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# Numerical Experiments on Low Impact Development for Urban Resilience Index

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**Abstract:** Low impact development (LID) has become one of the strategies that effectively mitigate the impacts of climate change. In addition to the ability to reduce nonpoint source (NPS) pollution caused by flash floods from the surface runoff, LID has also been applied to control water quantity under extreme rainfall events. Due to the fact that studies about LID configuration optimization tended to control water quantity and gradually ignored the main functions of water quality treatment, this study aims to consider water quantity and quality to estimate the benefits and optimal configuration of LID by Non-Dominated Genetic Algorithm (NSGA-II). In addition, regarding to the outlet peak flow, hydrologic footprint residence (HFR) was considered to be the water quantity indicator due to the ability to represent the dynamics of flow changes, and the modified quality indicator (Mass Emission First Flush ratio, $MEFF_{30}$) was corrected to represent the pollutant transport process in a large catchment area. The results show that the flood and $MEFF_{30}$ reduction rate of LID are inversely proportional to rainfall duration and intensity. The benefit of pollutant reduction, which can still be maintained by 20% and 15% under a big return period and the long duration was about three times than the quantity control. Taking the cost into account, although the rain barrel had the best effect of reduction per unit area, green roofs and permeable pavements had a higher unit cost reduction rate due to the lower costs. The upper and middle reaches of the open channel and the confluence of rainwater sewers should be the optimal LID configuration to achieve the benefits of both flood and pollution reduction.

**Keywords:** urban resilience; LID; HFR; $MEFF_{30}$ ratio; NSGA-II; SWMM

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## 1. Introduction

Low impact development (LID) can reduce nonpoint source (NPS) pollution caused by flash floods, from the surface runoff and buildings and improve the water quality [1–3]. The increasing frequency of extreme events and urbanization makes traditional sewer systems no longer capable to pass the water volume [4–8], so the application of LID to the control of water quantity for extreme events have become a mainstream method to reduce urban flooding [9–12]. LID configuration can increase the permeable pavement in developed areas and decrease the surface runoff and pollution burden [13–17]. The optimized configurations of LID to mitigate floods were analyzed mostly by combining simulation models [18–22]. Hsu [18] aimed at maximizing the benefit-to-cost ratio to analyze the optimal configuration of LID. By simulating the rainfall-runoff process through SWMM, parameter calibration, and model verification of the model through historical rainfall events, and then the optimal configuration was solved by Simulated Annealing (SA). Liang [19] estimated the benefits of LID via 36 rainfall scenarios with the SWMM model. From the sensitivity analysis of a single catchment area, the mechanism of reducing the flood peak in LID was discussed. The configuration and burden ratio, which includes bio-retention cells and permeable pavement in each sub-catchment area were adjusted. Finally, the configuration was optimized by a genetic algorithm (GA) with constant costs.

Ho [20] took a high-density development area as an example and selected suitable LID or retention ponds according to the land use of the study area. Multi-objective genetic algorithms (MOGA) were used to obtain the optimal spatial configuration under the relationship curve with flood peak, hydrologic footprint residence (HFR), and costs; it has been confirmed that LID could not only reduce the impact of water quality but also effectively decrease the water quantity, which would make the city have more ability to face the water problems under climate change, thereby increasing the resilience of the city. LID can achieve the purpose of adapting to extreme climates as a whole with minimal changes, so it is necessary to accelerate the development of adaptation policies to prevent and mitigate various disasters [23–25].

The main functions of water quality control and the pollutant transmission capability for LID were seldom considered in the optimization. Storm control management traditionally focuses on reducing peak flow and ignores the importance of water quality, so that the pollution carried by surface runoff directly enters the river and then changes river morphology, ecology, and water quality [26]; this study aims to consider water quantity and quality to estimate the LID optimization with numerical simulations and review the relevant literature on the evaluation technology of LID water quality treatment in recent years. Oraei [27] used SWMM model combined with Non-Dominated Genetic Algorithm (NSGA-II) and considered the reduction of peak flood, TSS, BOD, total runoff, and costs as target functions to define the optimal configuration of LID. Zhang [28] used the improved nondominated sorting genetic algorithm ($\varepsilon$-NSGA II) combined with SWMM model with the design rainfall of 10 and 24-year return periods. By optimizing the design size of LID with the global surface runoff and costs as the objective functions, it is shown that the higher proportion of bio-retention cells could have a significant effect on flood mitigation and pollutant reduction. Li [29] contributed to study urban flooding control and water quality management with the implementation of detention tanks and LID. A many-objective optimization (MOO) based design framework and analysis method was developed for achieving the optimal objective of USDS design. In view of the fact that the hydrological model that simulates the LID function oversimplifies its transport process for pollutant reduction, Baek [30] evaluated the effect on water quality of LID by modifying the corresponding module in SWMM, and also conducted the LID scenario analysis under the climate change scenarios. The aforementioned results reveal that the proper indicator for evaluating water quality is necessary for LID optimal configuration.

In terms of pollution reduction, LID was usually conducted to reduce TSS, BOD, total phosphorus (TP), and heavy metals in water. The flush water from the traditional storm management could carry large amounts of pollutants in the initial rainwater [31,32], which formed the first flush (FF) [33], scoured the downstream with the runoff, and made the concentration in the water body raising significantly. Therefore, if there was a relatively heavy first flush during the rainfall process, the initial rainwater would carry a large number of pollutants that could be intercepted, purified, and then discharged; this effect has a representative issue in the process of pollution transmission in the catchment runoff [33,34]. Baek [35] used the Mass First Flush ratio ($MFF_n$) as the objective function to analyze the benefits of LID in pollutant reduction; it was conducted with numerical simulations under different rainfall scenarios to optimize the size of LID. Since previous studies, it has been pointed out that $MFF_n$ is not suitable for large catchment areas [36]. The first flush is positively correlated with peak rainfall intensity, rainfall duration, and antecedent dry weather period, and the regression coefficients would vary with the characteristics of the catchment [37]; it is speculated that the runoff caused by rainfall needs to be transmitted over long distances in large catchment areas, thereby it would conceal the appearance of the first flush or decrease the accuracy of monitoring [38]; this study is the first one, in which the index $MFF_n$ is applied to the simulation of a large catchment area, so the original index is modified to the Mass Emission First Flush ratio ($MEFF_n$), which could more clearly estimate the volume of pollutants in the runoff under different rainfall scenarios. By evaluating the effectiveness of LID for quantity control, HFR could have a better ability to represent the time series and dynamics of flow changes rather than peak flow [20,39–41].

In this study, the objectives for the LID optimization configuration would apply HFR and the peak flow as the water quantity indicator, and $MEFF_n$ for the water quality to establish an assessment index in an urban area. SWMM is conducted in the high population area (Zhongyonghe district) and then the multi-objective optimization is performed with NSGA-II for the LID configuration with those indicators. The cost is also considered for the optimal configuration to discuss the achievement of urban resilience.

## 2. Materials and Methods

### *2.1. Resilience Assessment Index*

#### 2.1.1. Structure of the Resilience Assessment Index

This study aims to consider water quantity and quality with numerical simulations to establish an optimal configuration of LID strategies; it proposes to study the physical mechanism of LID and select appropriate assessment indicators for evaluation to define the configuration of each LID component. In terms of water quantity reduction, in addition to considering the reduction of downstream peak flow, climate change and urbanization have changed the process of the water cycle in the catchment area, which increases the runoff and flood duration time [42]. HFR is used to quantify the impact of flooding in the scenario of heavy rainfall [20,39], as described in Section 2.1.2. In terms of pollution reduction, the surface runoff caused by heavy rain carried a large number of pollutants such as sediment and TSS. Since it is difficult to determine it, and the model simulation needed to be correctly verified, so mass first flush was used to assess the accumulation rate of pollutants in the initial rainwater, as described in Section 2.1.3.

#### 2.1.2. Runoff Processes- HFR

HFR differs from traditional strategies by considering the change in land use and rainstorm control, it can reflect the degree of the hydrological change and assess the impact on the hydrological cycle. *HFR* can be regarded as the product of the flooded area and duration, which not only can contain the dynamic hydrological characteristics information and the flow that cannot be captured during the rainstorm [39] but it also can be used to measure the flow situation of the riverbank ecosystem, as shown in Equation (1):

$$HFR = (Area)_{flooding} \times (Time)_{flooding} \quad (1)$$

#### 2.1.3. Transport of Contaminants- $MEFF_n$

$MFF_n$ is a dimensionless quality indicator that corresponds to the $n$ percentage of runoff in a rainfall event, while the cumulative mass of pollutants divided by the runoff volume, indicates the pollutant discharge corresponding to the different runoff ratios. If LID was implemented in urban areas, the first flush caused by surface runoff would decrease, which can prove that pollutants are detained by LID. The value of the indicator is 0 at the beginning of the rainfall event and 1 at the end of the rainfall event. When the value is greater than 1, it means that the discharge of pollutants is greater than the runoff. The calculation process is shown in Equation (2):

$$MFF_n = \frac{\frac{\int_0^{t_1} C(t)Q(t)dt}{M}}{\frac{\int_0^{t_1} Q(t)dt}{V}} \quad (2)$$

where $n$ is the runoff percentage (%) in the rainfall event, $M$ is the total mass of pollutant (kg), $V$ is the total runoff volume, and $C(t)$ is the pollutant concentration with time.

The first flush is not suitable for large catchment areas. Samples from the second half of the rainfall event were often overlooked due to the long duration of flow decline in a large catchment, so the peaks in pollutant concentrations in some studies precluded the establishment of a first flush assessment [43–45]. Feng [36] pointed out that the runoff needs to be transmitted over long distances, which may conclude in the transmission process of pollutants and ignore the estimation of the volume of the first flush; this indicator is once applied in the large catchment area in this study, and the results show that the change of concentration of pollutants could not be reacted, and it is unreasonable that the value with LID is greater than 1 (Figure 1); it is necessary to require an index for the studies of water quality with LID in urban areas.

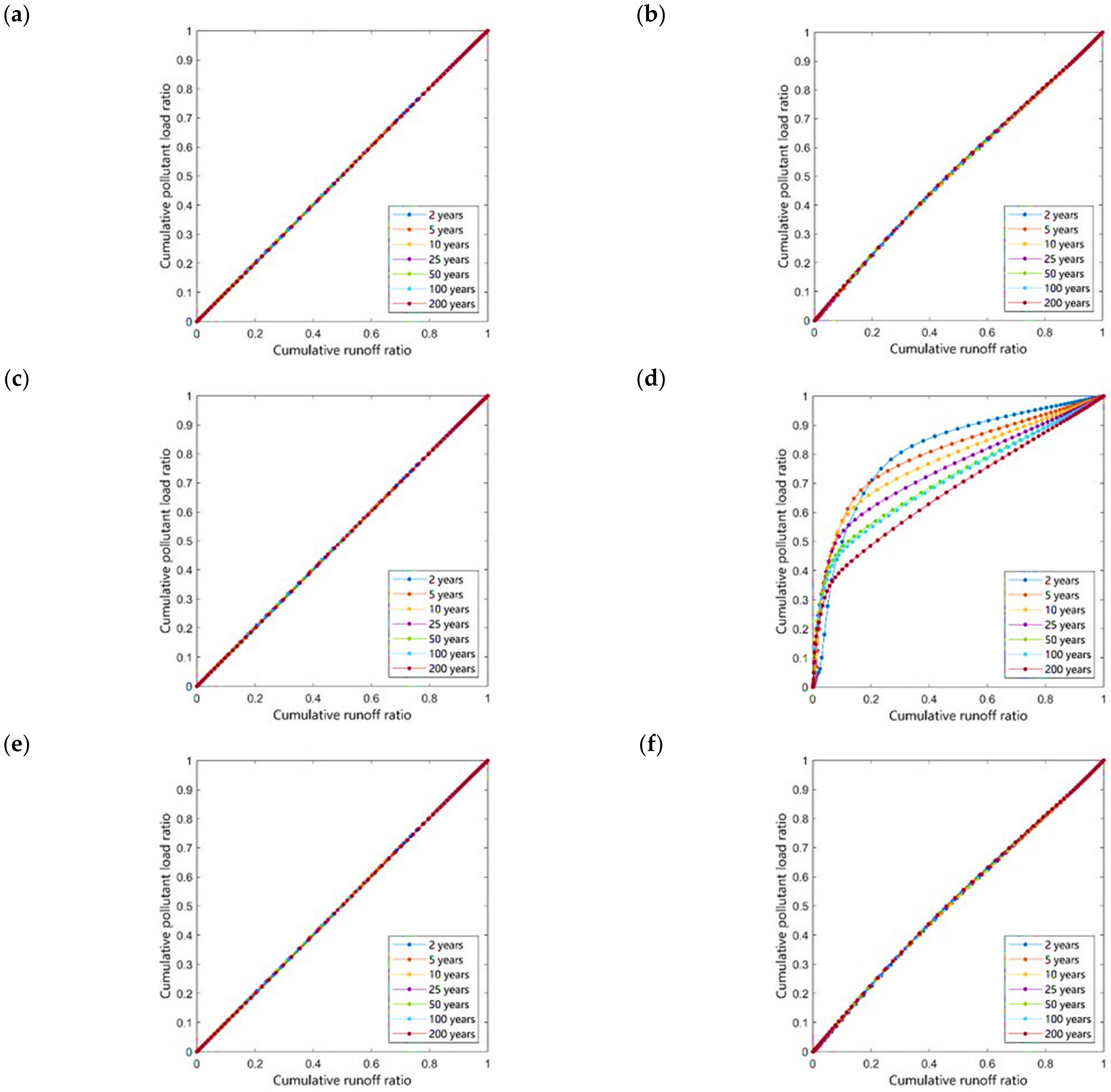


**Figure 1.** Three kinds of pollutants were assessed by $MFF_n$: (**a**,**b**) TSS, (**c**,**d**) TP, (**e**,**f**) BOD, which M(V) curve of the first flush was applied under the 6-h rainfall event between and without LID.

Figure 1 shows that it's necessary to require an index for the studies of water quality with LID in urban areas. An attempt is made in this study to revise the original indicator

$MFF_n$ by removing the total mass from the molecular term $\frac{\int_0^{t_1} C(t)Q(t)}{M}$ and redefine the new indicator $MEFF_n$, as shown in Equation (3):

$$MEFF_n = \frac{\int_0^{t_1} C(t)Q(t)dt}{\frac{\int_0^{t_1} Q(t)dt}{V}} \tag{3}$$

By removing the total mass, it is possible to clearly estimate the volume of pollutants that have been discharged by the flow of different cumulative runoff in the rainfall event. From Figure 2, it is shown the difference between LID and without LID by $MEFF_n$. The value is significantly lower with LID, which confirms that the correction of the quality indicator can reflect the effect of LID for detaining pollutants in large catchment areas. Bertrand-Krajewski [46] studied that 30% of pollutant emissions accumulated by the runoff are used as a schematic indicator to summarize the first flush of the entire rainfall event, so $MEFF_{30}$ is used as the water quality indicator in this study.

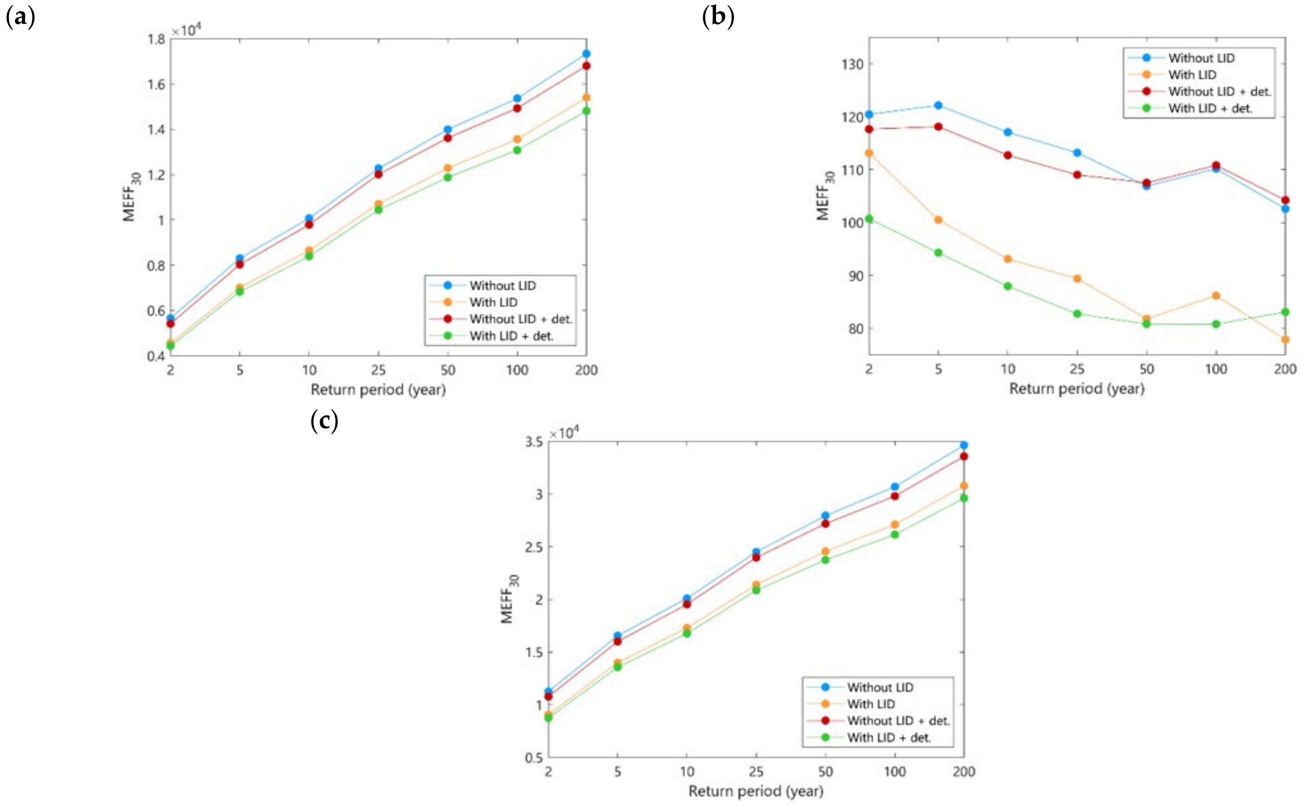


**Figure 2.** The proportion of pollutant emissions accumulated by 30% of runoff at the beginning of the rainfall event: (**a**) TSS, (**b**) TP, and (**c**) BOD.

### *2.2. Study Area*

The study area covers the administrative areas of Yonghe and Zhonghe District in New Taipei City, and the area of watershed is 24.2 km$^2$. The elevation is higher in the southeast and lower in the northwest, and the slope with an elevation which is more than 12 m accounts for one-third of the total area. Most of the soils in the study area are sandy, and there are four main channels in the area which flow into Xindian River through different pumping stations (Figure 3), all of which have been designed with concrete drainage. The drainage system can be divided into 3335 drainage pipelines in the study area (Figure 3). The separation rate of rainwater and sewage pipelines is 52% in the northeastern area and 77% in other areas, which shows the partially separate types and there would be partial pollutants entering stormwater sewers with rainwater during rainfall events. Sewage generated in this area would be collected and transported for treatment outside the study area.

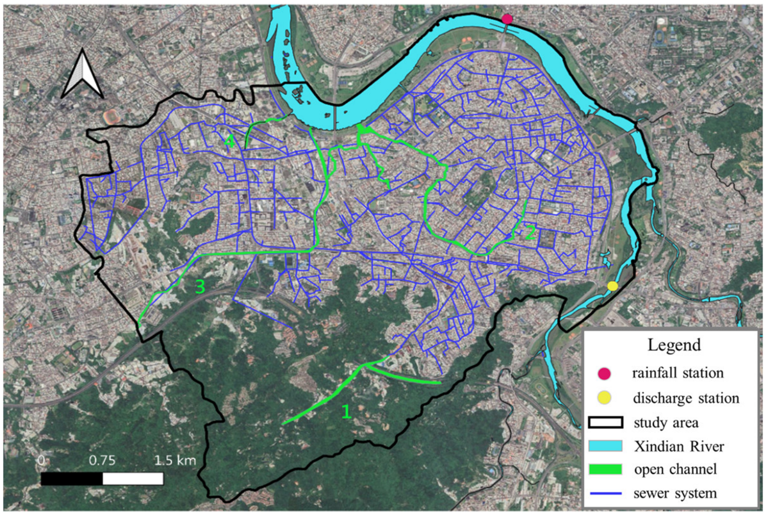


**Figure 3.** The information on the drainage system, open channels and river basin in the study area.

The population density of the study area is 28,100 (persons/km$^2$), which is the area with the highest population density in Taiwan. There are ten types of land use in this highly developed area, which are mainly residential areas (32%), commercial areas (3.4%), industrial areas (4.7%), parks and schools (6%), land used for the government (6%), and roads (21%). Due to the low proportion of green space and ground in the study area, the high limitation of the space that can be re-planned, and the concept of storm runoff control is almost the burden of the sewer system for urban development. Due to the subdued topography and the high degree of urbanization in the study area, there were many records of flooding disasters in history. In 2001, 2008, 2012, and 2014, the urban water caused by extreme rainfall events was insufficiently released which resulted in flooding disasters. The typhoon event in 2008 even raised the protection standard for flooding to a five-year return period. Given this, this study considers the types of land use of this area to reduce the impact of flooding on the city and ecology by optimizing the configuration of LID.

### 2.3. *SWMM Modeling*

To explore the effects on pollution reduction and flood reduction of LID configuration in large catchment areas, SWMM version 5.1 developed by the US EPA is used, which is a hydrological model that simulates urban water quality and hydrological process in urban areas. The parameter selection and correction of the model were carried out through sensitivity analysis and neural regression. The pollutant transport in the downstream, water transmission process of peak flow, and open channel were simulated by SWMM, and the differences in LID configuration for resilience index were obtained under different scenarios and cost considerations.

#### 2.3.1. Introduction to Modeling Computation

SWMM simplifies the overall hydrological process into a one-dimensional hydrological model, and simulates the process of surface runoff and pollutants before entering the sewer system with the runoff block and the pollutant accumulation flash block. Only the phenomenon of pollutants entering the rainwater pipeline from surface runoff is simply considered, and the benefits of LID for pollutant mitigation in this area are discussed without any sewage treatment. After the rainwater enters the sewer system, hydraulic simulation based on the power wave equation is performed to derive the required parameter data of water quality and water quantity index. The accumulated pollutants can be simulated with pollutant accumulation flash block mainly based on the control equation of Build-up and Wash-off under different land use on sunny days, the flash of pollutants in rainstorm events, and the reduction of pollution after LID setting.

2.3.2. Parameter Selection and Calibration

To decrease the uncertainty of the quality parameters in the simulation, Sobol global sensitivity analysis is conducted in this study to analyze the interactions among multiple parameters on the output values of water quality. The resulting data set will be analyzed through a deep neural network with two hidden layers to get the relationship between parameters of water quality and pollutant concentrations in downstream, and the error is minimized by the Adam method [47–49]. Using Monte Carlo simulation to generate a large number of parameter samples into SWMM and analyzing the output of the model. The difference between the first order and the global sensitivity index can be used to determine whether the input parameters interact with each other in the simulation, and the process of calculation is shown in Figure 4. The formula of correlation sensitivity is shown in Equations (4) and (5). Take the parameter $X = (Z_1, Z_2, \ldots, Z_k)$ between $Y$ in simple mathematical terms:

$$S_i(First\ order\ sensitivity\ index) = \frac{V\left[E\left(Y\,|X_i = \widetilde{X}\right)\right]}{V(Y)} \tag{4}$$

$$S_{Ti}(Total\ effect\ sensitivity\ index) = 1 - \frac{V[E(Y\,|X_{\sim i})]}{V(Y)} \tag{5}$$

where $V(Y)$ is the variations for the output of the model, $E(Y)$ is the expected value for the output of the model.

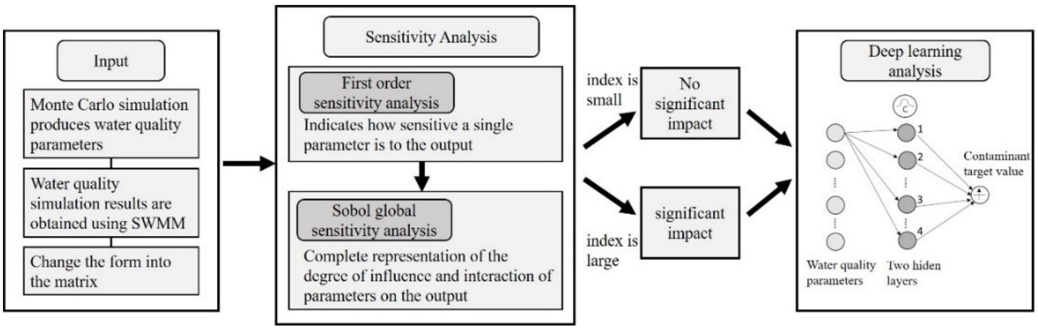


**Figure 4.** Instruction of selection and correction of water quality parameters.

2.3.3. Modelling Process

When establishing the SWMM model, the study area must be divided into several sub-watersheds, the number of which had to be decreased by combining it with the land use. The area and width of the sub-catchment were estimated through a spatial toolbox in ArcGIS to make runoff converge to the nearest manhole. Because the type of buildings in this study area are mostly flat roofs, the slope of the residential area and the hillside are set to 0.01 and the ratio of elevation difference to horizontal distance [9]. In the settings of the sewer system, manholes are the nodes that connect pipes in the system, and surface runoff can be accessed through manholes into the drainage system. The parameters of the manhole are the bottom level, depth, and which of the pipeline includes Manning friction coefficient, length, the nodes of inflow and outlet, and the bottom elevation. In addition to the above settings, the pumping stations were used as the boundary conditions in the study area to accurately get the simulation results.

*2.4. LID Configuration and Modeling Setting*

LID is an NPS strategy that can treat the problem of water quality and quantity, and is able to mitigate the negative impact of urbanization and the increase in impermeable areas. Therefore, the architectural types and land use were considered in this study to optimize the configuration of LID to reduce the impact of flooding and ecology in the city. When setting the LID, in order to consider the actual land use situation, the area where the LID is installed must be smaller than the area of the sub-catchment area. Therefore, the land use area is multiplied by an area reduction factor, which is the upper limit that can be configured with the LID [9]. The appropriate LID components (Table 1) and area reduction factor (Equation (6)) are applied for the configuration.

$$0 \leq A_{LID} \leq \phi A_S \tag{6}$$

where $A_{LID}$ is the configuration area for LID, $\phi$ is the area reduction factor, and $A_S$ is the area of the sub-catchment.

**Table 1.** The LID, area reduction factor, the proportion of impermeable areas, and setup cost for different land use.

| Land Use | LID Component | Proportion of Impermeable Areas | Area Reduction Factor | Setup Cost (NTD per m$^2$) |
|---|---|---|---|---|
| Agricultural land | No LID | - | - | - |
| Right-of-way | Permeable pavement | 10% | 0.1 | 3000 |
| Slope area | No LID | - | - | - |
| Residential land | Green roof | 60% | 0.6 | 3300 |
| Commercial land | Rain barrel | 95% | 0.1 | 20,000 |
| Industrial land | Permeable pavement | 20% | 0.1 | 3000 |
| Land used for agency | Rain garden | 50% | 0.2 | 6800 |
| School land | Bioretention cell | 90% | 0.2 | 6800 |
| Park & Recreation land | Bioretention cell | 90% | 0.5 | 6800 |

The types of land use in the study areas are residential areas, commercial areas, industrial areas, parks and schools, land used for the government, and roads. Among them, the residential areas are the main land use of the area. Therefore, a green roof with lower cost and lower maintenance cost was chosen to detain the surface runoff. LID with infiltration was not set up in the commercial area due to the less redundant open space. Comparatively, the ability in this area can afford LID with higher costs, so rain barrels were chosen. There is large green space in the parks and schools, that can be regarded as the bioretention cells on large scale by acquiring to the green soil to effectively conserve water sources. The land used for the government had more space to set up rain gardens, which is not only cheaper but also had the advantage to beautify the environment. Rigid impermeable pavements can be laid in industrial areas and on the right-of-way, and the weight of cars can be carried by strengthening the gradation. The rainfall immediately entered the storage layer and infiltrated into the soil at a natural rate, which achieved the purpose of reducing the flood peak and improving water quality. Agricultural areas and hillside land are natural forms of land use, so LID was not suitable for these areas. Table 1 shows the LID, area reduction factor, the proportion of impermeable areas, and setup cost for different land use.

In this study, five different LID settings were established by SWMM model. In the model, LID is made of several layers which are surface layer, pavement layer, soil layer, storage layer, and drainage layer and water quantity and quality can be treated. By setting up one or more LID in the existing sub-catchment, adjusting the original impermeability (Equation (7)), and width to different LID to reasonably allocate corresponding facilities to be responsible for the impervious surface runoff.

$$Percent\ Imperviousness(after\ the\ LID\ is\ added) = \frac{Impervious\ area\ remaining}{Non\ -\ LID\ area\ remaining} \tag{7}$$

### 2.5. NSGA-II Optimization

The multi-objective optimization method used in this study is NSGA-II. The possible combinations of target functions were applied to genes. Each individual had its unique gene, which was given due to the fitness value to assess the quality through selection, reproduction, crossover, and mutation to form the next generation. The optimal solution was identified in the method of elite selection strategy and diversity maintenance. Figure 5 shows the simulation steps of NSGA-II: (1) the parent generation that meets the fitness value was randomly generated through MATLAB, (2) the parent that survived to the next generation through nondominated sorting and crowded distance, (3) the spouse who produced offspring was selected by class and competition (4) according to the order of adaptability, 30 Pareto optimal solutions were directly used to become the next generation, (5) Non-Pareto solutions of contemporary generation mating and joining mutation mechanisms, and (6) the optimal solution was obtained after reaching the stopping condition. The appropriate LID for each land use were selected in the study. The change of $MEFF_{30}$, peak flow, and HFR were applied during the rainstorm, and the costs of LID was considered to be the objective function (Equations (8)–(10)) to define the optimal configuration and setting ratio of LID. The calculation was performed by using "gamultiobj" function with MATLAB.

$$min\begin{cases} \Delta MEFF_{30} = MEFF_a - MEFF_b \\ cost = \sum_i^N \sum_j^n (u_j - A_{i,j}) \end{cases} \tag{8}$$

$$min\begin{cases} \Delta HFR = HFR_a - HFR_b \\ cost = \sum_i^N \sum_j^n (u_j - A_{i,j}) \end{cases} \tag{9}$$

$$min\begin{cases} \Delta Peak = Peak_a - Peak_b \\ cost = \sum_i^N \sum_j^n (u_j - A_{i,j}) \end{cases} \tag{10}$$

where $MEFF_a$, $MEFF_b$, $\Delta MEFF_{30}$ are the mass emission first flush ratio and the change before and after LID setting. $HFR_a$, $HFR_b$, $\Delta HFR$ are the hydrological footprint and the change before and after LID setting. $Peak_a$, $Peak_b$, $\Delta Peak$ are peak flow of outlet and the change before and after LID setting. $u_j$ is the $j$th unit setting costs of LID, $A_{i,j}$ is the $j$th area of LID corresponding to the $i$th sub-catchment.

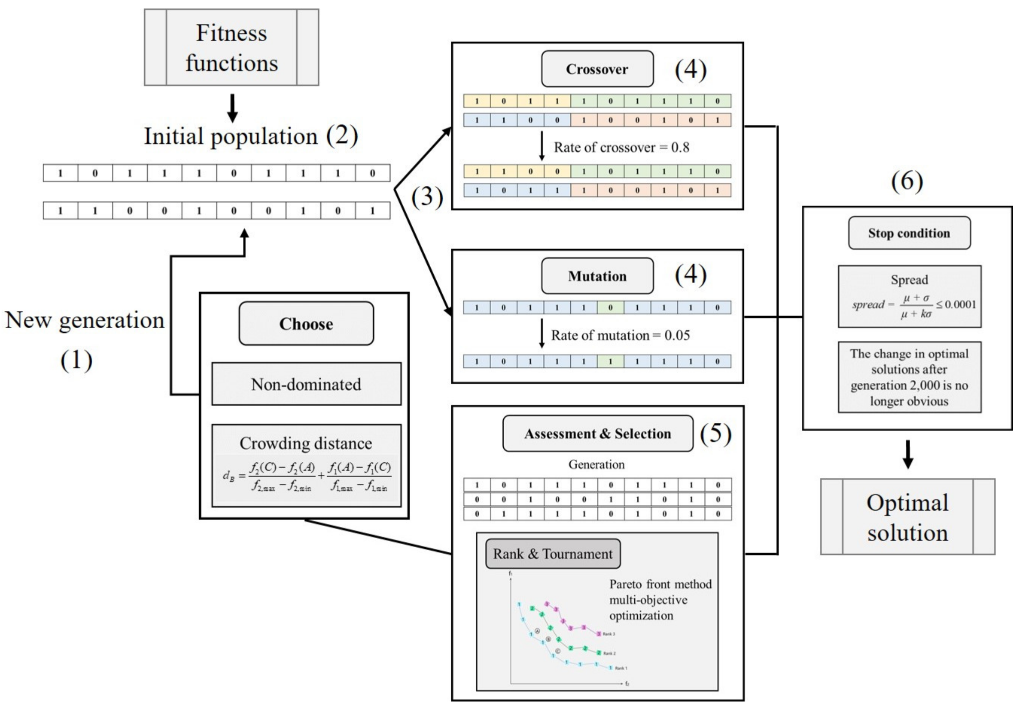


**Figure 5.** The multi-objective optimization method used for this study was NSGA-II.

## 3. Results and Discussion

### *3.1. The Effect of Rainfall Pattern on LID*

It must be evaluated to address in both water quality and quantity during extreme rainfall events before incorporating LID into the strategies of urban planning; this section explores two scenarios: The first one was to set the LID to the limit within the study area and the second one was to choose larger parks and open spaces to be converted into retention ponds. The simulations in different scenarios of seven return periods, combining short duration (6 h) and long duration (24 h) of rainfall to propose the effects on the $MEFF_{30}$, peak flood, and HFR mitigation of LID. In return, the design rain to be solved by LID was determined as the main focus.

#### 3.1.1. Considering the Benefits of LID and Retention Ponds

The effects of LID and retention ponds on three indicators under different rainfall scenarios were analyzed. $MEFF_{30}$ can be divided into TSS, TP, and BOD. In the case of short duration, the effects of reducing TSS and BOD were almost the same, which of LID was negatively correlated with the return periods, it can have a reduction rate bigger than 10% regardless of short-duration or long-duration. The former can still play an effect on pollution reduction in the scenario of long-duration rainfall; however, the effect of BOD reduction was better for LID in the low-intensity scenario. The effect of pollution reduction of the latter was not directly related to the return period. Therefore, the retention ponds can make up for the deficiency of LID in the high return period. LID can be the key, due to the ability to reduce TP under heavy rainfall through the adsorption of vegetation.

In terms of flood reduction, it can be divided into two indicators: peak reduction and HFR reduction. In the case of short-duration rainfall, the rate of flood reduction of LID showed a negative correlation with the return period, the limit of which was the rainfall scenario of a 10-year return period, the effect of reduction of peak flow with LID is the highest in the two-year return period, while the reduction effect of long-duration is less than 5%. In the case of long-duration rainfall, the effect of flood reduction of LID under different rainfall intensities was not significant, instead, retention pond was better than LID. LID mainly reduces runoff by increasing infiltration rate and small water storage space, so it can only effectively reduce the peak of flood during short-duration and low-intensity rainfall; it shows the different results in the reduction of HFR. In the case of short-duration rainfall, the proportion of reduction reached 1.08% and decreased as the return period increased, in which the long duration is half of one in short-duration. Although the retention ponds can reduce flood peak, the mechanism of flood mitigation is to accumulate the surface runoff in a certain place during a flood peak; it would increase the runoff after the flood peaks, which would have a negative effect on the downstream, and had a limited effect on HFR reduction.

Summarizing the results (Figure 6), retention ponds cannot be set up due to the lack of large open space in the study area. The appropriate location of the retention ponds was also unable to store a large amount of runoff. In addition, the mechanism of flood reduction and pollution reduction were different, so the reduction of quality and quantity were not as effective as LID. Therefore, the retention pond will be excluded in the follow-up, and only the assessment of LID for the catchment area would be considered. In addition, it is shown that LID has the most significant effect on $MEFF_{30}$ reduction, the effect of LID starts to flatten after the 10-year return period, and the rate of pollution reduction would remain at about 15%, which the flood reduction would be 5%, and the HFR reduction would be only 1%. Based on the above factors, in order to achieve the effects of flood reduction and pollution reduction at the same time, a 6-h duration was selected as the analysis scenario (Figure 7).

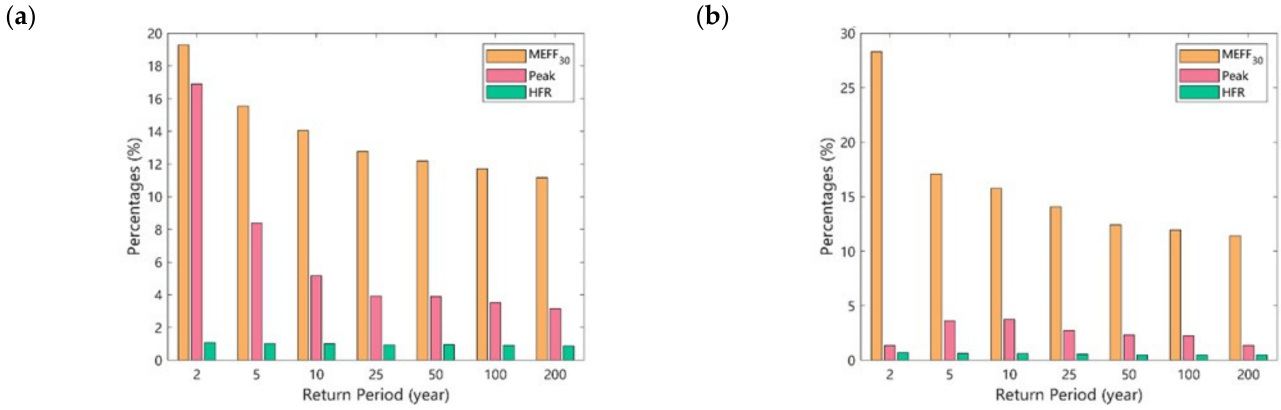


**Figure 6.** Benefit of LID on $MEFF_{30}$ Reduction, Flood Peak, HFR in the different rainfall scenarios. (**a**) Percentages of reduction in 6-hr rainfall, (**b**) percentages of reduction in 24-hr rainfall; it is shown that LID has the most significant effect on $MEFF_{30}$ reduction.

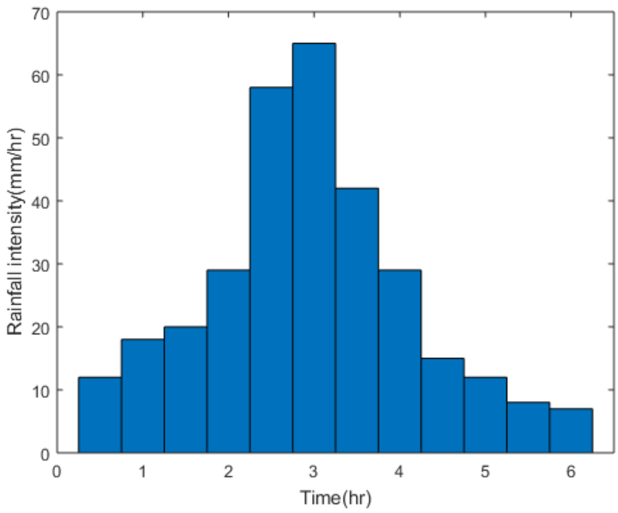


**Figure 7.** The hyetograph of a 5-year return period in 6-h rainfall in the study area. Based on the rainfall scenario LID can withstand; this rainfall scenario will be used as the design rain.

### 3.1.2. Considering LID Components and Costs

Based on the analysis of short-duration rainfall scenarios, if all LID are configured at the same time in the urban area, the results would be huge costs and not be in line according to the principle of benefit-to-cost ratio. Therefore, the effects on pollutant reduction and quantity control of different LID were divided in the study area, in which LID element configuration or the cost of LID were applied to assess the benefits of each LID element.

In the case of the benefit of TSS reduction, rain barrels had the highest reduction benefits per unit for different return periods, but the effect decreases as the return period increases. By considering the reduction effect of unit cost and unit area, it is recommended to use rain barrels in the event of a rainfall with a 5-year return period; however, the effectiveness per unit cost of green roofs and permeable pavements were better than the rain barrels under the rainfall intensity of a 25-year return period. Permeable pavements were likely to be blocked by suspended solids and would decrease infiltration capacity to make the benefits decline over time. BOD can be the indicator to estimate the degree of water pollution, therefore the benefit of BOD reduction per unit area are the same as that of TSS, which indicates that rain barrels are the main LID configuration. In the benefit of TP reduction, the permeable pavement is the best choice whether the reduction rate per unit or cost are considered; however, TP may be released in the form of a dissolved state in the case of increased rainfall intensity. In terms of flood reduction, because the rainwater barrel is not LID with an infiltration type, which did not require a large area to be installed, the collected rainwater would not discharge the runoff to the downstream area after the flood. Therefore, the benefits of rain barrels for flood peaks and HFR reduction are the best solution under the rainfall scenario of 25-year return period, but as the return period increases, the benefits decrease, and it still has potential for cities with higher densities and fewer open spaces.

In addition to cost considerations, in line with the reduction of TSS, although the rain barrel had the best effect of reduction per unit area due to the advantages of directly reducing the surface runoff and small area, green roofs and permeable pavements have a higher unit cost reduction rate due to the lower costs. Summarizing the results, if only the reduction benefit per unit area were considered, rain barrels should be the best choice. The reason why green roof and permeable pavements have the best effect of reduction per unit cost is that it can detain the runoff, and the cost is low, so the benefit is second only to the rain barrel in most cases. The results of this analysis will also be used to discuss the LID configuration.

### *3.2. Optimize the Spatial Configuration of LID*

Under the situation of no land use redistribution and cost consideration, the overdeveloped cities would be discussed in this study by applying the NSGA-II to find the optimal configuration of LID and achieve the maximum effect of pollution reduction and flood reduction. The Monte Carlo test is used to explore how to optimize the configuration of land use by achieving the universality of this study.

#### 3.2.1. The Benefits of Extreme LID Configurations

To prove that LID settings in different areas would have the effects of the water quality improvement and quantity control on downstream, the optimal allocation ratio was generated for each zone according to the principle of proportionality (Equation (11)). Sub-catchments were selected randomly, and appropriate LID were set according to the land use.

$$R(LID\ average\ percentage) = \frac{\sum A_{LID}}{\phi A_S} \times 100\% \quad (11)$$

where $\sum A_{LID}$ is the set area of LID, $\sum \phi A_S$ is the available area of LID.

First, LID of a single area to the limit was configured, and then divided by the cost of the area to obtain the reduction rate of different indicators; it can be seen from Figure 8a, the area with higher $MEFF_{30}$ reduction rate was in the northwest–southeast, and the area with the highest benefit was located in a densely populated area, because of NPS pollution such as domestic wastewater. While the blue area is the agricultural and industrial areas, there is no pipeline to collect agricultural wastewater, so LID must be prioritized to reduce pollution in downstream areas. According to Figure 8b, it can be found that the area with higher flood peak reduction is the northwest-southeast. Among them, the area with the highest benefit is located on the east side. The runoff in this area mainly flows to upstream of the drainage system through the culvert. The area with the second-highest benefit is the area with severe elevation changes. The configuration of LID through the concept of source control could mitigate the situation of flood damage at downstream; it can be seen from Figure 8c that the higher benefit of reducing HFR is in the east-south. In the east, the sewer system in this area would directly flow into the end of the drainage and then flow directly into the Xindian River through the pumping station. There was a little effect on the runoff mitigation. The effect of HFR reduction on the western side of the area is also lower because some of the runoff did not flow into the three open channels in the study area. In the area with high intermediate efficiency, the runoff was discharged to the tributaries of the drainage channel through the sewers. Due to the high degree of development in this area, the HFR can be reduced by LID because the runoff from the mountains on the south side is directly discharged into the drainage. Overall, the areas with high flood peak reduction and HFR benefits are mostly located in the middle and upstream of the open channels.

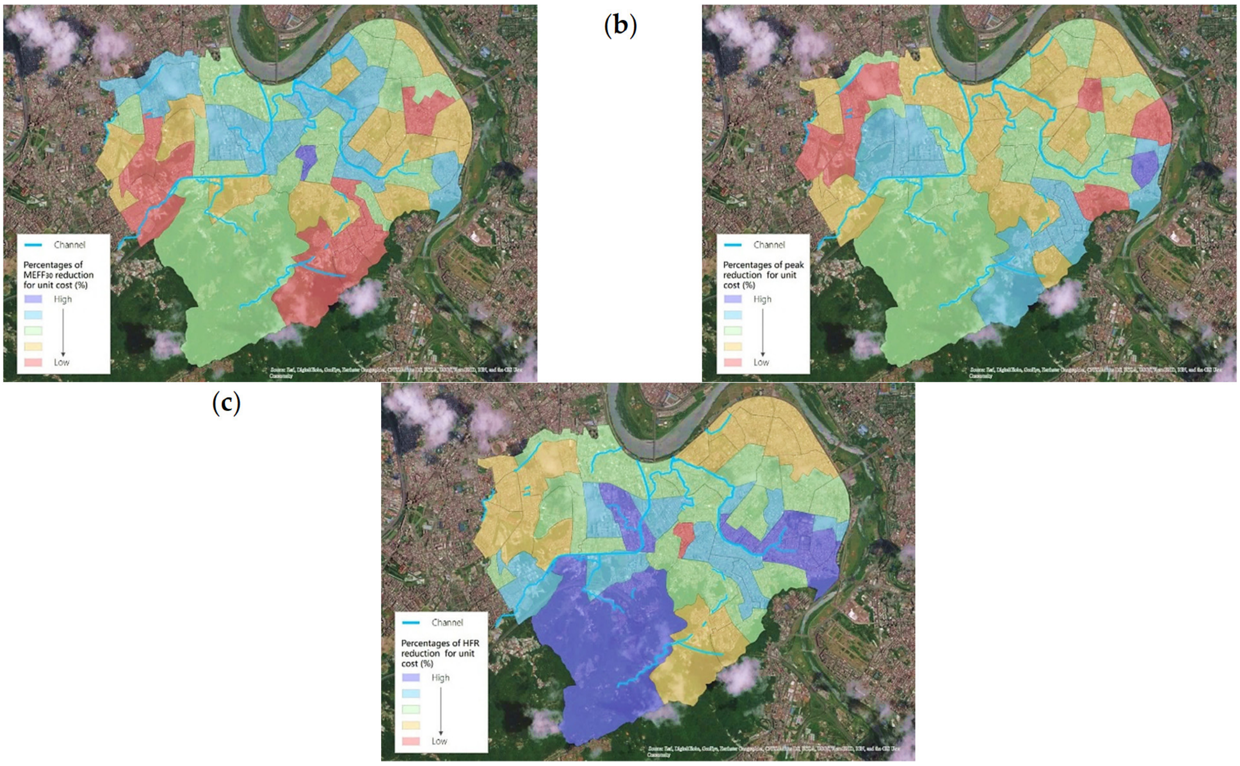


**Figure 8.** First, allocate the LID of a single area to the limit, and then divided by the cost to obtain the unit cost reduction of the single area (**a**) $MEFF_{30}$ (**b**) flood peak reduction rate, and (**c**) HFR reduction rate, where the purple area configures the priority zones.

3.2.2. Optimal Space Configuration of LID

Deploying LID in different areas had a great impact on water quality and quantity at downstream. To estimate the benefits under different costs of LID benefits, 30%, 50%, and 80% of costs according to different goals through a nondominated sorting algorithm were assessed. The optimal LID configuration for different cost configurations can be determined by obtaining the relationship between the indicators of quantity control and pollution mitigation, in which water improvement quality and water quantity reduction were positively correlated with the cost. Among the effects of the reduction in $MEFF_{30}$, peak flow and HFR, the maximum benefit-to-cost ratios fell at 88%, 52%, and 65% of costs, and the ratios that can be reduced are about 15.6%, 6.64%, and 0.81%, respectively. When the time costs exceed the maximum profit-to-price ratio, the reduction rate would gradually flatten (Figure 9).

In the case of 30% cost, configuring LID at the source of the open channel and the confluence of the sewer system would effectively reduce $MEFF_{30}$ and HFR; this shows that LID can not only control the source to intercept pollutants to improve water quality but also mitigate flooding. If the flood peaks needed to be reduced, LID must be set along the drainage to prevent the overflow caused by heavy runoff. When the budget of flood mitigation is increased to 50%, deploying LID in areas with higher or undulating terrain can simultaneously improve the performance of the three indicators. LID can also be installed in the upper and middle of the drainage system to reduce the runoff to mitigate the risk of flooding. Raising the setup cost to 80%, the reduction is no different than in the case of the LID limit setting and even less than the setting with a 50% cost in the HFR reduction. In the southeast and northeast areas with low allocation ratios, since the rainwater did not flow into the open channel but into the stream, it means that the effect of LID in this area is less significant in pollution reduction. The latter is mainly the school areas, and the corresponding LID was the bioretention cell that can only detain the runoff of its area. In addition, considering the form of land use corresponds to different LID configurations, LID in industries, densely populated areas, and agricultural areas can effectively retain pollutants. The areas with a relatively low allocation ratio were mostly forest areas with high water permeability, so there was no need to configure LID, and the effect of pollution reduction can be achieved through infiltration and vegetation.

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

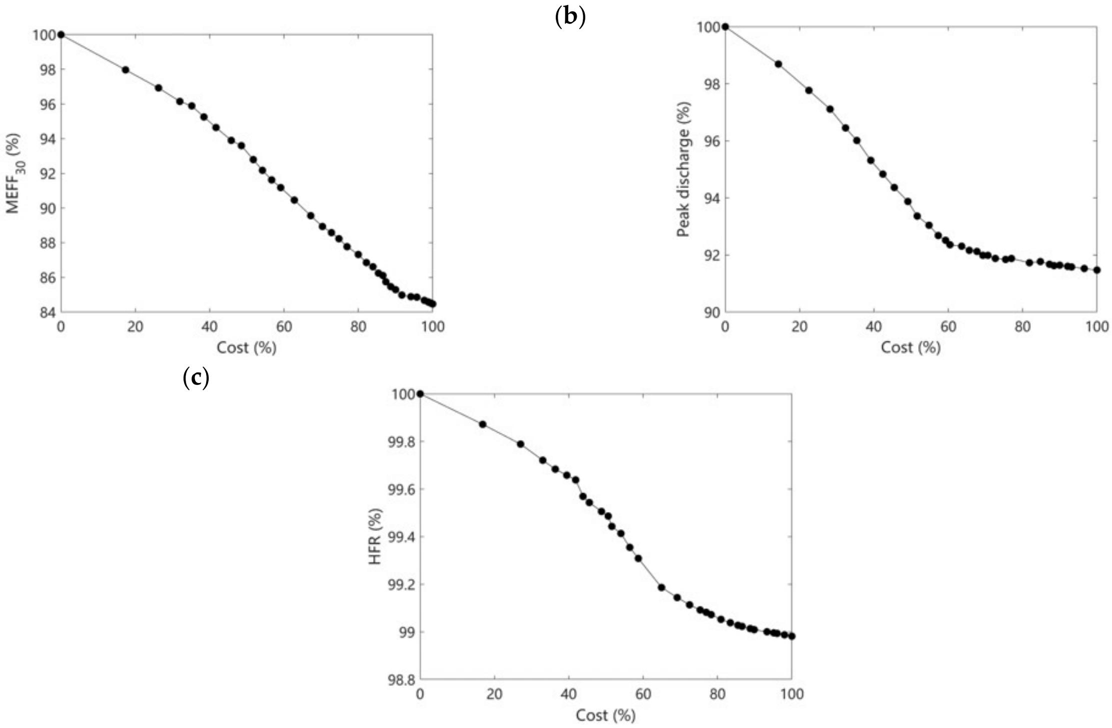


**Figure 9.** The correlation curve of different indicators and costs of optimal configuration. (**a**) $MEFF_{30}$ (**b**) peak flow (**c**) HFR.

In terms of flood mitigation, parks, green spaces, roads, and residential areas were the main areas with high allocation ratios. The parks and green spaces can be regarded as large-scale bioretention cells when combined with LID, and the green roof can be set combined with road land and roofs in residential areas, which can effectively increase the effect of flood reduction; it is prior LID setting to places with obvious topographic changes and the confluence of rainwater and sewers to directly solve the problem of flooding in urban areas and the retention of pollutants under the limited budget. Conversely, LID can be set on upstream to mitigate peak flow to reduce flooding at downstream. The optimization analysis results of different indicators corresponding to 50% costs are presented in Figure 10.

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

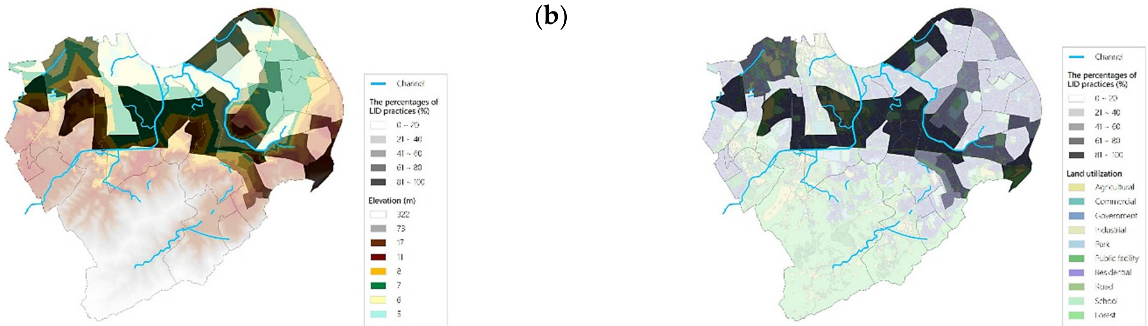


**Figure 10.** *Cont.*

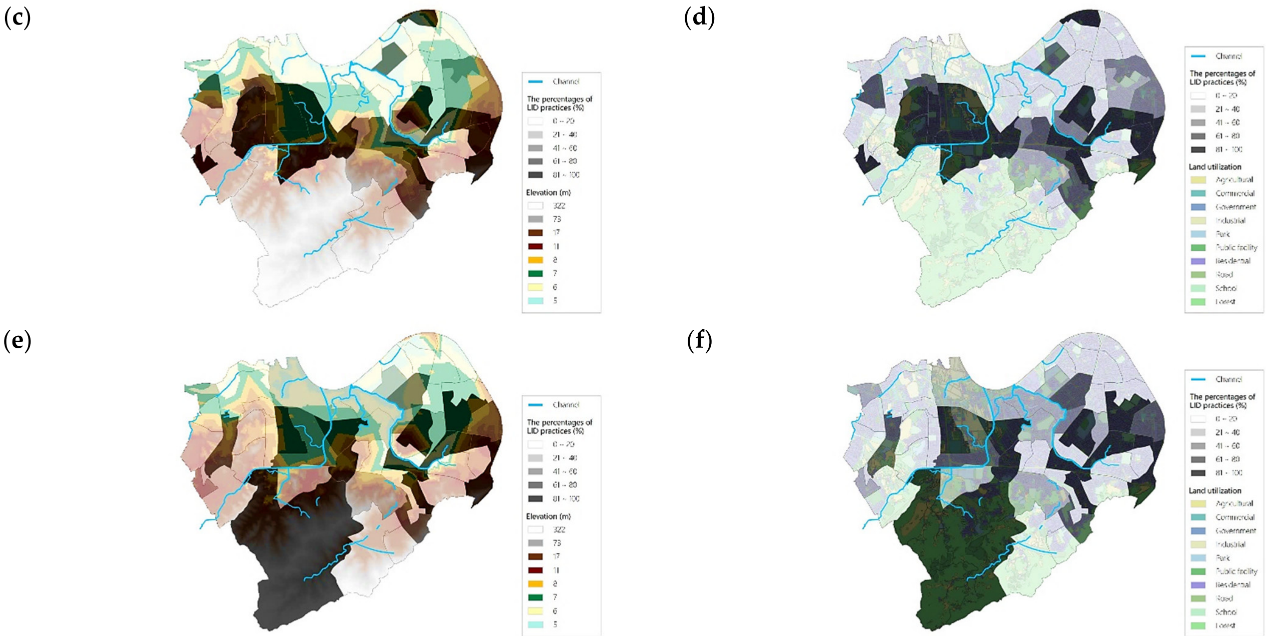


**Figure 10.** The optimized analysis results in 50% costs corresponding to different indicators in the DEM and land use: (**a**,**b**) $MEFF_{30}$, (**c**,**d**) outfall peak flow, (**e**,**f**) HFR.

### 3.2.3. Correlation between the Optimal Configuration of LID and the Type of Land Use

To provide the plan of land use and the comprehensive renewal of old cities to the undeveloped urban areas, the study area was taken as a demonstration case to show that the distribution of the optimal configuration of LID would be different when the type of urban development changes. To understand the relationship between the optimal configuration of LID and the types of land use, in which different sub-catchments were randomly changed through the Monte Carlo test, and the average impervious rate of each sub-catchment was calculated to represent the degree of development. Each group of samples would aim to minimize the cost of reducing $MEFF_{30}$, flood peak and HFR to find the Pareto solution through NSGA-II, and then the LID corresponding to the average impermeability of these 23 units were recorded (Figure 11).

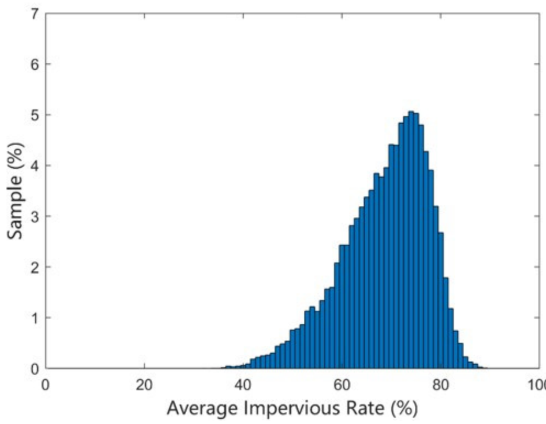


**Figure 11.** A total of 2260 sets of samples were generated in this test. Each set of these samples includes the average impermeability of 23 zones, and the overall average imperviousness of the city is about 74%.

Whether for the effects of reducing $MEFF_{30}$, flood peaks, or HFR, the optimal LID configuration is positively correlated with the average imperviousness of the area (Figure 12). Among them, the trend of $MEFF_{30}$ reduction is more significant than the flood peak and HFR as the proportion of LID increased. When the impermeability rates are 40% to 60%, the allocation ratio of LID was lesser but resulted as a higher effect on $MEFF_{30}$ reduction; it proves that the function of LID focused on the treatment of pollutants and the improvement of water quality. When the impermeability rate exceeds 80%, the average allocation rate begins to decline, and the relative limit of reducing $MEFF_{30}$ is also 85%; it can be seen that LID had a limit on the effect of pollution reduction.

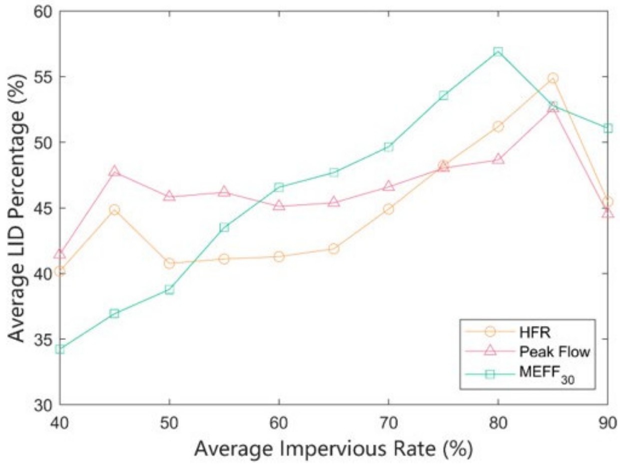


**Figure 12.** The relationship between the average impermeability and the LID optimal configuration.

In areas with a high impermeability, more LID is needed to be deployed to effectively reduce flood peaks. From Figure 12, it can be seen that the impervious rate has an increase from 50% to 80%, and the average LID allocation ratio is between 45% and 50% which is a minor change; it shows that LID also has limited benefits for flooding mitigation. In other words, when the flood peak is considered to be the target, the LID should be preferentially configured in areas with a high impermeability. For the reduction of HFR, the trend is more significant than the flood peaks but less than $MEFF_{30}$, and the increment in impervious areas in cities was the main reason for the flooding. Therefore, HFR can also be effectively reduced by setting LID to intercept runoff.

Through the Monte Carlo test, we can understand the benefits of LID in improving water quality, and also confirms the limit of flood reduction. According to the different morphology of urban areas, the appropriate strategies of LID settings and decision-making can be defined in this study to effectively improve urban resilience.

## 4. Conclusions

This study aims to focus on the capability of the LID pollutant reduction, combined with the effects on water quantity control to comprehensively analyze the effects of LID on resilience in highly urbanized areas. The optimal LID components for different land uses are discussed based on the principle of suitability and rainfall analysis, and then NSGA-II is used to define the multi-objective optimization. The HFR and outlet peak flow reduction are used as the basis for water quantity indicators. The results show that the modified $MEFF_{30}$ is capable to reflect the pollutants volume from the runoff. The effectiveness of flood reduction rate and $MEFF_{30}$ reduction rate is negatively correlated with the rainfall return period; it shows that $MEFF_{30}$ reduction was maintained at even 20% under a 200-year return period; however, the flood reduction was subtle when the return period exceeded 10-year; moreover, the $MEFF_{30}$ reduction and flood reduction both shows a similar trend for the rainfall duration; it shows that $MEFF_{30}$ reduction is maintained at 15% under whether long-duration events or not; however, the flood reduction is decreased to 5% under long-duration events. The design criteria should consider water quality improvement more than water quantity control, considering the effect of LID on reducing pollutants is much higher than reducing flooding. Regarding the benefits of different LID components, cities should choose pavements and green roofs which are cost-effective permeable, or rain barrels with high area efficiency.

When taking cost into consideration, the priority of LID settings should be given to the location where the middle and upper reaches of the open channel, the confluence of the rainwater sewer, and the catchment area covered by industrial and agricultural areas are used to achieve the benefits of pollution reduction. If the target was to reduce flood peak and HFR, LID should be preferentially set in places where the topography changes severely at the end of the sewer system, and in the middle and upper reaches of open channels. After all, the confluence at the middle and upper reaches of the open channel and the sewer system were the optimal LID configuration location for both flood reduction and pollution reduction. Furthermore, it is used as an index for evaluating urban resilience, and the Monte Carlo test was used to increase the generality in this study. The results showed that the benefits of LID in improving water quality are greater than controlling water quantity. If flood reduction is to be included in the utility target of LID, the intensity and duration of rainfall events to be resolved should be considered in advance to increase the capacity and recovery in the concept of resilience.

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## References


1. United States Environmental Protection Agency. *Benefits of Low Impact Development. How LID Can Protect Your Community's Resources*; Office of Wetlands, Oceans, and Watersheds: Washington, DC, USA, 2012.
2. Rosa, D.J.; Clausen, J.C.; Dietz, M.E. Calibration and verification of SWMM for low impact development. *JAWRA J. Am. Water Resour. Assoc.* **2015**, *51*, 746–757. [CrossRef]
3. Dietz, M.E.; Clausen, J.C. Stormwater runoff and export changes with development in a traditional and low impact subdivision. *J. Environ. Manag.* **2008**, *87*, 560–566. [CrossRef] [PubMed]
4. Zahmatkesh, Z.; Karamouz, M.; Goharian, E.; Burian, S.J. Analysis of the effects of climate change on urban storm water runoff using statistically downscaled precipitation data and a change factor approach. *J. Hydrol. Eng.* **2014**, *20*, 05014022. [CrossRef]
5. Willems, P.; Olsson, J.; Arnbjerg-Nielsen, K.; Beecham, S.; Assela, P.; Gregersen, I.B.; Madsen, H.; Nguyen, V.-T.-V. *Impacts of Climate Change on Rainfall Extremes and Urban Drainage Systems*; IWA: London, UK, 2012.
6. Vörösmarty, C.J.; Green, P.; Salisbury, J.; Lammers, R.B. Global water resources: Vulnerability from climate change and population growth. *Science* **2000**, *289*, 284–288. [CrossRef]
7. United Nations. *World Urbanization Prospects: The 2018 Revision*; Department of Economic and Social Affairs, United Nations: New York, NY, USA, 2019.
8. IPCC. *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; IPCC: Geneva, Switzerland, 2014.
9. Roy, A.H.; Purcell, A.H.; Walsh, C.J.; Wenger, S.J. Urbanization and stream ecology: Five years later. *J. N. Am. Benthol. Soc.* **2009**, *28*, 908–910. [CrossRef]

10. Misra, A.K. Impact of urbanization on the hydrology of Ganga Basin (India). *Water Resour. Manag.* **2011**, *25*, 705–719. [CrossRef]
11. Ahiablame, L.M.; Engel, B.A.; Chaubey, I.J.W. Effectiveness of low impact development practices: Literature review and suggestions for future research. *Water Air Soil Pollut.* **2012**, *223*, 4253–4273. [CrossRef]
12. Emerson, C.H.; Welty, C.; Traver, R.G. Watershed-scale evaluation of a system of storm water detention basins. *J. Hydrol. Eng.* **2005**, *10*, 237–242. [CrossRef]
13. Fekete, A.; Hufschmidt, G.; Kruse, S. Benefits and Challenges of Resilience and Vulnerability for Disaster Risk Management. *Int. J. Disaster Risk Sci.* **2014**, *5*, 3–20. [CrossRef]
14. Eckart, K.; McPhee, Z.; Bolisetti, T. Performance and implementation of low impact development—A review. *Sci. Total Environ.* **2017**, *607–608*, 413–432. [CrossRef]
15. Sørup, H.J.D.; Fryd, O.; Liu, L.; Arnbjerg-Nielsen, K.; Jensen, M.B. An SDG-based framework for assessing urban stormwater management systems. *Blue-Green Syst.* **2019**, *1*, 102–118. [CrossRef]
16. Guo, J.C.; Urbonas, B.; MacKenzie, K. Water quality capture volume for storm water BMP and LID designs. *J. Hydrol. Eng.* **2014**, *19*, 682–686. [CrossRef]
17. Tang, S.; Jiang, J.; Zheng, Y.; Hong, Y.; Chung, E.-S.; Shamseldin, A.Y.; Wei, Y.; Wang, X. Robustness analysis of storm water quality modelling with LID infrastructures from natural event-based field monitoring. *Sci. Total Environ.* **2021**, *753*, 142007. [CrossRef] [PubMed]
18. Hsu, N.S.; Hunag, Y.H.; Liu, H.J.; Cheng, W.M. The Research of Optimal Arrangement of Low Impact Development Infrastructure: A Case Study of Min-Sheng Community. *Sinotech Eng.* **2016**, *131*, 77–86.
19. Liang, C.-Y.; You, J.-Y.; Lee, H.-Y. Investigating the effectiveness and optimal spatial arrangement of low-impact development facilities. *J. Hydrol.* **2019**, *577*, 124008. [CrossRef]
20. Ho, H.-C.; Lin, S.-W.; Lee, H.-Y.; Huang, C.C. Evaluation of a Multi-Objective Genetic Algorithm for Low Impact Development in an Overcrowded City. *Water* **2019**, *11*, 2010. [CrossRef]
21. Taghizadeh, S.; Khani, S.; Rajaee, T. Hybrid SWMM and particle swarm optimization model for urban runoff water quality control by using green infrastructures (LID-BMPs). *Urban For. Urban Green.* **2021**, *60*, 127032. [CrossRef]
22. Giacomoni, M.; Joseph, J. Multi-objective evolutionary optimization and Monte Carlo simulation for placement of low impact development in the catchment scale. *J. Water Resour. Plan. Manag.* **2017**, *143*, 04017053. [CrossRef]
23. Ashley, R.M.; Balmforth, D.J.; Saul, A.J.; Blanskby, J.D. Flooding in the future—Predicting climate change, risks and responses in urban areas. *Water Sci. Technol.* **2005**, *52*, 265–273. [CrossRef]
24. Eckstein, D.; Hutfils, M.-L.; Winges, M. *Global Climate Risk Index 2019. Who Suffers Most from Extreme Weather Events*; Germanwatch: Bonn, Germany, 2018.
25. Eckstein, D.; Künzel, V.; Schäfer, L. *Global Climate Risk Index 2021. Who Suffers Most from Extreme Weather Events? Weather-Related Loss Events in 2019 and 2000–2019*; Germanwatch: Bonn, Germany, 2021.
26. Walsh, C.J.; Roy, A.H.; Feminella, J.W.; Cottingham, P.D.; Groffman, P.M.; Morgan, R.P. The urban stream syndrome: Current knowledge and the search for a cure. *J. N. Am. Benthol. Soc.* **2005**, *24*, 706–723. [CrossRef]
27. Oraei Zare, S.; Saghafian, B.; Shamsai, A. Multi-objective optimization for combined quality–quantity urban runoff control. *Hydrol. Earth Syst. Sci.* **2012**, *16*, 4531–4542. [CrossRef]
28. Zhang, G.; Hamlett, J.M.; Reed, P.; Tang, Y. Multi-Objective Optimization of Low Impact Development Designs in an Urbanizing Watershed. *J. Optim.* **2013**, *2*, 40368. [CrossRef]
29. Li, F.; Yan, X.-F.; Duan, H.-F. Sustainable design of urban stormwater drainage systems by implementing detention tank and LID measures for flooding risk control and water quality management. *Water Resour. Manag.* **2019**, *33*, 3271–3288. [CrossRef]
30. Baek, S.-S.; Ligaray, M.; Pyo, J.; Park, J.-P.; Kang, J.-H.; Pachepsky, Y.; Chun, J.A.; Cho, K.H. A novel water quality module of the SWMM model for assessing low impact development (LID) in urban watersheds. *J. Hydrol.* **2020**, *586*, 124886. [CrossRef]
31. Goonetilleke, A.; Thomas, E.; Ginn, S.; Gilbert, D. Understanding the role of land use in urban stormwater quality management. *J. Environ. Manag.* **2005**, *74*, 31–42. [CrossRef]
32. Ma, Z.-B.; Ni, H.-G.; Zeng, H.; Wei, J.-B. Function formula for first flush analysis in mixed watersheds: A comparison of power and polynomial methods. *J. Hydrol.* **2011**, *402*, 333–339. [CrossRef]
33. Li, L.-Q.; Yin, C.-Q.; He, Q.-C.; Kong, L.-L. First flush of storm runoff pollution from an urban catchment in China. *J. Environ. Sci.* **2007**, *19*, 295–299. [CrossRef]
34. Park, I.; Kim, H.; Chae, S.-K.; Ha, S. Probability mass first flush evaluation for combined sewer discharges. *J. Environ. Sci.* **2010**, *22*, 915–922. [CrossRef]
35. Baek, S.-S.; Choi, D.-H.; Jung, J.-W.; Lee, H.-J.; Lee, H.; Yoon, K.-S.; Cho, K.H. Optimizing low impact development (LID) for stormwater runoff treatment in urban area, Korea: Experimental and modeling approach. *Water Res.* **2015**, *86*, 122–131. [CrossRef]
36. Feng, W.; Wang, J.; Che, W. Analysis on characteristics of stormwater runoff flush on different land surfaces. *Chin. J. Environ. Eng.* **2012**, *6*, 817–822.
37. Gupta, K.; Saul, A.J. Specific relationships for the first flush load in combined sewer flows. *Water Res.* **1996**, *30*, 1244–1252. [CrossRef]
38. Stenstrom, M.K.; Kayhanian, M. *First Flush Phenomenon Characterization*; California Department of Transportation Division of Environmental Analysis: Sacramento, CA, USA, 2005.
39. Giacomoni, M.H.; Zechman, E.M.; Brumbelow, K. Hydrologic footprint residence: Environmentally friendly criteria for best management practices. *J. Hydrol. Eng.* **2011**, *17*, 99–108. [CrossRef]

40. Scott, T.J.; Politte, A.; Saathoff, S.; Collard, S.; Berglund, E.; Barbour, J.; Sprintson, A. An evaluation of the Stormwater Footprint Calculator and the Hydrological Footprint Residence for communicating about sustainability in stormwater management. *Sustain. Sci. Pract. Policy* **2014**, *10*, 14–27. [CrossRef]
41. Giacomoni, M.; Gomez, R.; Berglund, E. Hydrologic impact assessment of land cover change and stormwater management using the hydrologic footprint residence. *JAWRA J. Am. Water Resour. Assoc.* **2014**, *50*, 1242–1256. [CrossRef]
42. Huong, H.T.L.; Pathirana, A. Urbanization and climate change impacts on future urban flooding in Can Tho city, Vietnam. *Hydrol. Earth Syst. Sci.* **2013**, *17*, 379–394. [CrossRef]
43. Chow, M.F.; Yusop, Z. Sizing first flush pollutant loading of stormwater runoff in tropical urban catchments. *Environ. Earth Sci.* **2014**, *72*, 4047–4058. [CrossRef]
44. Carpenter, S.R.; Caraco, N.F.; Correll, D.L.; Howarth, R.W.; Sharpley, A.N.; Smith, V.H. Nonpoint pollution of surface waters with phosphorus and nitrogen. *Ecol. Appl.* **1998**, *8*, 559–568. [CrossRef]
45. Singh, R.; Baz, M.; Gehlot, A.; Rashid, M.; Khurana, M.; Akram, S.V.; Alshamrani, S.S.; AlGhamdi, A.S. Water Quality Monitoring and Management of Building Water Tank Using Industrial Internet of Things. *Sustainability* **2021**, *13*, 8452. [CrossRef]
46. Bertrand-Krajewski, J.-L.; Chebbo, G.; Saget, A. Distribution of pollutant mass vs volume in stormwater discharges and the first flush phenomenon. *Water Res.* **1998**, *32*, 2341–2356. [CrossRef]
47. Kingma, D.P.; Ba, J. *Adam: A Method for Stochastic Optimization*; Cornell University: New York, NY, USA, 2017.
48. Glorot, X.; Bengio, Y. Understanding the difficulty of training deep feedforward neural networks. In Proceedings of the Thirteenth International Conference on Artificial Intelligence and Statistics, Chia Laguna Resort, Sardinia, Italy, 13–15 May 2010.
49. Ishigami, T.; Homma, T. An importance quantification technique in uncertainty analysis for computer models. In Proceedings of the First International Symposium on Uncertainty Modeling and Analysis, College Park, MD, USA, 3–5 December 1990.