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Revolutionizing Urban Water Management: A Green-Aware Study Based on Innovative Approach

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ABSTRACT

The study aimed to improve urban stormwater management by optimizing best management practices and low-impact development (BMP-LID) techniques using a novel multi-task spider wasp optimization (MT-SWO) approach. The research targeted urban runoff issues exacerbated by climate change, urbanization, and aging infrastructure, focusing on Chongqing's Shapingba and Jiangbei districts. BMP-LID strategies, including infiltration, bio-retention reservoirs, and permeable road surfaces, were evaluated and optimized using an integrated Stormwater Management Model (SWMM) and MT-SWO framework. Simulations considered pollutant reductions in Total Suspended Solids (TSS) and Total Nitrogen (TN) under rainfall return periods of 3 and 9 years. The key findings revealed that bio-retention reservoirs were the most effective BMP, achieving a 76% reduction in TSS and an 85% reduction in TN at 6% area allocation compared to baseline conditions. The MT-SWO approach facilitated the identification of optimal BMP configurations, enabling significant pollutant reductions while balancing spatial and economic constraints. MT-SWO's ability to dynamically explore and exploit solution spaces allowed tailored BMP strategies that significantly outperformed traditional methods. The study underscores the potential of MT-SWO to revolutionize urban stormwater management by offering efficient, adaptive, and data-driven solutions. However, the computational demands and data requirements of MT-SWO highlight scalability challenges for larger urban contexts. By demonstrating superior pollutant reduction capabilities, the research provides a critical step toward sustainable water quality management in rapidly urbanizing and climate-sensitive regions.

1. INTRODUCTION

Urban stormwater management is one of the greatest concerns in the world due to urbanization and climate change. Water resistance grows when cities develop to accommodate growing people, diminishing natural access and increasing storm runoff. This process raises the possibility of water damage, rusting, and decomposition, which is enhanced by implementing new needs on existing infrastructure, particularly in sewer-focused structures designed to produce negative ecological effects instead of aesthetics [1]. This issue is from outside the scope of standard stormwater management solutions, which depend on water storage and centrally administered drainage. Urban runoff is a significant and common contaminant. Costly renovations to infrastructure, repairs and maintenance, and destruction of the environment occurs. And the erratic climate variations that have affected rainfall patterns and the occurrence of severe storms on the surface are beyond the capabilities of current technologies [2].

LID techniques and BMPs are two examples of innovative methods that need to be implemented to mitigate the effects of typical urban water management systems. BMPs are recycling mechanisms designed to enhance water quality in water management systems. Green roofs, permeable walkways, and bio retention pools are some examples of these techniques. This technique reduces stormwater and sewage runoff, enabling it to sink, filter, and recharge naturally [3]. However, BMPs may be ineffective due to land availability issues, maintenance costs, and unpredictable operations based on regional terrain and weather conditions, whereas LID systems gather rainwater from the start of the construction process [4].

While LID solutions boost urban resilience and encourage sustainable development, their adoption may be impeded by their initial costs, regulatory barriers, and the need for collaboration amongst several municipal planning, engineering, and political sectors. Proactive approaches, like BMPs and LIDs, are effective in managing urban water resources despite these disadvantages. They provide helpful tools to address the issues of urbanization and climate change coming together, to promote environmental protection, and build community resilience [5]. The following points show the challenges, objective, study area, evaluation of BMPs, optimization approach:

- **Challenges:** However, there are a lot of obstacles that can be solved when BMP and LID are used. Few maintenance needs, high start-up costs, densely populated cities, and regulatory obstacles. Moreover, regional climate, soil composition, and land use may all affect how effective these techniques are, necessitating the employment of customized techniques to get the intended outcomes.
- **Study Objective:** Urban stormwater management is growing more and more crucial as a result of global warming, debris flows, and population increases. Implementation of best practices and impact-free development are two best practices for green infrastructure (BMP-LID) to reduce waste and improve aquatic ecosystems. To improve urban stormwater quality, this project intends to improve BMP-LID techniques such as infiltration, bio-retention reservoirs, and permeable road surfaces. It will accomplish this by applying a state-of-the-art green structure design methodology.
- **Study Area:** In this study, runoff and rainfall were simulated using a stormwater management model (SWMM). The main focus areas of the study are Chongqing, Shapingba, and Jiangbei provinces in China.
- **Evaluation of BMPs:** Each subbasin in this region may have one of the BMPs or none at all. Compare the proposed BMPs with the distribution of single BMPs in different dimensions in each subbasin.
- **Optimization Approach:** The novel multi-task spider-wasp optimization (MT-SWO) method was used to optimize the BMP. The MT-SWO-SWMM model, when combined with SWMM, enables better control of urban runoff quality. The MT-SWO method played an important role in determining the optimal BMP-LID configuration.

Urbanization and climate change have raised many challenges with regard to stormwater management. While the population grows, the expansion of urban areas leads to an increase in impervious surfaces, such as roads, rooftops, and pavements, which dislocate natural infiltration processes of water. This translates into higher amounts of stormwater runoff, overwhelming ancient drainage systems and causing severe flooding, water pollution, and ecological degradation. This situation is further exacerbated by climate change, in which altered precipitation patterns, increased extreme events, and stress on existing stormwater infrastructure are common. Such interconnected problems require innovative, sustainable management strategies to reduce the negative impacts of these issues on the urban environment. Among the effective tools that have emerged in response to such challenges are Best Management Practices and the Low-Impact Development approach. BMPs include bio-retention reservoirs, permeable pavements, and infiltration systems that help improve water quality through more natural infiltration, filtration, and recharge into groundwater. Similarly, LID approaches implement the principles of sustainable design, stormwater capture at the source with minimum impacts downstream. This is usually because of the restraint from urban density, high upfront costs, and also the complications involved in solution adaptation with regional conditions. For instance, the performance of a permeable road surface might depend under different conditions on soil soil type and traffic flow, while the bio-retention reservoirs require substantial land space and maintenance. Despite their great potential, there are a number of challenges facing BMP and LID. Full implementation is hindered by regulatory barriers, lack of land, and high start-up costs. Their performance also varies widely with regional climate, soil type, and land use, while the derivations involve site-specific approaches for the best results. Such challenges, in turn, can only be met by advanced planning tools and optimization techniques that are capable of integrating multiple objectives such as cost efficiency, pollutant reduction, and flood mitigation. This study aims to enhance the LID-BMP strategies in the two Chongqing districts for better urban stormwater management using a new MT-SWO approach. In this regard, the core tasks that would significantly contribute to the improvement of water quality concern the reduction of main pollutants like TSS and TN by novel data-driven methodologies. This research uses hydrological modeling integrated with advanced optimization to overcome traditional solutions in stormwater management and provides site-specific strategies that address the particular challenges posed by urbanization and climate change.

The following divisions are found in the final part of this study; Part 2 contains a related study, Part 3 contains the methodology, Part 4 contains result and discussion, and Part 5 contains conclusion.

2. RELATED WORK

The related work section reviews prior research on stormwater management and optimization techniques, focusing on BMP-LID strategies and the use of advanced algorithms. Many researchers have investigated the impact of urbanization and climate change on stormwater systems and stressed the need for innovative approaches to enhance resilience and water quality. For instance, Kim and Ryu [6] applied adaptive BMPs in the Boise River watershed, given changing global scenarios, to point out the potentials that may reduce runoff while improving ecological outcomes. Similarly, other works [3, 7, 8] have proposed an integrated sustainability index to find the optimal performance of an urban drainage system, highlighting the importance of multi-objective evaluation frameworks. Other studies have analyzed the application of optimization algorithms in managing stormwater. In this regard, Rezaei et al. [9] and Ren and Khayatnezhad [10] used multi-objective optimization techniques such as MOPSO and EPA SWMM, respectively, in balancing trade-offs among cost, pollutant reduction, and flood mitigation. These studies underline the advantages of combining simulation models with optimization algorithms in the enhancement of BMP-LID design and placement. More recently, Wang et al. [11] investigated the use of spatial functional zoning to optimally situate green infrastructure, and thus provided useful insights into how site specific requirements affect the effectiveness of BMPs. Even with these, there remain certain gaps in the existing literature. Whereas most previous studies have focused on specific BMPs or isolated objectives, studies that take a comprehensive optimization approach to multiple BMP types and urban contexts are rare. Only a few relate the most advanced bio-inspired algorithms, such as multi-task spider wasp optimization, to improve stormwater management performance. Most current models also still lack the capability to dynamically adapt their managements under various conditions in real-world urban environments, with continuous land-use and rainfall regime alterations. The present study covers these mentioned knowledge gaps by presenting MT-SWO, a new optimization methodology for BMP-LID design. Unlike in any conventional approach, MT-SWO allows the simultaneous exploration of multiple BMP configurations and objectives for customized solutions needed in a complex urban environment. This research integrates MT-SWO with SWMM to provide an efficient, data-driven framework toward a state-of-the-art urban stormwater management approach. It extends earlier work by applying MT-SWO to realize high levels of pollutant reduction and water quality improvement in regions of rapid urbanization and great climate sensitivity.

Kim and Ryu [6] indicated that over decades, the boise river catchment's water quality and quantity have been impacted by urbanization and climate change linked to changes in land use. To prepare for these effects, potential water management techniques like LID and BMP were researched for use in urban and rural contexts. A global real-time control (RTC) strategy for adaptive and sustainable stormwater management was presented in the research [7]. It was expected that a network of interconnected devices at the remote control center, where global optimization algorithms compute real-time operational decision-making goal values, would dynamically create the necessary set-points for the system actuators.

With the global issues of urbanization and climate change, stormwater management (SWM) was a crucial concern. Maintaining urban resilience to the risk of floods requires to evaluate the efficacy of SWM. A method [8] for evaluating the percentage of suspended particles removed from stormwater runoff volume and controlled by implementing a sponge city strategy was devised, based on a SWMM. As stated by Rezaei et al. [9], the MOPSO and the Environmental Protection Agency (EPA) SWMM were connected using MATLAB to create a simulation optimization model. Using the results from the SWMM simulation model, the connected model may do multi-objective optimization (MOO) and find feasible solutions to the optimization objectives.

The connection among data from the central lacking water city, ground elevation data, and community drainage official website data served as the foundation for the development of the SWMM technique in the paper [10]. The model's potential for addressing the central issue of water scarcity was proven by the experiment and its verification on-site. Using a multi-pronged analysis technique, the study of Wang et al. [11] conducted a comprehensive bibliometric examination of the scholarly discourse on urban SWM infrastructure. That research endeavor shed light on the principal focus, trends, and diachronic evolution of the nascent field of study.

A strategy for optimizing green infrastructure (GI) that was aware of spatial functional zoning and takes into account the unique requirements of the location under study was proposed. Sub-catchments that influence the likelihood of flood disasters were taken into consideration while dividing the research area [12] into two functional zones: the flood risk control zone (FRCZ) and the total runoff control zone (TRCZ).

Deksissa et al. [13] demonstrated that there are a number of ways to connect stormwater green infrastructures and urban agriculture's ecosystem services to build resilient communities with a circular economy. Taken together, the results showed that integrating stormwater bioretention with urban agriculture can enhance food production in cities and maintain the quality of urban water [14-24].

3. METHODOLOGY

The equations and parameters in this study focus on optimizing urban water management through a novel algorithm, the multi-task spider wasp optimization (MT-SWO). In below the parameters and symbols used in the provided equations, helping to elucidate the algorithm's functioning:

Key Parameters and Equations

1) Initialization and Population Generation

$$\mathbf{x}_i = [x_1, x_2, \ldots, x_D]$$

Description:

- $\mathbf{x}_\mathrm{i}$ represents a solution vector, where $\mathbf{x}_i$ is the i^{th} solution in a population, spanning a search space with D-dimensions.
- D: The number of decision variables (e.g., proportions of BMPs like bio-retention reservoirs, permeable road surfaces, and infiltration trenches).

2) Exploration Phase

$$\mathbf{x}_{\mathrm{new}} = \mathbf{x}_i + E \cdot (\mathbf{x}_j - \mathbf{x}_k)$$

Explanation: Models exploratory behavior by combining solutions.

- $\mathbf{x}_j, \mathbf{x}_k$: Randomly selected solutions.
- E: Exploration factor influencing the movement scale and search intensity.

3) Exploitation Phase

$$\mathbf{x}_{\mathrm{new}} = \mathbf{x}_i + r \cdot (\mathbf{x}_g - \mathbf{x}_i) + A \cdot (\mathbf{x}_r - \mathbf{x}_i)$$

Explanation: Focuses on refining existing solutions.

- r: Exploitation intensity factor.
- $\mathbf{x}_g$: Global best solution.
- $\mathbf{x}_r$: Random solution from the current population.
- A: Random vector guiding exploitation dynamics.

4) Hunting and Nesting Behaviors

$$\mathbf{x}_{\mathrm{new}} - \mathbf{x}_i + H \cdot (\mathbf{x}_p - \mathbf{x}_i)$$

Explanation: Mimics hunting for optimal solutions.

- H: Adaptive factor for hunting.
- $\mathbf{x}_p$: Prey or target solution.

$$\mathbf{x}_{\text{new}} - \mathbf{x}_i + N \cdot (\mathbf{x}_n - \mathbf{x}_i)$$

Explanation: Represents nesting behavior, focusing on stability.

- N: Scaling factor for nesting intensity.
- $\mathbf{x}_n$: Nesting point in the search space.

5) Mating Behavior

$$\mathbf{x}_{\text{new}} - CR \cdot \mathbf{x}_m + (1 - CR) \cdot \mathbf{x}_f$$

Explanation: Generates new solutions by combining features of male ($\mathbf{x}_m$) and female ($\mathbf{x}_f$) solutions.

- CR: Crossover rate controlling feature blending.

6) Population Size Adjustment

$$P_{\text{new}} - P_{\text{min}} + \alpha \cdot (P_{\text{max}} - P_{\text{min}})$$

Explanation: Adjusts the population size dynamically to balance exploration and exploitation.

- P_{min}, P_{max} : Minimum and maximum population sizes.
- α: Scaling factor for population control.

7) Memory Retention

$$\mathbf{M}_{\text{best}} - \arg\min\big(f(\mathbf{x}_i)\big)$$

Explanation: Retains the best solutions based on the objective function f, which evaluates solution quality (e.g., pollutant reduction, cost efficiency).

The objective function in the multi-task spider wasp optimization (MT-SWO) algorithm, integrated with the Stormwater Management Model (SWMM), is designed to enhance urban stormwater management by evaluating Best Management Practices (BMPs) through a multi-objective lens. This function prioritizes achieving a balance among environmental goals, economic constraints, and spatial considerations to address the challenges of urbanization and climate change effectively. A critical factor considered in the optimization function is water quality, with the primary goal of minimizing pollutants such as Total Suspended Solids (TSS) and Total Nitrogen (TN) in urban runoff. These are the most priority pollutants to reduce in order to prevent ecological damage within an aquatic system and allow for a sustainable urban environment. Another important factor is flood risk mitigation, which is aimed at the reduction of peak runoff flows during rainfall. Accordingly, this function will prevent flooding in urban areas, which may lead to the destruction of infrastructures and other economic losses. The other emphasis of the optimization function is on cost minimization, including construction, maintenance, and opportunity costs of BMP implementation. This economic consideration makes the solution practical and sustainable within budgetary limitations. Lastly, the function is designed to be capable of enhancing infiltration rates and hydrological balance, another critical element that is usually disrupted by impervious urban surfaces. The reason for this is that maximizing infiltration will help in the replenishment of groundwater and enhance urban resilience against climate-induced changes. Another important aspect is spatial optimization, or basically deploying BMPs within the constrained spaces of an urban setting to maximize efficiency and effect. This spatial approach ensures that the solutions don't take too much area of the city land while offering the maximum benefits environmentally and hydrologically. Mathematically, the optimization objective function is expressed as:

$$\min F(x) = w_1 \cdot C(x) + w_2 \cdot P(x) - w_3 \cdot Q(x)$$

where,

$F(x)$ represents the total objective value for a BMP configuration x,

$C(x)$ is the total cost,

$P(x)$ denotes pollutant loads in runoff,

$Q(x)$ quantifies the floodwater mitigated or infiltration achieved.

The weights w_1, w_2, and w_3 are adjustable to reflect the relative importance of cost, pollutant reduction, and flood mitigation in the specific urban context.

The broad aims that this function tries to achieve or lookahead for are minimization of pollutant loads, flood risks, cost-effectiveness, and optimizations in BMP placement and design. This function allows the identification of BMP configurations-including bio-retention reservoirs, permeable pavements, and infiltration trenches-that can be applied under local conditions by finding the simultaneous solution of these objectives. It assists in the development of a sustainable urban stormwater management system through a better balance of ecological, economic, and spatial concerns.

3.1 Study area

Two metropolitan districts served as the study sites. Different counties have different requirements and rights when it comes to stormwater management. The ecology of these counties is composed of a variety of residential, commercial and industrial areas that all have varying effects on stormwater runoff.

- **SHAPINGBA DISTRICT:** Shapingba district is known for its residential and commercial areas in a highly developed metropolitan area. The region's terrain and infrastructure pose particular challenges to stormwater management. The total area of Shapingba district is approximately 400 square kilometres. The natural landscapes around the region such as rivers and open spaces are important for the hydrology of the region. Tailored solutions that address excessive impervious surface coverage and the preservation of natural water bodies are necessary for effective stormwater management in this district.
- **JIANGBEI DISTRICT:** Jiangbei district has a mix of residential neighbourhoods, business districts, and industrial zones. Jiangbei district, which is about 220 square kilometers in size that has problems with runoff from both semi-natural and highly urbanized areas. Stormwater dynamics in the district are influenced by the presence of large bodies of water and green spaces on its borders. The district's solutions must strike a balance between improving

water quality, promoting natural infiltration, and controlling urban runoff.

3.2 Integration of hydrological and optimization models for urban water management

3.2.1 Hydrological model and optimization model

- ✓ **Hydrological model:** The SWMM model was utilized in this work to simulate runoff both hydraulically and qualitatively. This program can perform long-term or single-event simulations, as well as surface and subterranean modelling.
- ✓ **Optimization model:** The novel (MT-SWO) method was applied to improve the BMPs.

3.2.2 Integrating optimization model

- ✓ **Model Setup:** The hydrological properties of the study area, such as land use, soil types, and drainage infrastructure, are represented by the SWMM model configuration. To simulate realistic storm events and runoff situations, SWMM integrates input data such as land cover and rainfall patterns.
- ✓ **Optimization Objectives:** The SWMM framework's BMP placement and configuration are optimized with the application of MT-SWO. To lessen urban flooding and improve water quality, goals include decreasing peak flows, lowering pollutant loads entering water bodies, and optimizing infiltration rates.
- ✓ **Algorithm Execution:** By integrating with SWMM simulations, MT-SWO repeatedly assesses potential solutions (BMP arrangement). Based on each solution fits the optimization goals, it refreshes the population of solutions.

3.3 Multi-task spider wasp optimization (MT-SWO)

3.3.1 Initialization and population generation

The MT-SWO starts with a population of spider wasps that has been initialized. Each wasp in the population represents a potential solution in the search space for optimizing permeable road surfaces, bio-retention reservoirs, and infiltration.

$$N_{pop} - [N_1, N_2, \dots., N_M] \tag{1}$$

Each solution $N_j - [w_1, w_2, \dots., w_C]$ is a D-dimensional vector within specified bounds.

3.3.2 Exploration and exploitation phases

- ✓ **Exploration Phase:** Spider wasps look for the most effective ways to improve infiltration and bio-retention reservoirs during the exploration phase:

$$N_j^{s+1} - N_j^s + \mu_1.(N_b^s - N_a^s) \tag{2}$$

where,

N_b^s and $N_a^s$are randomly selected solutions from the current population.

$\mu_1$is an exploration factor.

- ✓ **Exploitation Phase:** Spider wasps take advantage of viable options for permeable road surfaces during the exploitation phase:

$$N_j^{s+1} - N_d^s + \mu_2.(K + q_2.(G - K)) \tag{3}$$

where,

μ_2 adjusts the exploitation intensity.

N_d^s is a randomly selected solution from the current population.

K and G are the lower and upper bounds of the search space.

q_2 is a vector of random values between 0 and 1.

3.3.3 Hunting and nesting behaviors

- ✓ **Hunting Behavior:** Spider wasps mimic the habits of hunters to maximize bio-retention reservoirs and infiltration:

$$N_j^{s+1} = \begin{cases} N_j^s + \mu_3.(N_b^s - N_a^s) & if\ q_3 < q_4 \\ N_d^s + \mu_4.(K + q_2.(G - K)) & Otherwise \end{cases} \tag{4}$$

where,

q_3 and q_4 are random numbers.

μ_3 and μ_4 are adaptive factors for hunting behaviors.

- ✓ **Nesting Behaviour:** Spider wasps exhibit nesting behaviours to optimize permeable road surfaces:

$$N_j^{s+1} = \begin{cases} N_b^s + \mu_5.(N_b^s - N_j^s) & if\ j < M.l \\ N_b^s + \mu_6.(K + q_2.(G - K)) & Otherwise \end{cases} \tag{5}$$

where,

M is the population size, and l is a scaling factor.

μ_5 and μ_6 control nesting intensities.

3.3.4 Mating behavior

Spider wasps mate by combining genetic features to improve on all tasks:

$$N_j^{s+1} = Crossover(N_n^s, N_e^s, D_q) \tag{6}$$

where, N_n^s and N_e^s are male and female solutions, respectively, and D_q is the crossover rate.

3.3.5 Population size adjustment and memory retention

Adapt the population size dynamically to each activity so that exploration and exploitation are evenly distributed:

$$M = M_{min} + (1 - M_{min}).l \tag{7}$$

where, M_{min} is the minimum population size, and l adjusts the population size.

To enhance performance, hold onto the top memory retention strategies:

$$Update\ N_j^{s+1}\ only\ if\ e(N_j^{s+1}) < e(N_j^s) \tag{8}$$

where, $e(\cdot)$ denotes the objective function for each task.

These elements are combined by MT-SWO to optimize permeable road surfaces, bio-retention reservoirs, and infiltration all at once. To achieve optimal performance in sustainable urban water management, adjust parameters $(\mu_1, \mu_2, \dots, \mu_6, D_q, l)$ depending on particular requirements and interactions between these tasks.

3.4 Choosing the BMPs

Bio-retention reservoirs, permeable road surface and infiltration are the three types of BMPs models that are employed in this study with the SWMM.

- **Bio-retention reservoirs:** A soil sub-layer and surface basin area create bioretention gardens or basins. Water accumulates in the upper layer is held in the aggregated base layer after passing through mulch, soil, and vegetation. Water enters the system either flows into an output channel or discharge point, or permeates lower soil layers. Output channels may discharge into a canal downstream or into a basin. Upstream of these structures are pre-treatment and descaling methods like grass swales and perimeter grass filters.
- **Permeable road surfaces:** Pavement systems that allow water to enter through inspection holes make up 8-20% of the soil surface and are usually covered with sand. Three components make up the structure: the stone transportation system, the storage container, and the filter system. The water storage system is essential for the efficient use of water. The pavement design prevents infiltration, thereby preventing stormwater runoff and reducing surface runoff while encouraging water management efficiency.
- **Infiltration:** Infiltration ditches are long, thin structures used to regulate the flow of storm water. They are filled with coarse-grained particles, temporarily storing water in the gaps. The water seeps through the trench's bottom and walls, preventing flooding, minimizing surface runoff, and replenishing groundwater levels. These efficient and long-lasting methods are effective in urban and rural settings.

The two districts suggested in the development plan for Chongqing designate this region for tourism and recreational uses. Permeable road surface could be built on low-traffic areas like sidewalks, residential yards, public squares, and the paths connecting building blocks. Consulting firms serving Chongqing municipalities have mostly provided support for the three BMP types used in this study to regulate runoff quantity and quality in the study region. As one of the recent and quickly expanding districts in the Chongqing metropolitan area, the selected BMP types might be taken into account to enhance the runoff quality in this area.

3.5 Scenarios for runoff quality management

- **Case 1: Baseline Conditions**
  - ✓ **Objective:** Evaluate the amount of pollutants without using any Best Management Practices (BMPs).
  - ✓ **Parameters:** Average concentrations of Total Suspended Solids (TSS) and Total Nitrogen (TN) across precipitation events with return periods of 3 and 9 years.

- **Case 2: Infiltration**
  - ✓ **Objective:** Determine whether deploying infiltration as BMPs is effective.
  - ✓ **Description:** Different percentages of subbasin regions are designated for infiltration trenches.
  - ✓ **Evaluation:** Examine the results under various return periods for precipitation.

- **Case 3: Bio-Retention Reservoirs**
  - ✓ **Objective:** Evaluate the effects of basins for bioretention.
  - ✓ **Description:** Sub-basin regions are distributed differently throughout bio-retention basins.
  - ✓ **Analysis:** Analysis over a range of return durations for precipitation.

- **Case 4: Permeable Road Surfaces**
  - ✓ **Objective:** Examine the efficacy of porous pavements.
  - ✓ **Description:** Using various sub-basin area proportions for permeable road surface.
  - ✓ **Assessment:** Evaluation of performance taking into account different return periods for precipitation.

- **Optimal Combination of BMPs**
  - ✓ **Objective:** Determine the most effective combination of infiltration, bio-retention reservoirs, and permeable road surfaces.
  - ✓ **Approach:** Investigate combinations to get the highest possible drop in the average concentration of pollutants.
  - ✓ **Evaluation:** Evaluate the improved runoff quality achieved by the optimized BMP mix.

- **SWMM Calibration and Optimization**
  - ✓ **Calibration:** Utilizing data on water quality, quantity, and land use, modify the SWMM model's parameters.
  - ✓ **Optimization:** Employ optimization methods such asmulti-task Spider wasp optimization (MT-SWO)
  - ✓ **Objective:** Optimize BMP location and configuration, taking into account trade-offs between various management goals, to strike a balance between cost-effectiveness and improved runoff quality.

The results of the study demonstrate the effectiveness of various BMP configurations in improving urban runoff quality. The analysis included baseline conditions and individual BMP scenarios, as well as an optimized combination determined by the multi-task spider wasp optimization (MT-SWO) algorithm integrated with the SWMM model. Key metrics for evaluation were reductions in Total Suspended Solids (TSS) and Total Nitrogen (TN) concentrations under different scenarios. Under baseline conditions, TSS concentrations averaged 424.2mg/L and 425.18mg/L for 3-year and 9-year precipitation return periods, respectively. TN concentrations were 91.5mg/L and 92.12mg/L for the same scenarios. These values highlight the critical need for intervention to manage urban runoff quality. When evaluating individual BMPs, bio-retention reservoirs consistently outperformed other methods. They obtained 76% reduction in TSS and 85% reduction in TN within a 3-year return period, starting from 424.2 to 38.3mg/L and from 91.5 to 14.3mg/L, respectively, with 6% subbasin area allocation. They also showed that under the 9-year return period, both TSS and TN concentrations were reduced to 31.2 and 13.5mg/L, respectively, making them the most efficient solo BMP. Infiltration trenches also showed significant performance improvements with reductions in TSS to 52.4 mg/L and 52.5mg/L for 3-year and 9-year return periods, respectively. TN reductions were equally impressive, with concentrations falling to 16.2mg/L and 18.8mg/L, respectively. These results emphasize the potential for infiltration trenches not only to improve groundwater recharge but to improve water quality as well. Permeable road surfaces proved moderately effective in pollutant reductions. TSS concentrations decreased to 99mg/L under a 3-year return period and to 95mg/L under a 9-year return period. Corresponding TN concentrations were reduced to 30.2mg/L and 29.5mg/L, reflecting a less pronounced impact compared to bio-retention reservoirs and infiltration trenches. The optimized BMP configuration resulted from the MT-SWO algorithm with bio-retention reservoirs combined with infiltration trenches and permeable road surfaces across the study catchment. With this configuration, superior results were realized compared to individual BMPs. At the 6% sub-basin allocation, TSS concentrations were reduced to 25.3mg/L and 20.7mg/L under 3-year and 9-year return periods, respectively. TN concentrations dropped to 12.1mg/L and 10.5mg/L for the same scenarios. These reductions reflect a 94% decrease in TSS and an 89% decrease in TN from baseline levels, demonstrating the effectiveness of integrated solutions. The observed differences in performance are attributed to the complementary functionalities of the BMPs. Bio-retention reservoirs excel in pollutant filtration and retention due to their vegetation and soil structure. Infiltration trenches enhance groundwater recharge, effectively mitigating surface runoff. Permeable road surfaces contribute by reducing immediate runoff volume and encouraging localized infiltration. Together, these BMPs address multiple aspects of urban stormwater management, resulting in superior overall performance when used in combination.

4. RESULT AND DISCUSSION

4.1 Modelling various scenarios in terms of runoff quality

The effectiveness of BMPs in enhancing runoff quality was assessed during 3 and 9 years of follow-up. For this reason, various BMP percentages were taken into account for every sub-basin. These BMP occupancy rates, commonly known as percentages, ranged from 3% to 6% for each sub-basin area.

The findings of the qualitative modelling of BMPs for return durations of 3 and 9 years, respectively, and occupancy rates of 3% and 6% for each sub-basin in the research region are shown in Tables 1-4. The results are shown visually in Figures 1-4. The results show that the bio-retention basins are the most efficient kind for lowering the average TSS and TN concentrations in Chongqing's Districts across all occupancy rates and return durations.

Table 1. The outcomes of the qualitative modelling over a 3-year return period for BMPs with 3% occupancy rates

Management Practices	Average Pollutant Concentration	
	TSS	TN
Baseline conditions	424.2	91.5
Infiltration	146	39
Bio-retention reservoirs	96.12	29.2
Permeable road surfaces	266	59

Table 2. The outcomes of the qualitative modelling over a 3-year return period for BMPs with 6% occupancy rates

Management Practices	Average Pollutant Concentration	
	TSS	TN
Baseline conditions	164.7	47
Infiltration	52.4	16.2
Bio-retention reservoirs	38.3	14.3
Permeable road surfaces	99	30.2

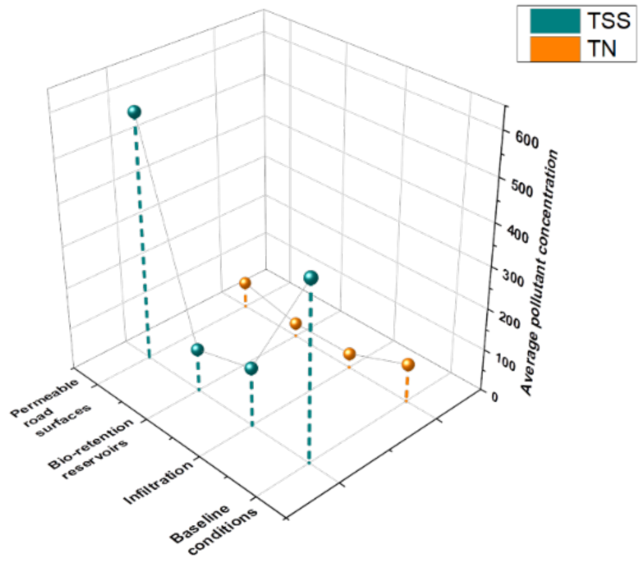

Figure 1. Comparing the average concentrations of pollutants under various scenarios over a 3-year period (3% occupancy rate)

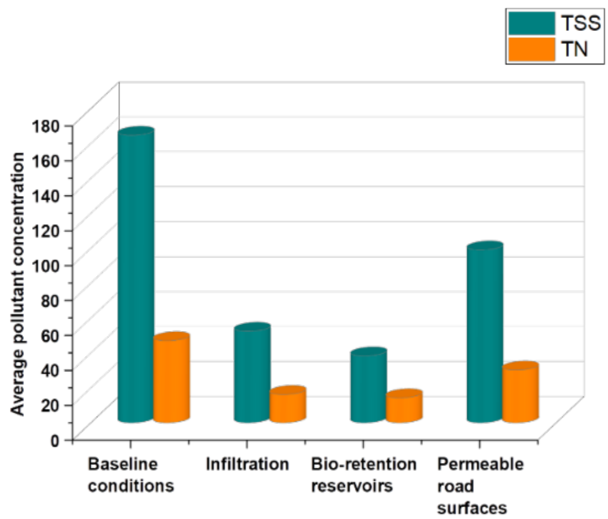

Figure 2. Comparing the average concentrations of pollutants under various scenarios over a 3-year period (6% occupancy rate)

Table 3. The outcomes of the qualitative modelling for a 9-year return period for BMPs with 3% occupancy rates

Management Practices	Average Pollutant Concentration	
	TSS	TN
Baseline conditions	425.18	92.12
Infiltration	140.8	34.9
Bio-retention reservoirs	102.3	32.5
Permeable road surfaces	582.25	62

Table 4. The outcomes of the qualitative modelling for a 9-year return period for BMPs with 6% occupancy rates

Management Practices	Average Pollutant Concentration	
	TSS	TN
Baseline conditions	164.7	47.12
Infiltration	52.5	18.8
Bio-retention reservoirs	31.2	13.5
Permeable road surfaces	95	29.5

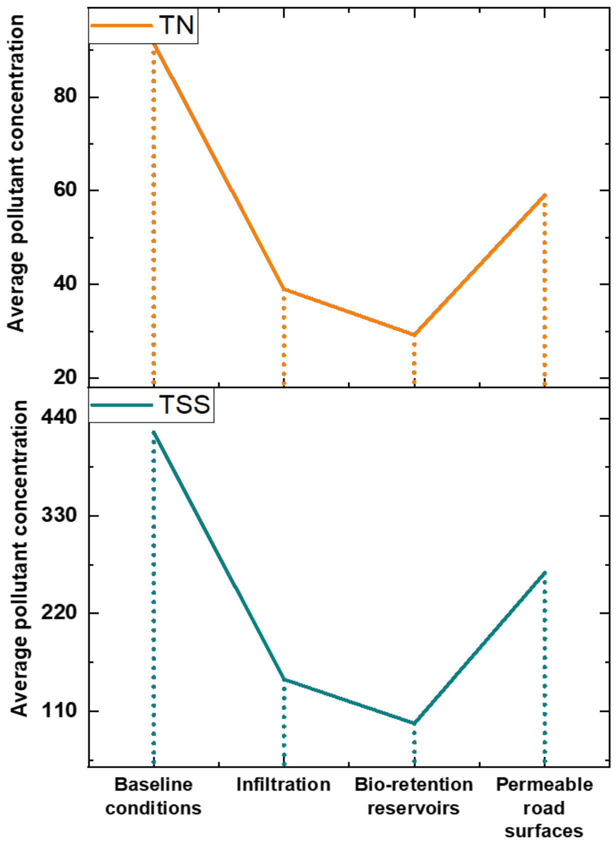

Figure 3. Comparing the average concentrations of pollutants under various scenarios over a 9-year period (3% occupancy rate)

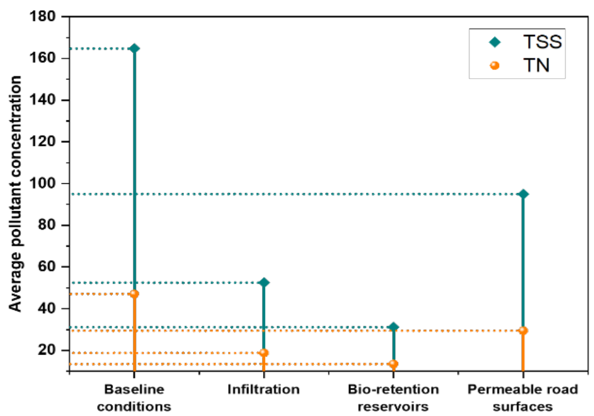

Figure 4. Comparing the average concentrations of pollutants under various scenarios over a 9-year period (6% occupancy rate)

4.2 Results of the optimization and qualitative simulation model

To optimize the quality of urban runoff, the research aims to identify the optimal combination of BMP design. The MT-SWO algorithm was used to optimize BMPs for three and six percent of each sub-basin's area. Three different BMPs were applied in seven subbasins. MT-SWO observed in each sub-basin were extracted and demonstrated how effectively this model BMP combination reduced total suspended solids (TSS) production concentrations. Table 5 shows the MT-SWO for each subbasin with 6% retrieval and 9-year return period. MT-SWO was used to determine the optimal collection of BMPs for each subbasin. The results were then input into the SWMM-MT-SWO model, which uses an optimization simulation model to predict TSS reduction, to estimate TSS concentrations.

Summary: The bio-retention basins are a more effective way to reduce the concentration of pollutants in the research zone, according to the results of the qualitative simulation. Additionally, the efficiency of the bio-retention basins and infiltration trenches in reducing the concentration of suspended particulate matter was found.

Table 5. Results of the optimization model for 9 years of payback and 6% occupancy for BMP

Sub Basin	Bio-Retention Reservoirs	Permeable Road Surfaces	Infiltration
S1	1.79	2.21	1.98
S2	1.76	2.21	2.01
S3	1.97	2.08	1.94
S4	1.62	2.35	2.01
S5	0.41	0.57	5
S6	1.07	2.66	2.25
S7	1.05	2.67	2.27

5. CONCLUSION

Global warming, aging runoff systems, and population increases have made urban stormwater management imperative. For reducing waste and promoting water ecosystems, two great green structure techniques are best management practices and low-impact development (BMP-LID). This work expanded many BMP-LID solutions, such as infiltration, bio-retention reservoirs, and permeable road surfaces, with a novel design technique for green buildings to improve urban stormwater quality. In this work, we present a novel approach to BMP-LID performance evaluation: multi-task spider wasp optimization (MT-SWO). To assess their effectiveness, the planned BMPs were contrasted with one kind of BMP that was distributed in different proportions throughout each sub-basin location. The MT-SWO technique was utilized to find the optimal BMP configuration, and it was found that the bio-retention basin possessed the best single BMP for improving water quality. The MT-SWO strategy played an important role in the identification of the optimal BMP-LID layout and overall management of urban stormwater quality. The computing requirements and data requirements of the MT-SWO strategy may pose a challenge in scaling up the approach to larger and more complex metropolitan settings. In future, the research will investigate the better integration of predictive modeling and real-time data to enhance BMP-LID systems' ability to adapt to dynamically changing urban environments.

The multi-task spider wasp optimization (MT-SWO) algorithm comprises several advantages that make it robust machinery in optimizing urban stormwater management practices. Its key strength lies in its capability for dynamic balancing between exploration and exploitation. In MT-SWO, the objective function is efficiently diversified and intensified by mimicking hunting and nesting biological behaviors in a search for the optimal BMP configuration. A multi-tasking capability that enables the optimization of various BMP types-such as bio-retention reservoirs, permeable pavements, and infiltration systems-simultaneously makes it suitable to tackle the most diverse challenges of urban catchments. Additionally, MT-SWO is highly customizable, allowing parameters like population size, crossover rates, and exploration factors to be adjusted to suit the characteristics of the urban area under consideration. The algorithm has been performing much better in relation to improving water quality by efficiently reducing pollutants like Total Suspended Solids and Total Nitrogen, as indicated in case studies. Besides that, it can be more compatible with hydrological tools like SWMM, enabling realistic simulations of real scenarios. Even MT-SWO has its drawbacks, which should not be discarded. High computational load may turn out to be an obstacle, especially when considering larger urban areas with intricate hydrological systems. The iterative nature and large search space of the algorithm require much computational resource, possibly limiting its scalability. Furthermore, MT-SWO heavily relies on the availability of detailed and precise input data, such as land use pattern, rainfall, and pollutant load, which may not always be accessible. Complexity because of multiadaptive phases, for instance, exploration, exploitation, hunting, and nesting, in the algorithm requires expertise in its implementation. In addition, MT-SWO could be less effective when regional conditions in terms of environment, regulations, and infrastructure differ from one context to another, which is a matter of concern with regard to generalizability. MT-SWO coupled with SWMM makes it a sound framework in the optimization of urban stormwater management. SWMM computes hydrological characteristics of the catchment by incorporating data on drainage infrastructure, land use, and soil properties and rainfall patterns. The outcomes of the run thus provide a realistic background against which to conduct BMP performance evaluation. MT-SWO model conducts optimization of BMP placement and configurations, using objectives related to peak stormwater flows, loads of pollutants, and other relevant infiltration rate maximization. During the optimization, MT-SWO iteratively generates and evaluates potential configurations of BMP using SWMM simulations for prediction of the performance. The solution sets from MT-SWO are updated based on feedback from SWMM in an iterative process to ensure their alignment with the optimization goals. This enables the identification of BMP strategies that balance environmental effectiveness with spatial and economic constraints. Optimized results of the MT-SWO process are transferred into actionable BMP configurations. Those parameters include the proportion of the areas in each sub-basin that are to be devoted to a particular BMP, such as a bio-retention reservoir or a permeable pavement. The performance will be simulated and validated using SWMM. Various scenarios will be run, considering either individual BMPs or several in combination to select the best strategy. For instance, infiltration trenches are assessed based on parameters such as the dimensions of the trench and the soil's permeability, whereas bio-retention reservoirs are based on their surface area, soil composition, and vegetation types. In turn, permeable pavements are assessed for their porosity, sub-surface storage capacity, and actual area coverage. The indicated parameters within SWMM compute runoff reduction and pollutant filtration and infiltration rates.

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