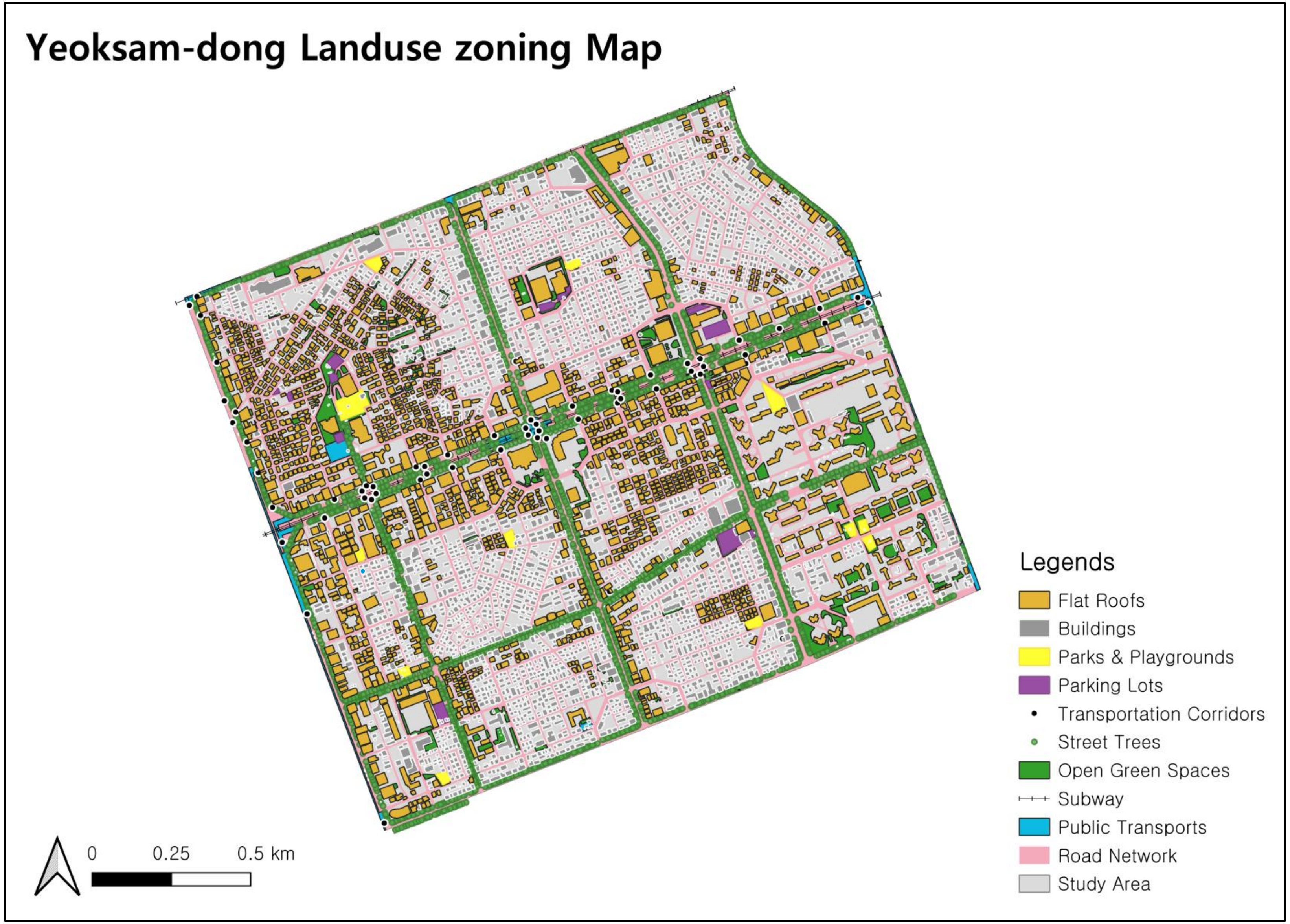


Figure 9: Yeoksam-dong Landuse Zoning Map

02. Research Methodology

2.3. Research Steps

2.3.2. Step 2: GI Planning Scenarios

I. Identifying GI benefits

- **Economic Values**
  - Rainwater Harvesting
  - Real Estate Value
- **Social Values**
  - Amenity & Aesthetic
  - Recreation
- **Environmental Values**
  - Water Quality
  - Groundwater Recharge

4Rs of Resilience	Theoretical Concept	Flood Adaptive GI Planning
Robustness	Ability or strength to withstand	Reduce runoff
Rapidity	Rate of system recovery and capacity to restore to a given performance level	Adjusting rate of rainwater runoff
Redundancy	Extent to which elements, systems, or other units of analysis exist that are substitutable	Control the flow rate and volume of rainwater
Resourcefulness	Capacity to identify problems and mobilize resources	Network construction of social and ecological disaster prevention facilities

Sources: Bonstrom and Corotis (2016), Cimellaro et al. (2010), Tierney and Bruneau (2007)

Table 1: Strategy for food-adaptive green infrastructure planning utilizing the 4Rs of resilience

02. Research Methodology

2.3. Research Steps

2.3.2. Step 2: GI Planning Scenarios

II. Establishing GI Benefits Impact Indicators

	Environmental		Social		Economic	
Name	Water Quality	Ground Water Recharge	Amenity & Aesthetics	Recreation	Rainwater Harvesting	Real Estate Value
Bio-Retention	4	2	5	1	1	3
Rain Garden	4	1	5	1	1	3
Pervious Pavement	4	3	2	1	2	1
Green Roof	3	0	4	3	1	3
Vegetative Swale	4	2	3	3	1	1
Infiltration Trench	5	4	3	1	2	2
Rain Barrel	0	3	0	0	5	2

Sources: Woods-Ballard et al. (2007), Shoemaker L. et al. (2009), Berghage R. et al. (2009), Jia H. et al. (2013).

Table 2: GI Benefits Impact Factor

02. Research Methodology

2.3. Research Steps

2.3.2. Step 2: GI Planning Scenarios

III. Identification of GI Placement Sites

- Total Area: 3,500,000 ㎡
- Residential Area: 845,594.28 ㎡ (24.1%)
- Commercial Area: 1,115,176.35㎡ (32.5%)

- Imperviousness: Around 90%
- Perviousness: Around 10%

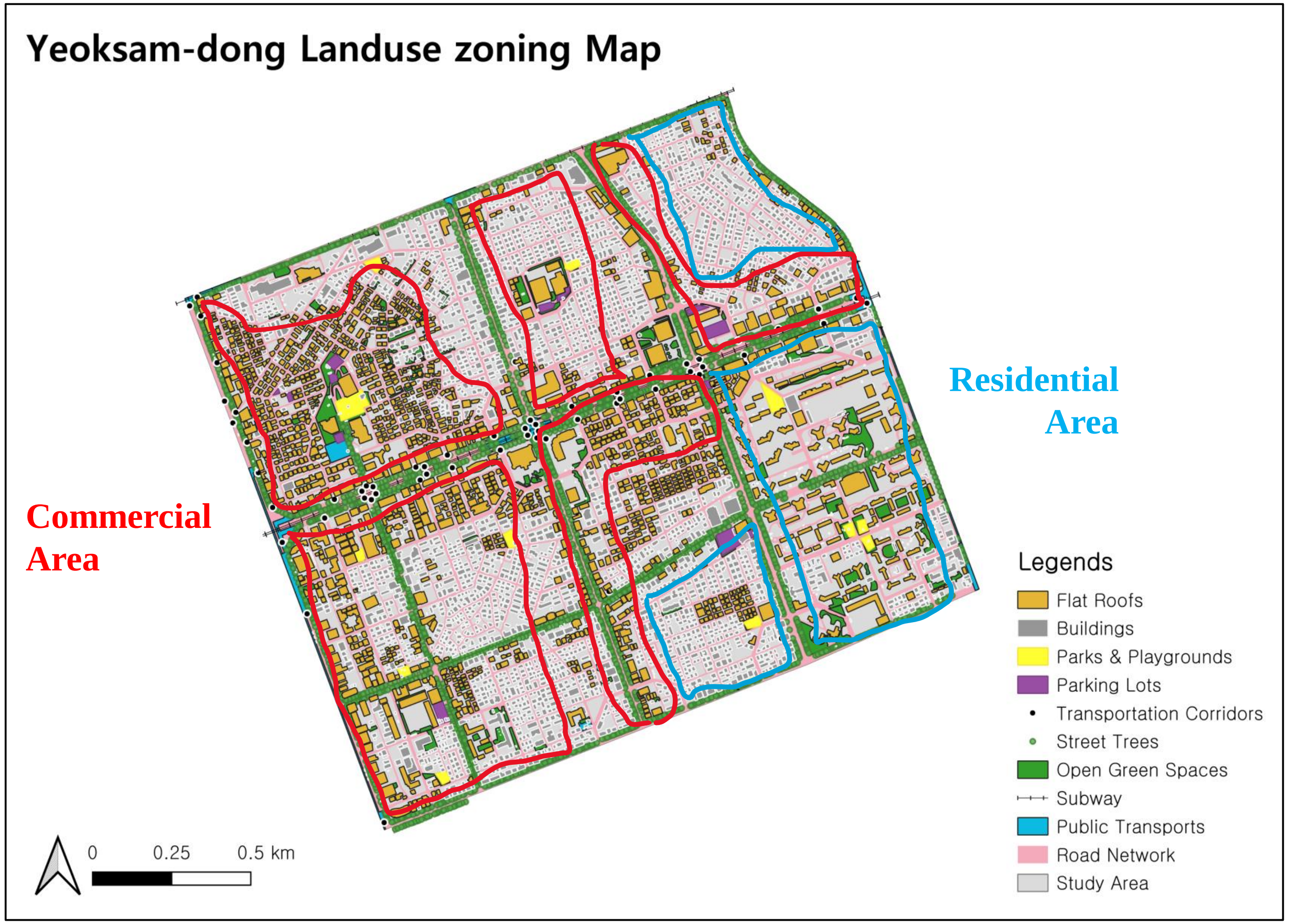


Figure 10: Yeoksam-dong Landuse Zoning Map

02. Research Methodology

2.3. Research Steps
2.3.2. Step 2: GI Planning Scenarios

III. Identification of GI Placement Sites

- Total Area: 3,500,000 ㎡
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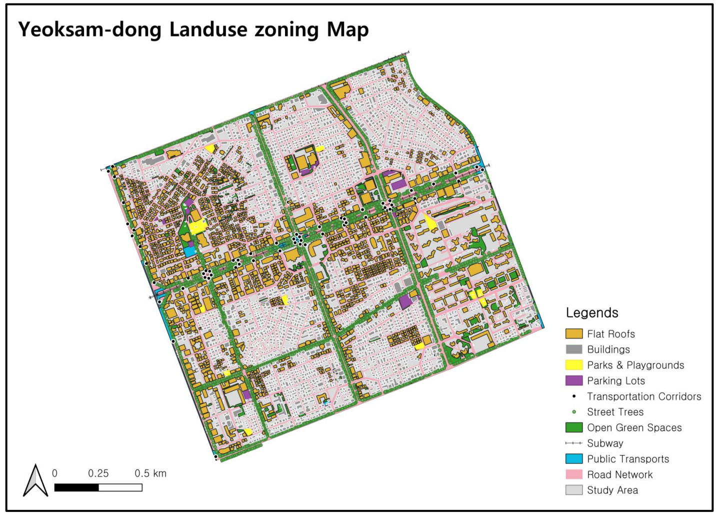


Type of Site	Bio-Retention	Rain-Garden	Green Roof	Vegetative-Swale	Infiltration Trench	Pervious pavements	Detention pond	Retention pond	Rain Barrel
Flat roofs									
Parking lots									
Transport corridor									
Green Spaces									
Parks									

Sources: Woods-Ballard et al. (2007), Shoemaker L. et al. (2009), Berghage R. et al. (2009), Jia H. et al. (2013).

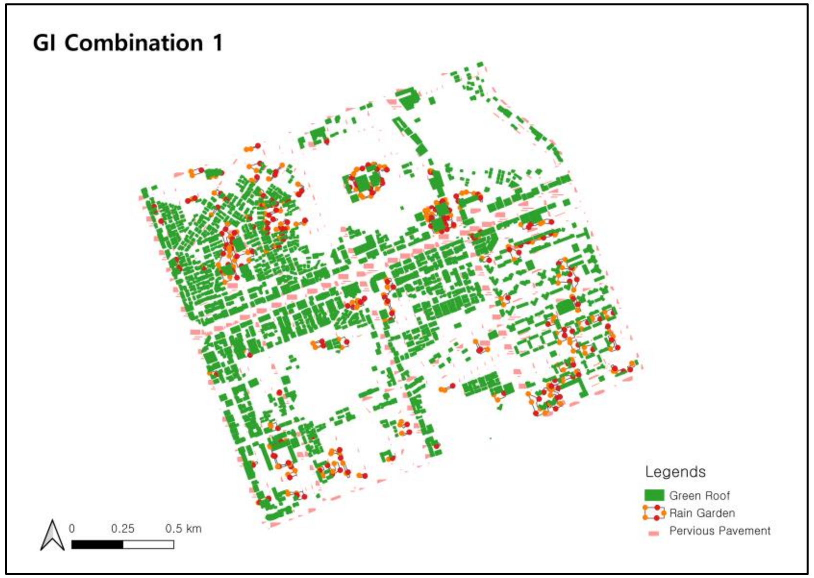
Table 3: Yeoksam-dong GI Placement Sites

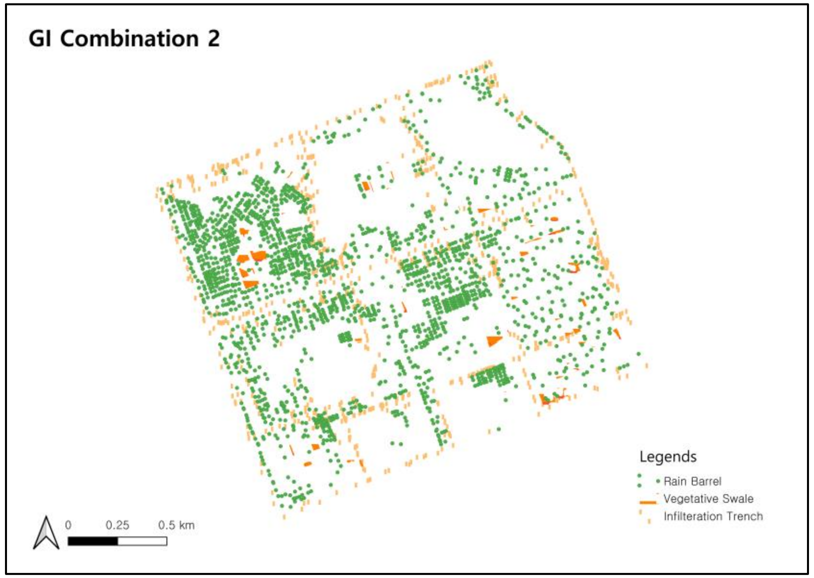
02. Research Methodology

2.3. Research Steps

2.3.2. Step 2: GI Planning Scenarios

Combination 1	Combination 2	Combination 3
Green Roof	Rain Barrel	Green Roof
Rain Garden	Vegetative Swale	Bio-retention
Pervious Pavement	Infiltration Trench	Pervious Pavement





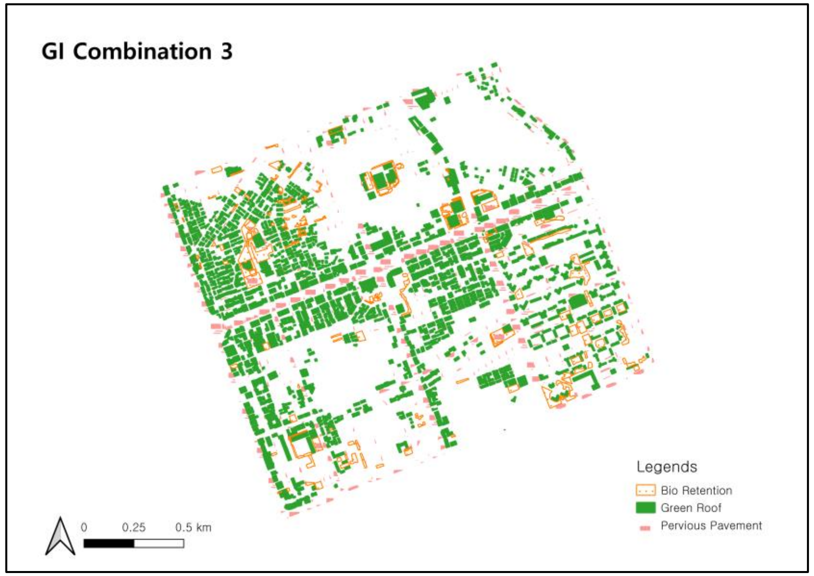


Figure 11: Yeoksam-dong GI Planning Scenarios- 3 Combinations

02. Research Methodology

2.3. Research Steps

2.3.3. Step 3: Simulation Modeling

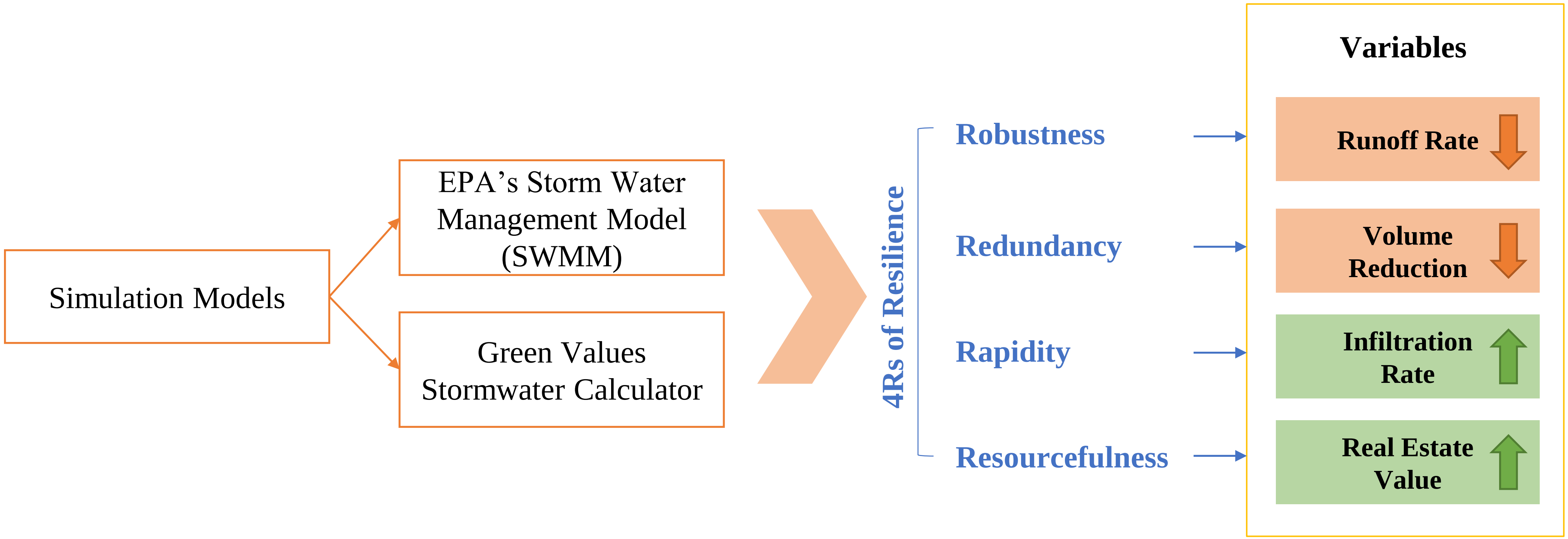


Figure 12: Simulation Modeling Framework

02. Research Methodology

2.3. Research Steps

2.3.3. Step 3: Simulation Modeling

I. SWMM

- 12 Hours Simulation
- 10 mins Interval
- 2022/08/08, 11:59am to 11:59pm

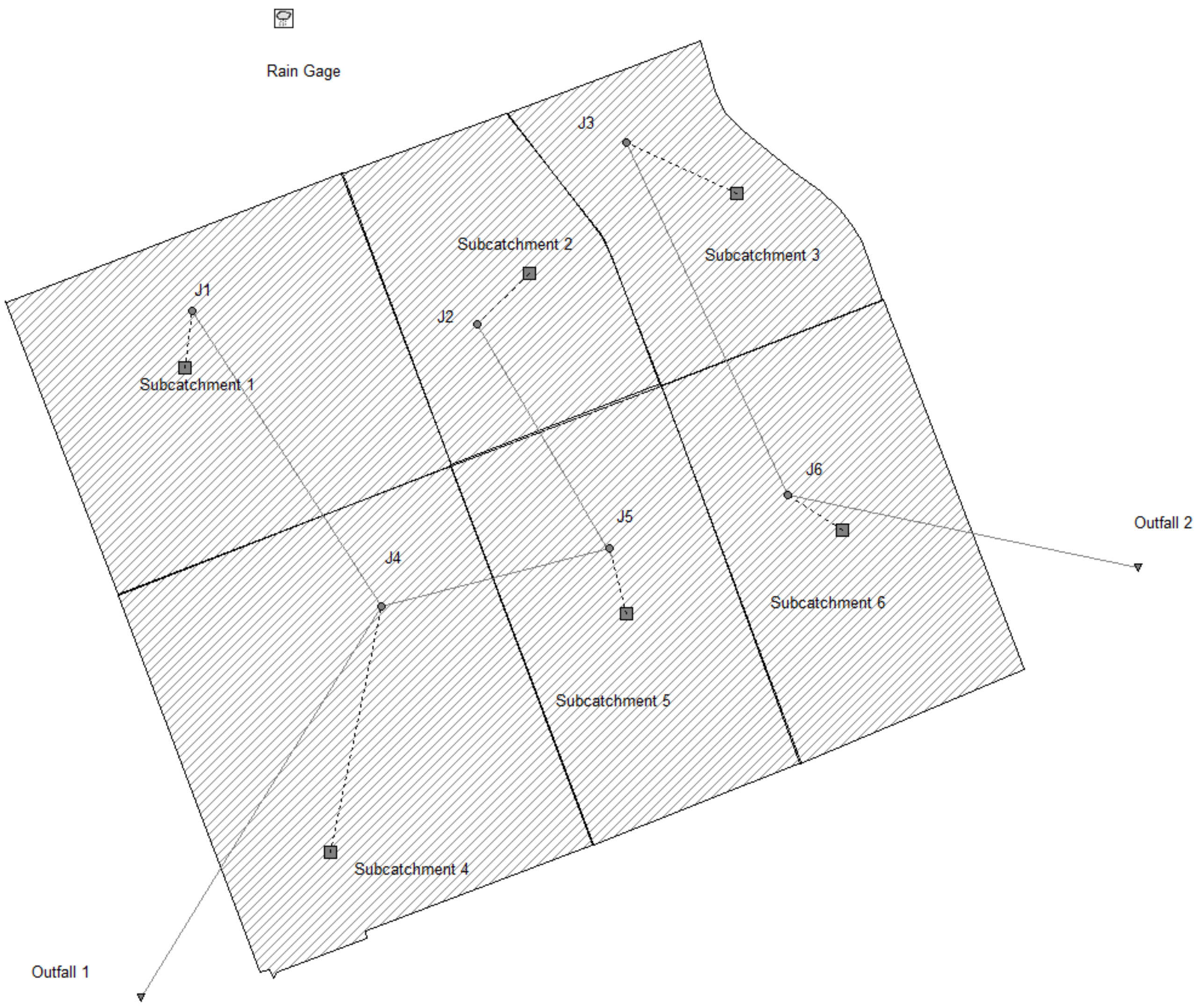


Figure 13: Study Area map on SWMM

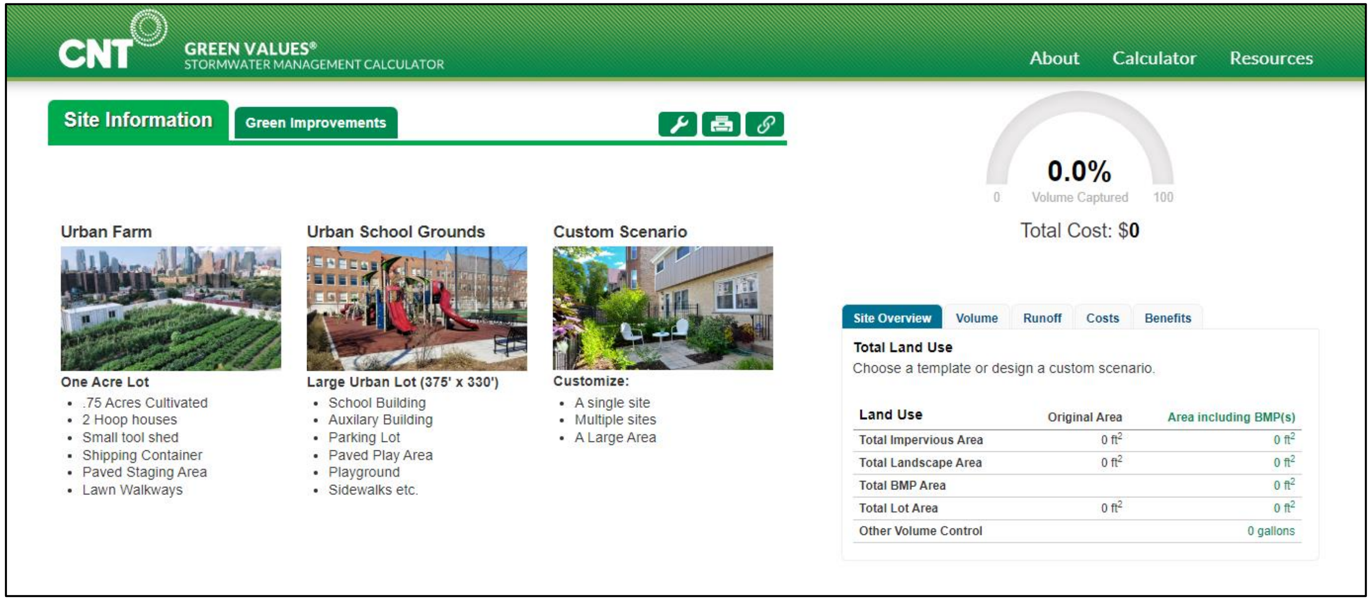
02. Research Methodology

2.3. Research Steps

2.3.3. Step 3: Simulation Modeling

II. Green Values Stormwater Calculator

- Custom Scenario for Large area
- Calibrated for the Study Site
- Average Standard Price for GI selected



Source: https://greenvalues.cnt.org/index.php#calculate

Figure 14: Green Values Stormwater Calculator

03. Results

- 3.1. EPA Stormwater Management Model (SWMM)
- 3.2. Green Values Stormwater Calculator
- 3.3. Best GI Planning Scenario for Yeoksam-dong

03. Results

3.1. Stormwater Management Model (SWMM)

- **Existing Condition**

The infiltration is very low, and the runoff coefficient is almost 1 which is not at all desirable.

Existing Condition					
Subcatachments	**Precipiation (in)**	**Infiltration (in)**	**Runnoff (in)**	**Runoff Volume (Gal)**	**Runoff Coeff**
S1	319	3.03	310.86	5791672.18	0.974
S2	319	0.75	313.61	3438003.11	0.983
S3	319	0.77	313.41	3411717.61	0.982
S4	319	2.46	310.54	7485570.33	0.973
S5	319	0.9	312.09	4684789.03	0.978
S6	319	9.36	303.87	4814613.69	0.953
Total Area		**2.88**	**310.73**	**4937727.66**	**0.97**

Table 4: Existing Condition of Flood Control in the Yeoksam-dong Area

03. Results

3.1. Stormwater Management Model (SWMM)

- The three GI combinations in all the scenarios showed improved flood control compared to the existing conditions.
- Highest infiltration rate in GI Combination 1, about 18.09 inches total in the study area.
- Highest reduction of runoff and runoff volume observed in the GI Combination 2

GI Combination 1					
Subcatachments	**Precipiation (in)**	**Infiltration (in)**	**Runnoff (in)**	**Runoff Volume (Gal)**	**Runoff Coeff**
S1	319	21.19	215.24	4010093.73	0.675
S2	319	14.28	218.26	2392690.74	0.684
S3	319	15.73	145.25	1581195.85	0.455
S4	319	21.35	243.25	5863643.41	0.763
S5	319	19.15	246.83	3705117.91	0.774
S6	319	16.85	237.79	3767662.27	0.745
Total Area		**18.09**	**217.77**	**3553400.65**	**0.68**

GI Combination 2					
Subcatachments	**Precipiation (in)**	**Infiltration (in)**	**Runnoff (in)**	**Runoff Volume (Gal)**	**Runoff Coeff**
S1	319	9.07	161.32	3005637.84	0.506
S2	319	11	224.86	2465082.9	0.705
S3	319	26.76	222.78	2425563.63	0.698
S4	319	24.68	171.43	4132094.12	0.537
S5	319	21.28	270.51	4060679.7	0.848
S6	319	13.25	149.66	2371351.96	0.469
Total Area		**17.67**	**200.09**	**3076735.03**	**0.63**

GI Combination 3					
Subcatachments	**Precipiation (in)**	**Infiltration (in)**	**Runnoff (in)**	**Runoff Volume (Gal)**	**Runoff Coeff**
S1	319	24.14	212.64	3961603.06	0.667
S2	319	14.93	240.03	2631365.39	0.752
S3	319	10.64	171.33	1864983.89	0.537
S4	319	15.08	277.39	6686716.68	0.87
S5	319	17.8	248.74	3733788.03	0.78
S6	319	22.64	264.74	4194640.65	0.83
Total Area		**17.54**	**235.81**	**3845516.28**	**0.74**

Table 5: Flood Control in the Yeoksam-dong Area of all the Scenarios

03. Results

3.1. Stormwater Management Model (SWMM)

- Comparisons among Different GI Combinations

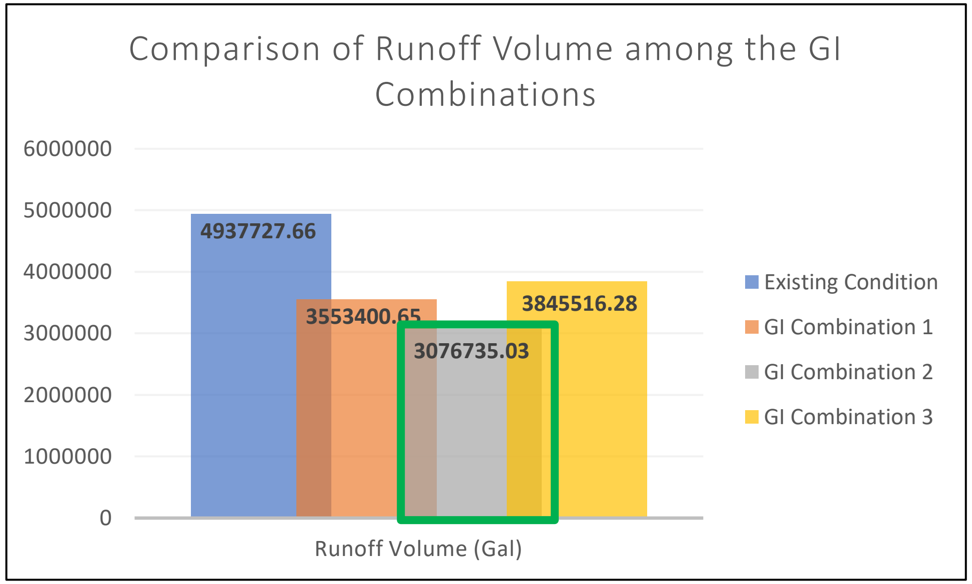


Figure 15: Comparison of Runoff Volume among the GI Combinations

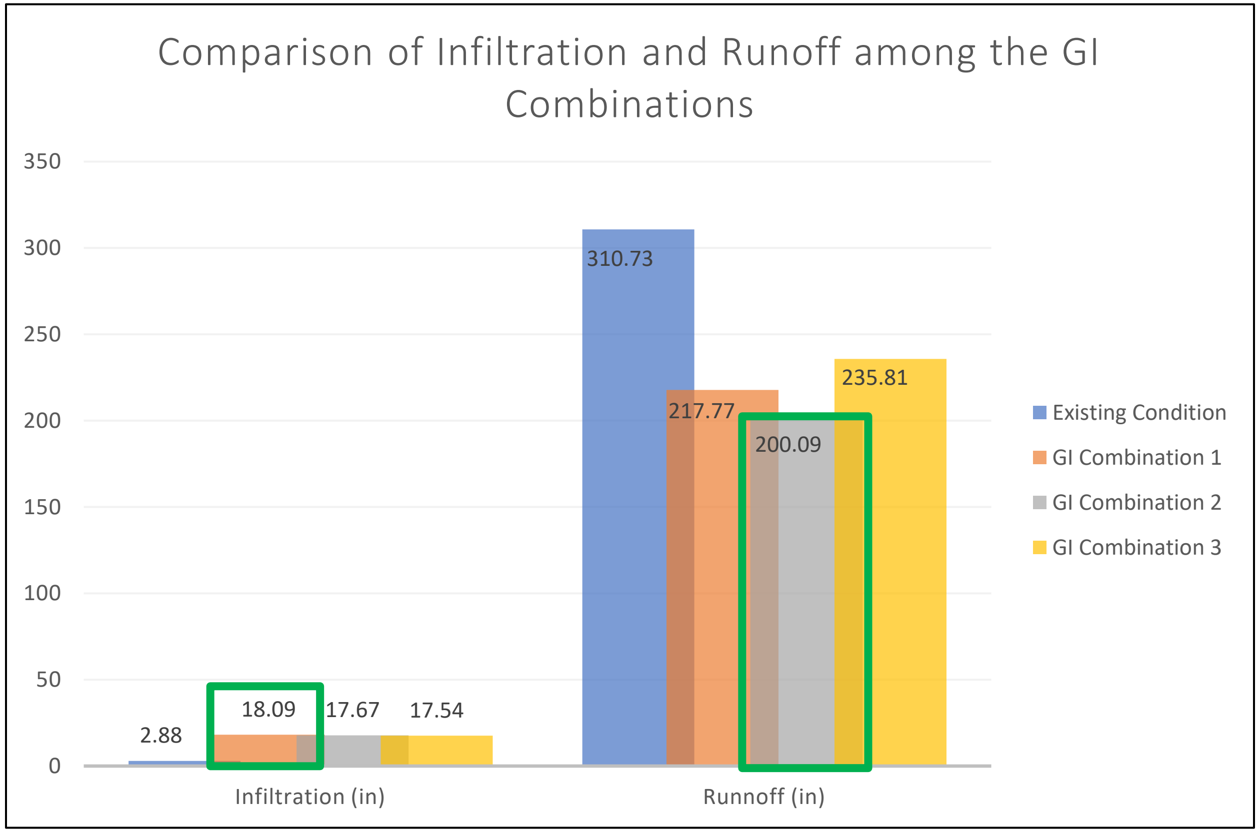


Figure 16: Comparison of Infiltration and Runoff among the GI Combinations

03. Results

3.1. Stormwater Management Model (SWMM)

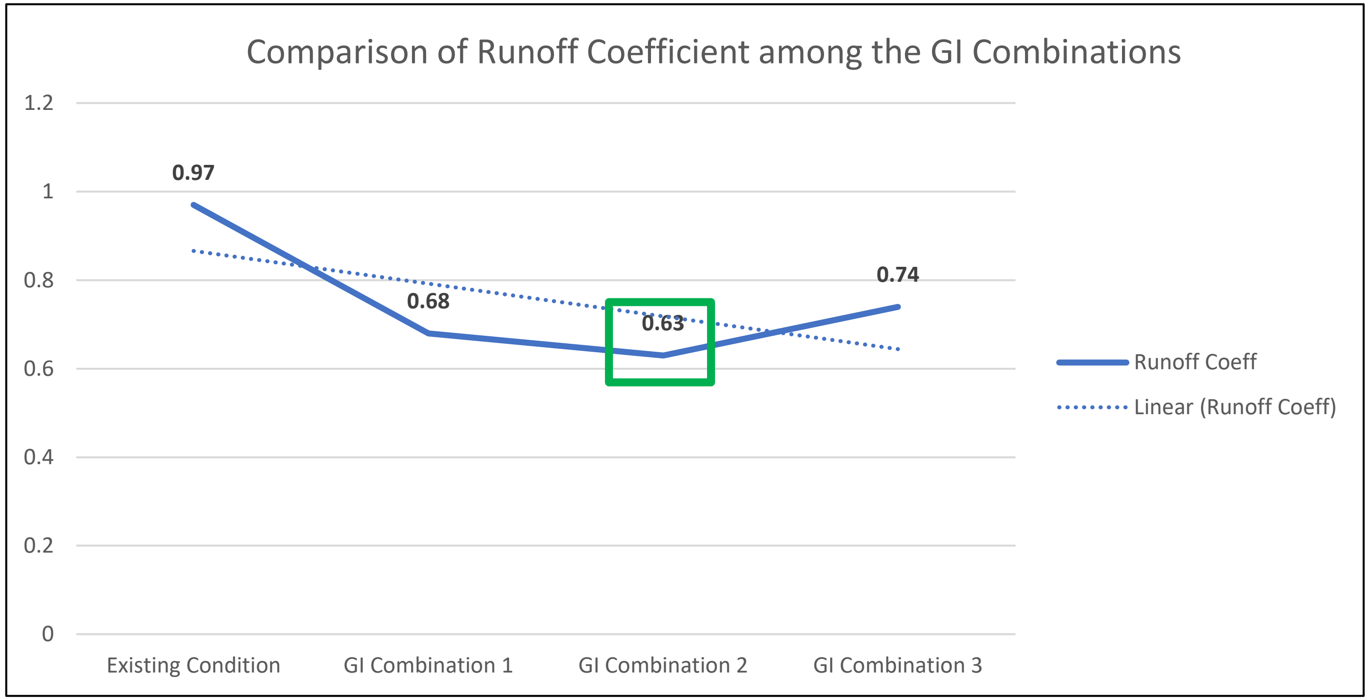


Figure 17: Comparison of Runoff Coefficient among the GI Combinations

03. Results

3.2. Green Values Stormwater Calculator

- **Economic Benefits**

All the three GI combination promotes economic value significantly while the combination 1 and 2 provides the best economic benefits with an increased real estate value of 22.8% and 22.3% respectively.

Green Infrastructure	Annual Benefits ($)	Life Cycle Benefit ($)	Increased Real Estate Value (%)
Combination 1	$180,516.25	$3,673,423.57	22.8
Combination 2	$140,302.31	$2,708,519.56	19.7
Combination 3	$180,172.92	$3,666,426.21	22.3

Table 6: Economic Benefits of the GI Combinations in the Yeoksam-dong Area

03. Results

3.2. Green Values Stormwater Calculator

- Comparison of Economic Benefits

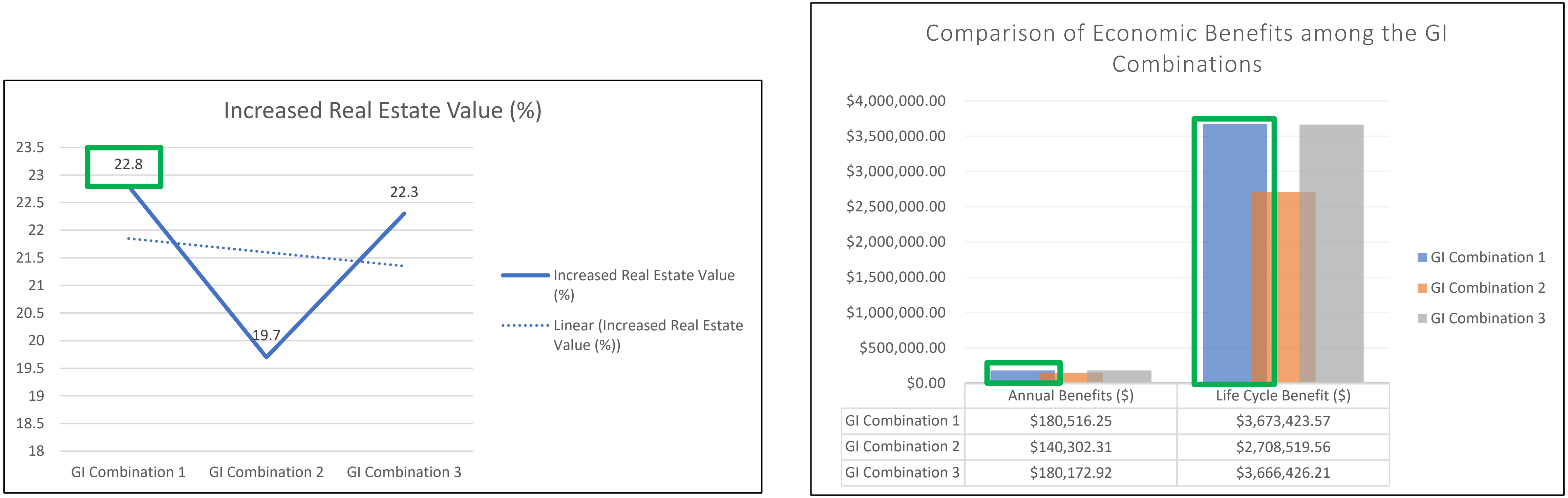


Figure 18: Economic Benefits of the GI Combinations in the Yeoksam-dong Area

03. Results

3.3. Best GI Combination for Yeoksam-dong

- GI Combination 1 showed highest percentage of increase for infiltration rate and real estate value.
- GI combination 2 accounts for the highest percentage of reduction for runoff rate and volume reduction.
- Difference for the infiltration rate between the Combination 1 and Combination 2 is marginal (0.17%) and increase of real estate value in Combination 2 also not far behind from the other two combinations.
- Overall, the GI Combination 2 performs better for all the four selected variables related to the 4Rs of Resilience.

Best Combination (GI Combination 2)

4Rs of Resilience	Variables	GI Combination 1	GI Combination 2	GI Combination 3
Robustness →	Runoff Rate ↓	29.9%	**35.61%**	24.11%
Redundancy →	Volume Reduction ↓	28.03%	**37.69%**	22.12%
Rapidity →	Infiltration Rate ↑	**19.64%**	19.47%	18.93%
Resourcefulness →	Real Estate Value ↑	**22.8%**	19.7%	22.3%

Figure 19: Best GI Combinations in the Yeoksam-dong Area

04. Conclusion

04. Conclusion

- The results showed that all the three combination of GI improves the flood control in the Yeoksam-dong area significantly compared to the existing condition.
- GI combination 2 performed better compared to the other two combinations for reduction of runoff rate and total runoff volume with 35.61% and 37.69% respectively.
- In terms of economic benefits, the all the GI combination increased the real estate value almost up to 23% compared to the existing condition for a 30 years life cycle of the GIs.
- In all the scenarios regardless of which combination performed the best, significant reduction in runoff and volume observed, while infiltration and real estate value also spiked.

04. Conclusion

- Simulation result suggest that all the three scenarios comply with the 4Rs of Resiliency.
- Methodology used in the research can be adapted to any sites that has similar problems. So, this research framework can be implemented in similar sites to planning for adaptive flood control.

What's Next?

- Addressing the limitations of selecting one best scenario.
- GI co-benefit analysis in accordance with the stakeholders' perception will be conducted in the future studies to address the current gap.

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Thank You

Thanks for your patience and time to listen to my presentation.