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Article

Flood and CO_2 Mitigation: Analysis of Climate-Change Response of Greening Vacant Houses in Old Downtown Metropolitan Areas

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Abstract: This study aims to evaluate the climate-change response of greening persistently vacant houses and barren sites in deteriorated high-density residential areas in old downtown metropolitan areas. The current status of building demolition sites in Ami-dong and Chojang-dong, Busan Metropolitan City, was examined. In this area, of the 340 vacant houses from 2017, 246 (72.35%) remained persistently vacant till 2020. In 2020, 213 barren sites were neglected after building demolition. Amongst these sites, 177 (83.10%) were paved with concrete. Persistently vacant houses and barren sites were afforested, and the climate-change response was quantified in terms of flood reduction and CO_2 mitigation in four scenarios (current, concrete, ground cover plants, and trees). Runoff analysis was performed using the Korea low-impact development model (K-LIDM) to assess flood mitigation. The tree scenario showed average runoff mitigations of 1.71%, 2.38%, and 3.06% in the long-term, 30-year, and 2-year rainfall scenarios, respectively. Additionally, 3058 deciduous broadleaf trees may be planted in the study area to promote CO_2 mitigation. Thus, an additional annual carbon fixation of 62,123.78 kg CO_2 may be expected. The greening of vacant houses and demolished sites was effective in all aspects of the climate-change response, and tree-based greening exhibited the most significant effect.

Keywords: vacant house; old downtown metropolitan areas; greening; flood mitigation; CO_2 mitigation; climate change

1. Introduction

The problem of vacant and abandoned houses is expanding around the original downtown locations in rural and metropolitan areas in South Korea. This is a result of the natural population decline owing to the low birth rate, aging population, and movement of the population from city centers to the suburbs [1–3]. Neglected and unmanaged vacant houses can cause social problems, such as crimes, deterioration of the surrounding landscape, and creating a cycle of producing other vacant houses [1,4–6].

South Korea has been preparing various measures to alleviate these problems. The Fifth Comprehensive Land Development Plan (2020–2040) and Fifth Comprehensive National Environmental Management Plan (2020–2040), presenting the basic directions for national land and environment management, suggest strengthening the small-scale maintenance methods of old abandoned buildings, monitoring vacant houses, and implementing measures to prevent changes to vacant houses for the planned management and utilization of old buildings and vacant houses. These plans emphasize sustainable smart-shrinking strategies, such as removing vacant houses with low development demand or that are difficult to reuse, rather than replacing them with artificial structures, such as buildings, to preserve them as green spaces.

Strategies to preserve vacant houses and idle spaces in city centers as green spaces can have various effects on the declining downtown metropolitan areas. Large cities in South Korea developed rapidly during a period of high economic growth since the 1970s. Therefore, buildings are overcrowded, and green spaces are scarce [7]. Busan Metropolitan City, the second largest city in South Korea, does not have sufficient land available for development because slopes with an inclination of 10° or more occupy more than 50% of the total area [8]. After the Korean War, densely populated residential areas for low-income workers were developed on steep slopes. Thus, the original downtown residential area was formed where individual building sites were narrow, and the infrastructure, including parks and green areas, was highly inadequate [9]. Moreover, Busan has become a highly vulnerable region where the amount of runoff during intensive rainfall increases rapidly owing to the steep slopes, causing considerable flood damage. In addition, citizens have to endure the heat in summer because air circulation is poor, owing to the concentration of houses. If green spaces are provided in these areas, they can provide not only resting and leisure spaces for citizens but also climate-change-response effects, such as flood and CO_2 mitigations, which are currently being emphasized. However, the reality of local governments is that vacant houses are often neglected for a long time owing to a lack of financial resources for maintenance and owners' non-agreement. Although vacant houses are demolished through vacant-house maintenance, they are typically left as barren sites with concrete pavements [10].

The effectiveness of various aspects of the greening strategies for the demolition of persistently vacant houses, emphasized in this policy, and barren sites left behind after demolition needs to be reviewed before these strategies are applied and spread in practice. Data-based quantitative effects can be used as a powerful basis to introduce and implement policies. The effects of greening vacant houses and idle spaces have been evaluated from various aspects in other countries, including rising real-estate prices [11], crime suppression [12–14], health improvement [12,15], improvement in access to green spaces [16,17], ecosystem connectivity [18], and fire protection [19]. Only Chae et al. [20] and Lee [7] have investigated the effects of greening vacant houses in South Korea. Chae et al. [20] identified the effects of demolishing vacant houses and creating vegetable gardens as part of a crime-safe village pilot project in Cheonan, Chungcheongnam-do through a survey of residents. They found that demolishing vacant houses and gardening effectively reduced the fear of crime and formed a community of residents. Lee [7] simulated the thermal-environment improvement effects of creating green spaces in a residential area densely populated with vacant houses as an urban regeneration project in Daegu City. The results indicated that small-scale green-space formations, such as gardens, had an insignificant effect on temperature reduction; nevertheless, a temperature-reduction effect of 1.1–3.7 ℃ was observed when a relatively large park was created. However, little empirical research has been conducted on the effects of greening strategies in South Korea. One reason is that there are few examples of greening vacant houses and idle spaces. In addition, the areas of vacant houses and idle spaces are small. Therefore, this study analyzes the planning process using simulations and focuses on the climate-change-response effects of green spaces, which has been recently highlighted among response effects that allow simulation analysis. Responses to climate change can be classified into mitigation of greenhouse gases that cause climate change and adaptation to reduce damage caused by increasing disasters and extreme weather events owing to climate change. Considering that the greening strategy is for the co-benefit of mitigation and adaptation effects, this study examines the greening effects of vacant houses and demolished sites in terms of flood and CO_2 mitigation effects.

No previous studies on flood and CO_2 mitigation are directly linked to greening vacant houses. However, there are studies on land-cover changes regarding the flood or CO_2 mitigation effects. Studies on the flood mitigation effect of green spaces in urban planning have provided implications for land use, environmental, and disaster prevention planning by analyzing runoff according to land cover or changes in land use primarily using simulation tools based on water circulation models [21–23]. Studies on the CO_2 mitigation effect of green spaces can be classified into those that calculate the carbon fixation of a unit green space by measurement [24–26] and those of a target area using the estimated carbon fixation of a unit green space [27–31].

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In summary, this study examines the current status of vacant houses and demolished sites in Ami-dong and Chojang-dong, Seo-gu, Busan Metropolitan City, deteriorated high-density sloped residential areas in old downtown metropolitan areas with a serious vacant-house problem. In addition, this study evaluates the flood mitigation and carbon fixation effects when greening policies are introduced. The findings of this study can be a reference for considering vacant houses as space resources for green spaces in downtown areas, where securing green spaces is challenging. In addition, by quantitatively demonstrating the flood mitigation and carbon fixation effects of greening vacant houses, this research is expected to contribute to promoting vacant house greening policies to realize sustainable cities.

2. Materials and Methods

2.1. Study area and data

The areas selected in this study are Ami-dong and Chojang-dong, Seo-gu, Busan Metropolitan City, representative areas of urban decline in the original downtown areas of South Korea. The study areas are typical high-density sloped residential areas, where defective and illegal detached houses were spontaneously built on steep slopes. Urban decline has progressed, leading to an increase in vacant houses. Despite the efforts of the local government to maintain various vacant houses, the problem of vacant houses is spreading throughout the region, and measures to manage existing vacant houses are urgently required [1]. The total area of Ami-dong and Chojang-dong is 1.169 km^2. This area between Mount Cheonma and Mount Ami is a typical sloped residential area, where approximately 83% of the land has an inclination of 10° or more [10]. Figure 1 shows a map of the study area. The gray-shaded area in Figure 1 represents the area of the Haengbok public housing construction project (2014–2022) at the time of the survey in 2020. The research subject in this study has a total area of 1.118 km^2 and excludes this gray area.

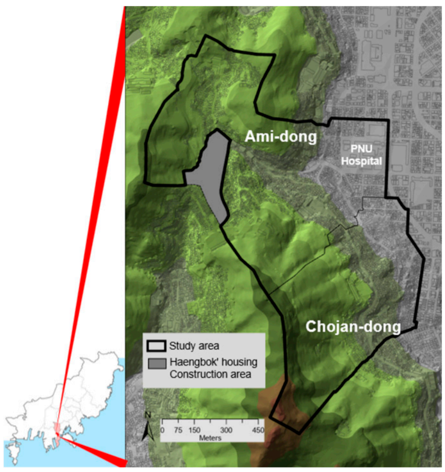

Figure 1. Map of Busan Metropolitan City, Ami-dong, and Chojang-dong.

This study simulated greening-strategy applications to barren sites that have been neglected after demolition and persistently vacant houses that have been neglected for a long time, with a low reuse potential and large negative impact on the surrounding area. Therefore, data on vacant houses and the current statistics on vacant houses after demolition were used. Data on vacant houses in 2017 and 2020 were used. For the 2017 statistics, the data collected in a study by Jung and Woo [10] were used. The research team collected data by conducting a full-scale local survey in November 2020 under the same conditions as that of the 2017 survey (see Figure 2). This study area is a detached-house site. Vacant houses refer to unused or unoccupied houses. The criteria for determining vacant houses are as follows: police notification stickers for vacant and closed houses, state of electricity meters (whether the meter is working or attached), stacking and leaving items such as garbage and mail, any trace of people entering and leaving the yard, and the use of the space for laundry and

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shoes. Moreover, nearby residents were asked whether the vacant houses had residents, and their answers were considered in the assessment. Persistently vacant houses refer to houses that remained vacant from 2017 to 2020.

In the 2020 survey, vacant houses and the conditions of the sites after the buildings were demolished were surveyed. Among the sites where buildings were demolished, some sites have been repaired and used as parking lots, and some were neglected and unused. In this study, the used and idle sites are referred to as "maintenance" and "barren" sites, respectively (see Figure 2). The maintenance and barren sites were investigated together with the land cover condition and purpose of use.

(**a**) (**b**) (**c**)

Figure 2. Photographs of vacant houses, barren sites, and maintenance sites: (**a**) Vacant house; (**b**) Barren site; (c) Maintenance site.

The data collected through full-scale local surveys were constructed as geographic information system (GIS) data based on the road name address electronic map (September 2020). The conditions of the vacant houses and demolished sites in the study area were examined using the constructed data, and greening scenarios were defined based on these conditions. Subsequently, the flood mitigation effects were calculated for each greening scenario. The CO_2 mitigation effects of tree planting in persistently vacant houses and barren sites were also analyzed.

2.2. Analysis method for flood mitigation effects

To analyze the flood mitigation effects of greening vacant houses, the rainfall runoff characteristics for each scenario were compared and evaluated using the Korea low-impact development model (K-LIDM), a runoff analysis model developed by Pusan National University's Korea GI·LID Center (http://www.pnugilid.or.kr/). The K-LIDM has complemented the low-impact development technique analysis function by linking with the storm water management model (SWMM), a runoff model developed by the U.S. Environmental Protection Agency. This model can analyze the change in land cover or water circulations before and after applying the LID technique. The rainfall runoff calculation was developed based on the Hydrological Simulation Program - Fortran (HSPF) model. The weather conditions can be input using the long- and short-term rainfall databases of 10 weather stations around the country, including Seoul and Busan. The K-LIDM consists of eight elements: scenario setting, meteorological data input, runoff analysis, mathematical calculation, LID control, SWMM-linked analysis, model condition setting, and results analysis. Figure 3 shows the overall structure of the K-LIDM. Although the K-LIDM specializes in LID evaluation, it was considered to be a suitable model for analyzing rainfall runoff for each greening scenario in this study because it allows detailed land-cover settings reflecting the basin topography, such as slope. In addition, it has a rainfall database that includes the study site.

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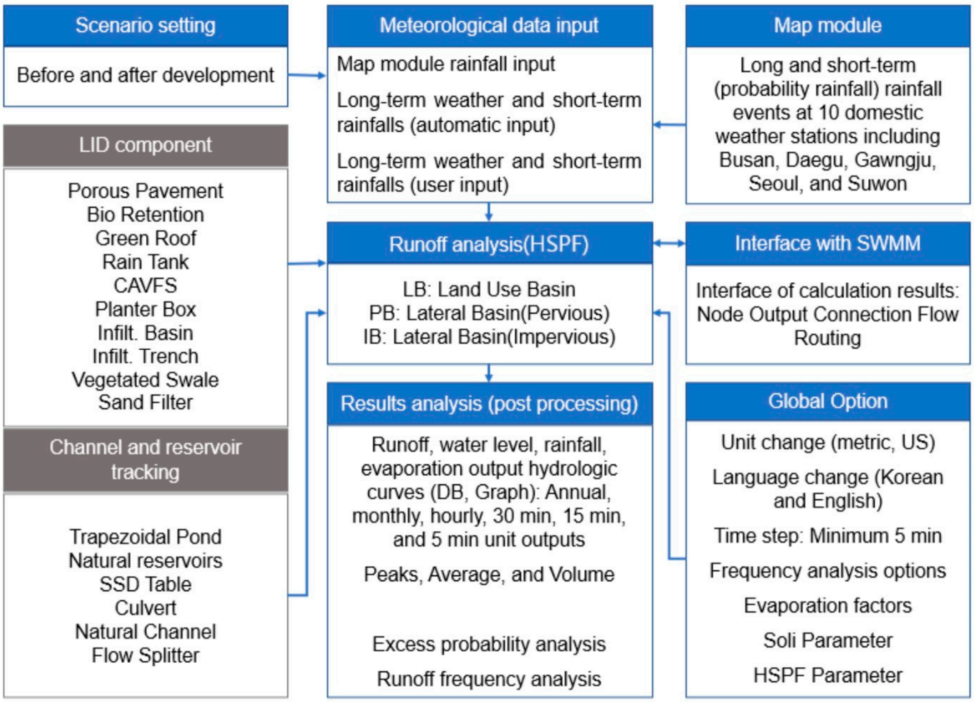

Figure 3. K-LIDM structure. Source: Reproduced by referring to K-LIDM User's Manual [38].

The input values required to perform the runoff analysis using the K-LIDM are the land cover areas for each inclination of the watershed. Table 1 summarizes the input conditions and usage data considered in this study. In the K-LIDM, the inclinations are divided into three levels: Flat (≥ 0° and < 5°), Mod (≥ 5° and < 15°), and Steep (≥ 15°). Permeable surface land cover can be classified into three types: forest, pasture, and grass. Impermeable surfaces can be selected from five types: road, roof, driveway, sidewalk, and parking lot. In this study, each land-cover area by slope was calculated using the site-slope raster data from a continuous digital-topographic map, land-cover map, road name address electronic map, and field survey results. The data were input for each scenario.

Table 1. K-LIDM input conditions.

Items			Description / Input values	Data
Surface	Impermeable	Building roof area Parking area Road area Sidewalk area	Each surface area by slope is calculated and input	Land-cover map of the Ministry of Environment (2021); Road name address electronic map of the Ministry of Public Administration and Security (2020.9); Full-scale local survey data (2020)
	Permeable	Tree area Grassland area		
Soil			Well infiltrating soils/ moderate infiltrating soils	K-LIDM default
Slope			-	Continuous digital topographic map v2 (1:5000)
Weather conditions	Short-term rainfall Long-term rainfall		2 y 180 min, 30 y 180 min 2005–2014	Busan Weather Station Data provided by K-LIDM

The runoff analysis was performed with short- and long-term rainfall settings. In the case of short-term rainfall, a 24 h runoff curve was derived by frequency (2 and 30 y), and the annual runoff was calculated for long-term rainfalls (2005–2014). The results were then compared by scenario.

2.3. Analysis method for CO_2 mitigation effect

The CO_2 mitigation effect of greening must consider the direct CO_2 absorption by plants and CO_2 emission owing to the decomposition of organic matter in soil and energy consumption for green-space management in urban green spaces. Furthermore, indirect CO_2 mitigation effects can be expected, such as the reduction in cooling energy consumption in summer through the mitigation of the thermal environment caused by the latent heat of evapotranspiration and solar radiation blocking in green spaces and reduction of heating energy consumption in winter by windbreaking [26,32]. In this study, the carbon inflow from the soil owing to withering fallen leaves and carbon emissions from the soil owing to the decomposition of soil organic matter were considered net zero. Moreover, the carbon fixation caused by ground-cover plants was excluded from the calculation because this value is negligibly small [33]. The carbon emissions from green-space maintenance were also excluded from the calculation owing to a lack of data. Indirect reduction effects were also excluded.

This study selected planting trees suitable for greening the study area through a literature review and calculated the extent of the CO_2 mitigation effect of greening using the carbon fixation determined in existing studies. Figure 4 illustrates the research process.

Figure 4. Calculation process for the annual carbon fixation by greening.

3. Results

3.1. Current state of persistently vacant houses and demolished building sites in the study area

An examination of the changes in vacant houses from 2017 to 2020 shows that there were 340 vacant houses out of 3787 detached houses in 2017. The number of persistently vacant houses in 2020 was 246, accounting for approximately 72.35% of all vacant houses in 2017. In 2020, 498 of 3675 detached houses were vacant, and there were 252 new vacant houses. These results indicate that once houses become vacant, they are unlikely to be reused. In the study area, the average annual increase rate of vacant houses was 13.57%, confirming that vacant houses exist throughout the area.

Table 2 summarizes the surface states of the demolished building sites as of 2020. In the study area, 313 sites were demolished building sites. Although the previous uses or reasons for demolition of the buildings could not be known, it was presumed that most of the sites were detached houses, owing to the characteristics of the area. Moreover, many vacant houses that were demolished owing to the vacant-house maintenance project carried out by the local government must also be included.

Table 2. Surface states of demolished sites in 2020 (number of sites).

Type of site	Perviousness	Vegetation		Total number of sites
		Absent	Present	
Barren	Impermeable	177	-	213
	Permeable	7	29	
Maintenance	Impermeable	63	-	100
	Permeable	4	33	

A total of 213 sites were left as barren sites after demolition, accounting for 68.05% of the total demolished sites. Among them, the surfaces of 177 sites (83.10%) were impermeable pavement with concrete (Table 2). In this area, there were many cases of concrete pavements for reasons such as the difficulty of management after demolition. In the case of barren sites on permeable surfaces, there

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were seven cases where gravel was laid to suppress plant propagation. Most permeable barren sites were neglected with overgrown weeds.

Among the demolished sites, 100 sites were maintained and used as parking lots. A review of the usage status of maintenance sites showed that 33 sites were maintained as roads or sidewalks, 29 were used as spaces for residents, such as parks or sports facilities, 24 were used as vegetable gardens, and five were used as parking lots.

3.2. Deriving greening scenarios

The greening scenarios for persistently vacant houses and barren sites include the current (S1), which is the base, concrete pavement (S2), ground cover plants (S3), and tree (S4) scenarios. Table 3 summarizes these scenarios.

Table 3. Greening scenarios.

Scenario	Persistently vacant houses	Surface of barren site
S1: Current	Current state	Current state
S2: Concrete	Concrete pavement after demolition	Concrete pavement
S3: Ground cover plants	Pavement with ground cover plants after demolition	Ground cover plants and pavement
S4: Tree	Planting ground cover plants + trees after demolition	Planting ground cover plants and trees

Table 4 summarizes the land covers for each scenario. The impermeable surfaces were classified into three types: building, concrete, and asphalt. The permeable surfaces were also classified into three types: barren, ground-cover plants, and trees. The area was calculated using field survey results, a road name address electronic map (September 2020), and a land-cover map (2021). First, the ground surface classified as a road in the land-cover map was classified as asphalt, and other urban/dry areas were classified as concrete. The building area on the road name address electronic map was calculated. The ground surfaces of the barren and maintenance sites of the field-survey data were then reflected. Forest areas in the land-cover map were classified as trees, grassland and agricultural areas as ground-cover plants, and barren sites as barren. In the current state (S1), the impermeable surface of the study area accounted for 53.80%, of which buildings accounted for 24.42%, of the total area. The study area is surrounded by Mount Ami and Mount Cheonma; thus, trees accounted for 33.50% of the total area. The total area of the persistently vacant houses and barren sites to be demolished was 19,764 m^2.

Table 4. Area and percentage of land cover according to scenarios.

Item		S1		S2		S3		S4	
		Area *	Rate	Area	Rate	Area	Rate	Area	Rate
Impermeable surface	Building	27.30	24.42	26.07	23.32	26.07	23.32	26.07	23.32
	Concrete	19.53	17.47	20.88	18.68	18.91	16.91	18.91	16.91
	Asphalt	13.32	11.92	13.32	11.92	13.32	11.92	13.32	11.92
	Sum.	60.15	53.80	60.28	53.92	58.30	52.15	58.30	52.15
Permeable surface	Trees	37.45	33.50	37.44	33.49	37.44	33.49	39.42	35.26
	Ground cover plants	13.02	11.67	12.91	11.55	14.89	13.32	12.91	11.55
	Barren	1.19	1.04	1.16	1.04	1.16	1.04	1.16	1.04
	Sum.	51.65	46.20	51.52	46.08	53.49	47.85	53.49	47.85
Total area		111.79							

* 10,000 m^2.

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3.3. Flood mitigation effect

Rainfall runoff was analyzed for each scenario using the K-LIDM to evaluate the flood mitigation effect of greening vacant houses and barren sites. Runoff flow was analyzed using long- and short-term rainfalls. In the case of short-term rainfall, 30 y and 2 y rainfall data were analyzed over 180 min.

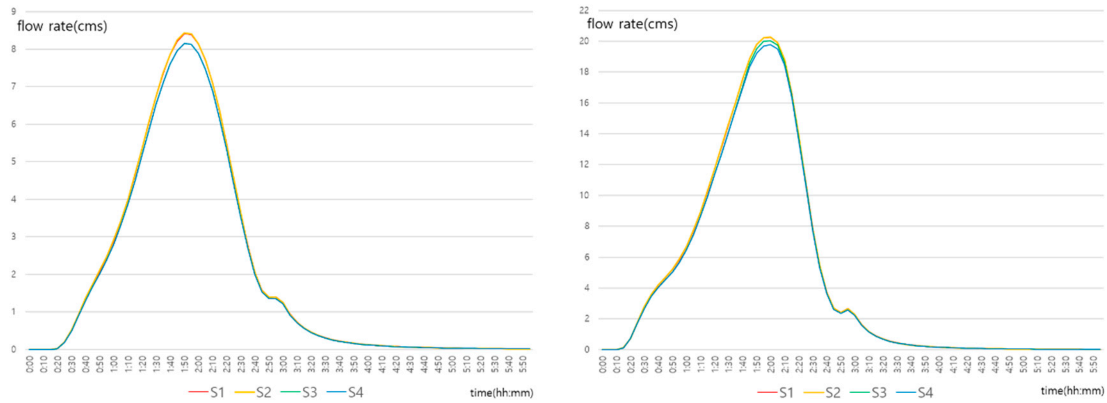
For the runoff analysis of long-term rainfall, the annual average flow rate of rainwater from the target site for each scenario was calculated and compared by scenario (Table 5). The flow rate increased by 0.16% in S2 compared with that in S1, where both the vacant houses and barren sites were paved with concrete. The flow rate decreased by 0.91% and 1.71% in S3 and S4, respectively. Compared with S2, which had the highest flow rate, the flow rates in S3 and S4 decreased by 1.07% and 1.86%, respectively.

Table 5. Flow-rate comparison of long-term rainfall by scenario.

Item		S1	S2	S3	S4
Average flow rate (CMS *)		12.68	12.70	12.57	12.47
Change rate (%)	Based on S1	-	+0.16	-0.91	-1.71
	Based on S2	-	-	-1.07	-1.86

* m^3/s.

The short-term rainfall runoff analysis results are shown as runoff curves for each of the 2 y and 30 y rainfall scenarios. In the case of the 2 y rainfall scenario (Figure 5a), S1 and S2 exhibited similar curves. S3 and S4 also showed overlapped curves. The 30 y rainfall curves (Figure 5b) also showed a similarity between S1 and S2, but there was a slight difference between S3 and S4. S4 had the smallest flow rate. The runoff curves did not exhibit differences in the peak time for all scenarios.



(**a**) (**b**)

Figure 5. Flow-rate comparison for short-term rainfall: (**a**) Short-term rainfall (2 years); (**b**) Short-term rainfall (30 years).

Table 6 summarizes the peak flow rates for each rainfall scenario. In the 2 y rainfall case, the peak flow rates of S3 and S4 were the same, and the peak flow rate decreased by 0.26 CMS (3.06%) compared with that of S1. The peak flow rate of S2, which had the highest flow rate, increased by 0.02 CMS (0.26%) compared with that of S1. By contrast, the flow reduction rate of S3 and S4 was 3.31%. In the 30 y rainfall case, the peak flow rate decreased in S3 and S4. Compared with that of S1, the peak flow rate of S3 and S4 decreased by 0.20 CMS (0.99%) and 0.48 CMS (2.38%), respectively. The peak flow rate of S2, which had the highest flow rate, increased by 0.01 CMS (0.01%) compared with that of S1. By contrast, the peak flow rate of S3 and S4 decreased by 0.21 CMS (1.04%) and 0.49 CMS (2.43%), respectively.

Table 6. Short-term rainfall peak flow rate by scenario.

Item		S1	S2	S3	S4
Flow rate of 2-y rainfall (CMS *)		8.41	8.43	8.15	8.15
Change rate (%)	Based on S1	-	+0.26	-3.06	-3.06
	Based on S2	-	-	-3.31	-3.31
Flow rate of 30-y rainfall (CMS)		20.24	20.25	20.04	19.76
Change rate (%)	Based on S1	-	+0.05	-0.99	-2.38
	Based on S2	-	-	-1.04	-2.43

* m^3/s.

The decrease in the peak flow rate in the greening scenario was larger for the 2 y rainfall than for the 30 y rainfall. In addition, the effect of greening was larger in lower rainfalls. Furthermore, in the 30 y rainfall case, there was a difference in the peak flow rates between S3 and S4. This suggests that in the case of strong rainfalls, S4 has a larger flood mitigation effect than S3.

3.4. CO_2 mitigation effect

The trees that can be planted for the CO_2 mitigation effect were first selected. Subsequently, the resulting CO_2 mitigation effect that can be obtained by planting the selected trees was calculated using an equation based on previous studies.

The following four conditions were set for the trees to be planted for greening the target sites: (1) trees with size that can be planted in vacant houses and barren sites, (2) landscape trees frequently planted in urban areas in South Korea, (3) trees with a relatively slow growth rate that do not require frequent pruning, and (4) deciduous broadleaf trees that block sunlight well in summer and pass solar radiation in winter. Condition (3) can be considered as a condition for trees from the climate-change mitigation perspective.

Before considering condition (1), the average area per site was first calculated. The average area per persistently vacant house and barren site to be demolished was 38.89 m^2 based on the road name address electronic map. Therefore, the appropriate size of the crowns for trees that can be planted on the vacant houses and barren sites after the removal of vacant houses was considered to be within 7.0 m in width. For the remaining conditions (2)–(4), it was assumed that deciduous broadleaf trees, such as Chinese maple and red maple, were planted based on a study by Lee [34], which established the quality-evaluation criteria by standardizing the measurements for 15 tree species considering the primary planting functions of landscape trees. The average diameter at breast height (DBH), mean crown width (W), and mean crown area of Chinese and red maples measured by Lee [34] were 13.0 cm, 2.8 m, and 6.2 m^2, respectively.

In this study, the equation 1 suggested by Lee [29] was used to calculate the annual carbon fixation of broad-leaved trees to evaluate the CO_2 mitigation effect of greening. This equation was developed based on a study on Korean trees. The carbon fixations of trees differ for each species. Moreover, the carbon fixations of the same species differ based on the forest type, forest age, growth conditions, stand density, and climate [35]. Therefore, the equation was considered suitable for application in this study.

$$\text{Annual carbon fixation } (CO_2\ \text{kg/tree}\cdot\text{y}) = -4.2136 + 1.9006DBH - 0.0068DBH^2 \quad (1)$$

The annual carbon fixation per deciduous broadleaf tree planted in the study area can be calculated as 19.35 CO_2 kg/tree·y by substituting the average value of the DBH shown in equation (1). The annual carbon fixation owing to the greening of the demolished vacant houses and barren sites (S4) can be calculated by multiplying the annual carbon fixation per tree by the number of trees to be planted. The number of trees that can be planted was calculated by dividing the total area of vacant houses and barren sites by the canopy area of the trees (6.2 m^2). Thus, 3,211 trees may be planted. Therefore, the annual carbon fixation owing to the greening with trees of the vacant houses and barren sites in the study area was calculated to be 62,123.78 CO_2 kg/y.

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Compared with S1, annual CO_2 reduction was calculated at 62,123.78 kg owing to the climate-change mitigation effect of demolishing persistently vacant houses and greening barren sites (S4). According to the National Greenhouse Gas Statistics of the National Statistical Office, the annual carbon dioxide emission per capita in South Korea was 14,088 kg in 2018. Greening of persistently vacant houses and barren sites in Ami-dong and Chojang-dong with trees can offset the emitted CO_2 of approximately 4.4 people per year.

4. Discussion and Conclusions

This study aimed to evaluate the climate-change response effects of greening vacant houses and barren sites in deteriorated high-density residential areas in old downtown metropolitan areas. The current status of demolished building sites was identified using Ami-dong and Chojang-dong, Seo-gu, Busan Metropolitan City as study areas. Furthermore, the effects of greening were evaluated quantitatively in terms of flood and CO_2 mitigation effects.

The analysis results showed that the number of vacant houses in the study area increased from 340 in 2017 to 498 in 2020. Among these, 246 (72.35%) were found to be neglected vacant houses. As of 2020, 313 building sites were demolished. However, approximately 77% of the demolished sites, including the barren and maintenance sites left unattended after demolition, were paved with impermeable surfaces. This suggests that securing green spaces is insufficient in vacant-house management. Of the 313 demolished sites, 213 were abandoned as barren sites with no specific use, and 177 sites (83%) were paved with concrete. It was confirmed that 100 sites were maintained with parks, parking lots, and sidewalk extensions. However, 63 (63%) of the maintenance sites also had impermeable surfaces. However, when viewed from another perspective, the 177 neglected idle spaces can serve as space resources for green spaces.

This study evaluated the flood mitigation effects in four scenarios: current scenario (S1), concrete scenario (S2), ground cover plants scenario (S3), and tree scenario (S4). The flood mitigation effect of greening persistently vacant houses and barren sites was the highest in S4. In the long-term rainfall scenario, the annual runoff decreased by 1.71% in S4 compared with that in S1. In the short-term rainfall scenario, the annual runoff decreased by 3.06% and 2.38% for the 2 y and 30 y rainfall cases, respectively. The study area is adjacent to an area with a high risk of flooding owing to inland water [37]; therefore, greening is expected to increase local disaster safety.

The CO_2 mitigation effect of greening was evaluated by calculating the annual CO_2 fixation of planted trees. Trees suitable for greening persistently vacant houses and barren sites include deciduous broadleaf trees that have relatively slow growth and do not require frequent pruning, such as the Chinese or red maple. A total of 3,211of these trees can be planted, allowing for a high carbon fixation of 62,123.78 CO_2 kg/y. Although individual effects may appear small owing to the versatility of green spaces, combining these effects can significantly improve environmental conditions.

The following policy implications were derived from the results of this study. As many previous studies have emphasized, greening vacant houses and idle spaces can be a sustainable management plan for vacant houses in the low-growth era. However, in reality, most vacant houses are left as concrete pavements after being demolished, as observed in the study area. The burden of management may be a primary reason why current barren sites are paved with concrete rather than greened. Barren sites that are not properly managed and are neglected after demolition can deteriorate the living environment. Therefore, a green-space management plan must be prepared to realize the greening strategy. In some areas of Japan and the USA, residents have been hired for green management after greening demolished sites. Greening of vacant houses can be more easily applied if incentives, such as hiring residents for green management, are provided. The effect of greening on responses to climate change was also verified in this study. However, the flood and CO_2 mitigation effects are also difficult for residents to experience directly. If the cooperation of the residents is necessary for greening, a plan to provide corresponding incentives should be presented.

This study is beneficial because it simulated and quantitatively analyzed the effects of greening vacant houses in terms of climate-change response when there are few relevant previous studies. The findings of this study are expected to incite a change in the perception of residents and local governments about greening vacant houses. However, this study only focused on a few benefits of green spaces (flood mitigation and carbon fixation). Because this study only performed an area-oriented analysis, the research results cannot be generalized. In future studies, various other effects of greening need to be examined, including the effect of improving the thermal environment and targeting various regions.

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