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Sustainable Rainwater Management through Green Infrastructure: A Rain Garden Project in Dharma Wanita Caruban Kindergarten, Bojonegoro

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Abstract: This community service program aims to implement a Rain Garden as a solution for water retention and infiltration while serving as a living laboratory for the cultivation of water conservation awareness within the school community. The implementation method of this community service activity uses a design and build approach through the engagement of stakeholders, following the systematic stages of Planning, Action, Observation, and Reflection (PAOR). The construction of a filtration layering structure utilized a calculated mixture of sand, compost, and local soil (5:2:3 ratio) over a 9.9 m² managed area with an excavation depth of 1.2 meters. The partners involved are the school community at Dharma Wanita Caruban Kindergarten, Bojonegoro. The evaluation instruments used in this activity were hydrological performance observations of infiltration rates and retention capacity, supplemented by Likert-scale structured observation sheets to measure partner competence. The data were analyzed using the descriptive-comparative technique. The results of this community service program indicate that the implemented system, with its calculated retention capacity, facilitates total rainwater infiltration within a 24-hour period, effectively eliminating surface ponding. Beyond hydrological performance, the project achieved a substantial average increase of 55% in partner competence, reaching a final proficiency level of 90%. The design successfully transforms passive land into a functional garden with adaptive vegetation for the maintenance of optimal soil porosity. This established Rain Garden provides a sustainable water conservation model and serves as an ecological educational instrument for students in Bojonegoro.

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Introduction

The management of rainwater represents an essential natural resource requiring prudent governance, particularly within residential environments and public educational facilities (Juwono & Subagiyo, 2017). The ideal paradigm in this field has transitioned from an orientation toward rapid disposal via conventional systems to a focus on conservation through the retention and infiltration of water into the subsoil (Pratomo & Suranto, 2019). Historically, rainwater management was dominated by a conventional drainage approach, characterized by a philosophical commitment to the swift removal of water from specific locations through concrete conduits and piping networks (Bertrand, 2021). Although effective in immediate flood prevention, this model lacks sustainability due to its disregard for the natural soil function in water absorption, thereby contributing to the depletion of groundwater levels and the amplification of downstream flood risks (Fryd, 2012). Consequently, the evolution toward Sustainable Rainwater Management (Younus, 2011) emphasizes the

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integration of water governance with spatial planning, prioritizing the restoration of local hydrological cycles (Ahammed, 2017; Singh et al., 2021).

At Dharma Wanita Caruban Kindergarten, the prevalence of impervious surfaces, such as rooftops and paving blocks, facilitates the generation of high-velocity surface runoff. Field observations indicate that approximately 75% of the total 250 m² school area is covered by these impervious surfaces, leaving very little room for natural soil infiltration. This condition results in the effective disconnection of rainwater from the soil, leading to a near-total reduction in infiltration rates at these sites (Arnold & Gibbons, 1996). During high-intensity rainfall, this lack of permeability causes significant water ponding in the students' outdoor play area, with water depths reaching 3–5 cm. These puddles often persist for several hours after the rain stops, creating a muddy environment that restricts student activities and poses safety risks. Such environmental characteristics pose significant challenges to groundwater conservation and the recovery of micro-hydrological systems (Masetti et al., 2016). Research consistently highlights a linear correlation between the expansion of impervious cover and the degradation of infiltration volumes (Chithra et al., 2015). Furthermore, the rapid velocity of runoff enables the transport of sediments and surface pollutants, necessitating the implementation of natural pretreatment mechanisms to ensure the protection of aquifer quality from contamination (Jokela et al., 2017; Kospa et al., 2020). Given the recurring inundation in functional school zones and the high ratio of paving-to-soil, the intervention of a Rain Garden is indeed urgently needed at this location to restore local hydrological functions and provide a dry, usable space for students.

The mitigation of these challenges requires the adoption of Green Infrastructure (GI) to facilitate the transformation of passive school grounds into functional areas for ecological water governance (Putri & Atharikusuma, 2024). GI serves as a multi-benefit network that enhances environmental aesthetics while performing vital roles in water filtration, pollutant sequestration, and micro-climate mitigation (Widyaputra, 2020; Rohilla et al., 2017; Adesoji & Pearce, 2024). Through the processes of interception, evaporation, and infiltration, GI elements effectively achieve the reduction of runoff volumes and the attenuation of peak flows (Copeland, 2016). For educational institutions, the application of small-scale Nature-Based Solutions (NBS) is highly recommended due to their reliance on local materials and the ease of community-based maintenance (Zerei & Shahab, 2025).

A primary manifestation of GI is the Rain Garden, a vegetated basin specifically engineered for the management of runoff through a sequence of detention, filtration, and infiltration (Dunnett & Clayden, 2007; Malaviya et al., 2019; Fandeli, 2021). The operational mechanism commences with temporary detention (Schlea, 2011; Felicia, 2023), followed by physical and biological filtration through specialized media and root systems for the removal of suspended solids and nutrients (Dietz & Clausen, 2005; Annisa, 2016). The final stage involves the accelerated infiltration of water back into the aquifer (Asleson, 2009; Ishimatsu et al., 2017). This holistic solution provides significant hydrological benefits, habitat provision, and local heat mitigation (Sharma & Malaviya, 2021; Wang et al., 2024).

The technical efficacy of a Rain Garden depends on precise dimensioning based on local hydrological calculations (Greksa et al., 2023) and the optimization of planting media composition. A mixture of sand, compost, and local soil is essential; the high sand content dramatically improves porosity, while the organic compost enhances the cation exchange capacity for pollutant capture (Burszta et al., 2023). Furthermore, the structural zonationcomprising the bottom, side, and top zones requires the selection of vegetation capable of enduring extreme fluctuations in soil moisture. The utilization of native species is

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prioritized for their superior climate adaptation and minimal maintenance requirements (Shi et al., 2024).

Beyond technical performance, the implementation of a Rain Garden at Dharma Wanita Caruban Kindergarten serves as a "living laboratory," facilitating the transfer of knowledge regarding water cycles and conservation to the school community (Vidal & Castro, 2022; Badowska et al., 2025). The integration of aesthetic elements is achieved through the selection of diverse, non-toxic flowering plants, which enhance the visual appeal of the school environment while ensuring suitability for early childhood sensitivity. Furthermore, the transformation of previously inundated areas into a structured green space contributes to the creation of a safe play environment. By the elimination of slippery surfaces and stagnant water, a secure outdoor zone for physical activity is established. This educational and functional integration is fundamental for the cultivation of an environmentally conscious generation (Fan & Li, 2021). Therefore, this community service project seeks the establishment of a sustainable rainwater management model that improves infiltration rates and functions as an ecological educational instrument, positioning Dharma Wanita Caruban Kindergarten as a regional pilot for Green Infrastructure application (Ferreira et al., 2022; Liu & Jansen, 2018).

Method

The execution of this community service project utilizes a participatory and educative assistance framework, ensuring the active involvement of partners across all stages, from initial planning to long-term maintenance. The designated site is Dharma Wanita Caruban Kindergarten, Bojonegoro Regency, strategically selected due to its high proportion of impervious surfaces. Approximately 75% of the 250 m² school area is covered by impervious surfaces, leading to significant water ponding of 3–5 cm during rainfall. To address these challenges, the systematic implementation is structured into four primary stages (Planning, Action, Observation, and Reflection) as illustrated in Figure 1.

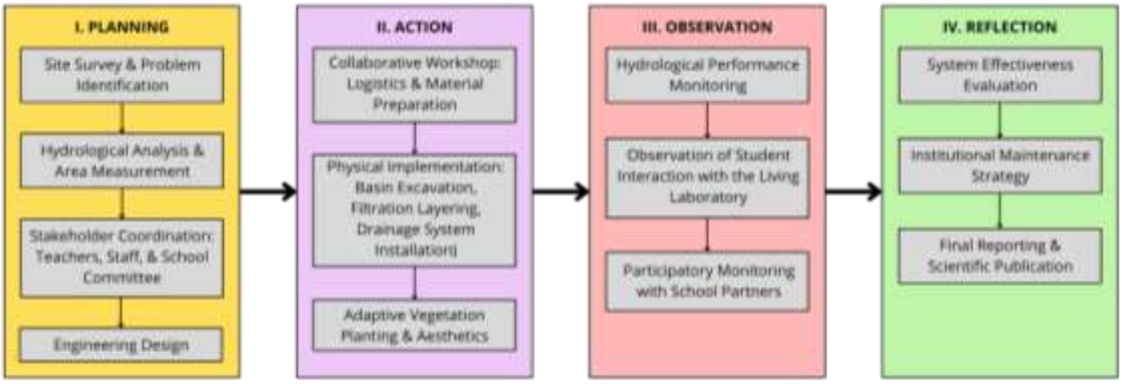

Figure 1. Flowchart of The Community Service Implementation Stages

In the Planning Stage, Participatory Action Research (PAR) was utilized to facilitate collaborative problem analysis with teachers and the school committee. The preparation phase involved topographic surveying to determine the minimum elevation point for optimal rain garden placement. Based on discharge measurements using the rational method synchronized with local rainfall intensities, a managed area of 9.9 m² was identified as the technical requirement for effective runoff mitigation. This stage culminated in the precision engineering of the infiltration structure using CAD and SketchUp software.

The Action Stage implemented the Demonstration Plot strategy serves as the pinnacle of technical assistance through the physical construction of the rain garden within the school area. This phase functions as an effective technical training medium for partners while providing tangible evidence of the effectiveness of rainwater management solutions. The implementation includes the planning of technical details such as dimensions, filter media, and vegetation selection followed by logistical preparations. The physical execution involves basin excavation, the installation of protective layers, the optimization of planting media composition (sand, compost, and local soil), and the installation of inlet/outlet systems through collaborative workshops

During the Observation Stage, the "Living Laboratory" approach was implemented to optimize pedagogical benefits. The primary evaluation instruments in this stage include direct field monitoring of infiltration rates and ponding durations, supplemented by qualitative observation of student interaction with the green infrastructure. Monitoring focuses on ensuring the rain garden achieves total infiltration within a 24-hour cycle post-rainfall.

In the Reflection Stage, the final evaluation of the program's impact on partner independence and environmental quality was conducted. Data analysis is performed using a descriptive-comparative technique, comparing post-implementation performance against the baseline conditions. To provide empirical evidence of increased partner independence, a quantitative assessment was performed using a Likert-scale structured observation sheet. This instrument evaluates the partners' proficiency across key indicators: site maintenance, plant health monitoring, and educational utilization. The results were analyzed by calculating percentage scores to demonstrate the quantitative increase in community competence before and after the assistance program. The findings are then compiled into scientific publications to ensure the sustainability of the intervention.

Result and Discussion

Technical assistance commenced with the identification and topographic surveying of the Dharma Wanita Caruban Kidergarten grounds to determine the minimum elevation point for optimal rain garden placement.

Figure 2. Existing Conditions of Dharma Wanita Caruban Kindergarten Grounds

The team performed rainwater runoff discharge measurements using the rational method to synchronize the retention pond capacity with local Bojonegoro rainfall intensities. Based on this data analysis, a managed area of 9,9 m² was identified as the minimum requirement for the effective mitigation of runoff originating from the school building’s rooftop. The existing condition of the rain garden placement location is shown in Figure 2.

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The subsequent phase involved the design assistance of an infiltration structure adhering to green infrastructure principles. The vertical profile of the rain garden was engineered with a multi-layered filter configuration, comprising local vegetation at the top layer, a specialized filter bed (planting media), and a transition layer for water storage. Precision visualization via CAD and SketchUp software established a required excavation depth of 1,2 meters from the original ground level to reach more permeable soil strata. The design of the rain garden is shown in Figure 3.

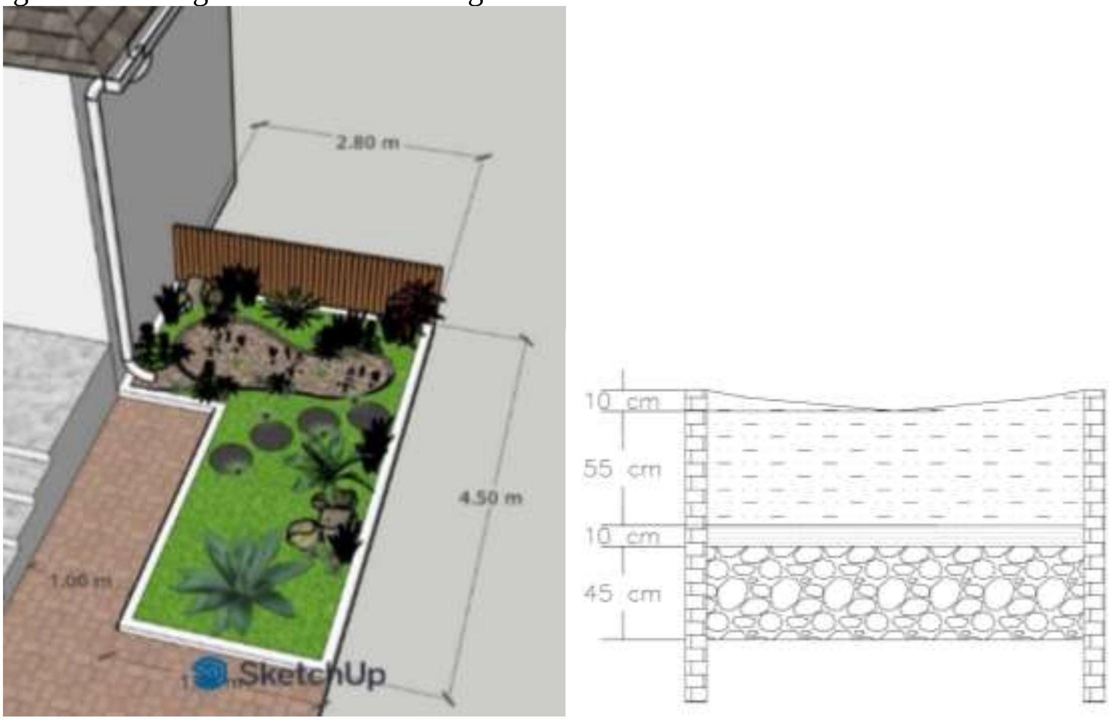

Figure 3. Rain Garden Design Plan and Vertical Structure

Construction assistance focused on the supervision of filter material selection, utilizing a precise mixture of coarse sand, compost, and local soil in a 5:2:3 ratio. This composition aims to ensure high water infiltration rates while optimizing the sequestration of surface pollutants. Technical documentation recorded the installation of an underdrain piping system with a 1% slope toward the main drainage as a mitigation measure against extreme rainfall exceeding design capacity.

Regarding functional aesthetics, the selection of vegetation was directed toward species with robust root systems and high tolerance for both saturated and dry conditions. The planting arrangement was organized through a zonation scheme, where the most flood-tolerant plants were placed at the basin floor. This design functions not only as an operational drainage system but also as a living laboratory for early childhood students to observe the water cycle. The types of plants are presented in Table 1.

Table 1. Plant Species Specifications and Vegetation Zonation Characteristics

No	Plant Species
1	Agave Desmetiana Variegata
2	Cordyline Australis
3	Bromelia
4	Sansevieria Trifasciata
5	Zephyranthes
6	Tradescantia Spanthacea

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7	Anthurium Plowmanii
8	Chlorophytum Comosum
9	Equisetum Hyemale
10	Cordyline Red Sister
11	Cordyline Fruticosa
12	Canna Indica
13	Stenochlaena Palustris
14	Asplenium Scolopendrium
15	Echinodorus Palaefolius
16	Axonopus Compressus

Evaluation of the assistance outcomes demonstrates significant technical success in the reduction of rainwater runoff velocity. Based on inundation simulation tests, the constructed structure facilitates total rainwater absorption in less than 24 hours following heavy rainfall. This performance aligns with environmental health standards for the elimination of potential mosquito breeding sites.

The success of the design is also measured by the structural resistance to bank erosion. The application of slope reinforcement techniques using river stones around the inlet area serves to dissipate the kinetic energy of rooftop runoff. Visual documentation confirms that these energy dissipators prevent the scouring of the planting media, ensuring the geometric stability of the retention pond remains intact according to the initial design. The reinforcement of the pond edge with river stones is shown in Figure 4.

Figure 4. Implementation of Slope Reinforcement using River Stones

The final stage of this assistance produced a comprehensive green infrastructure profile document as a permanent physical asset for the school. The construction outcome proves that environment-based civil engineering can be efficiently implemented on limited land. The precision of the physical structure, the efficacy of the filtration system, and the integration of a lush landscape are primary indicators of the successful achievement of the project's strategic targets. Figure 5 shows the rain garden that has been built at the location of Dharma Wanita Caruban Kindergarten.

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Figure 5. Final Condition of the Rain Garden as Active Green Infrastructure

Furthermore, the quantitative assessment conducted during the Reflection Stage provides empirical evidence of the project's impact on community empowerment. The evaluation of partner independence was performed using a Likert-scale structured observation, focusing on three primary indicators: technical maintenance, vegetation care, and educational utilization. The results of this assessment are presented in Table 2.

Table 2. Quantitative Assessment of Partner Independence and Competence

Assessment Indicator	Baseline Competence (%)	Post-Assistance Competence (%)	Improvement (%)
Technical Maintenance (Cleaning & Inlet Control)	35%	85%	50%
Vegetation Monitoring & Care	40%	90%	50%
Educational Utilization (Living Laboratory)	30%	95%	65%
Average Score	35%	90%	55%

The data in Table 2 indicates a substantial average increase of 55% in partner competence. The most significant progress was observed in the educational utilization indicator, which rose from 30% to 95%. This confirms that the "Living Laboratory" approach effectively transformed the green infrastructure into a functional pedagogical tool for teachers to explain the water cycle and environmental conservation to early childhood students. As emphasized by Vidal & Castro (2022) and Badowska et al. (2025) in the introduction, integrating green infrastructure into educational spaces transforms a safe outdoor environment into a powerful pedagogical tool.

In accordance with the descriptive-comparative analysis, these findings strengthen the conceptual claim that green infrastructure like rain gardens are not only technically viable for flood mitigation in confined school areas but also serve as sustainable instruments for environmental education. The high level of partner independence (90%) ensures the long-term functional sustainability of the rain garden, meeting the success criteria established during the initial planning phase. This transition from a "muddy environment" to a structured green space positions the school as a regional pilot for Green Infrastructure application (Ferreira et al., 2022; Liu & Jansen, 2018).

Discussion of the implementation results indicates that the green infrastructure approach is highly effective in mitigating drainage issues in confined areas. The transformation of surface runoff patterns from uncontrolled ponding (3–5 cm) to a regulated flow directed toward the 9.9 m^2 infiltration zone is a crucial achievement. This efficiency is rooted in the precise geometric design of the basin and the calibration of catchment area calculations against Bojonegoro's extreme rainfall intensities. This directly addresses the micro-hydrological degradation and high-velocity surface runoff issues noted by Juwono & Subagiyo (2017) and Chithra et al. (2015).

Analysis of the filter bed layering reveals the dual function of the sand-compost-soil mixture as both a pollutant filter and a retention medium. Hydraulically, this layer creates a crucial lag time for peak rainwater discharge before the infiltration process into the soil or final disposal. This confirms that the rain garden is a form of civil engineering intervention capable of improving micro-hydrological cycles through the enhancement of groundwater reserves. This technical efficacy aligns with the findings of Burszta et al. (2023) regarding the role of organic compost in enhancing cation exchange capacity for pollutant capture.

The success of this system is supported by the selection of deep-rooted vegetation, which plays a vital role in maintaining soil porosity and preventing clogging. Plant roots technically create soil macropores that accelerate infiltration rates even after successive heavy rainfall cycles. Evaluation documentation shows that the stability of the pond slopes remains maintained without surface degradation due to the effective integration of crushed stones at the inlet area. This zonation and structural reinforcement fulfill the requirements for enduring extreme fluctuations in soil moisture as suggested by Shi et al. (2024).

Overall, the discussion confirms that the adoption of green infrastructure at Dharma Wanita Caruban Kindergarten fulfills the functional standards of sustainable drainage. The presence of an underdrain pipe with a measured slope provides a guarantee of structural safety and the prevention of basin overflow during soil saturation. This model serves as a viable technical prototype for the development of other public facilities in Caruban Village due to its cost efficiency and high rainwater management performance.

Educational integration through the living laboratory concept provides added value to the school community. The transfer of knowledge via environmental learning modules allows teachers to integrate rain garden elements into teaching and learning activities. This strengthens the school's role as an agent of change in fostering water conservation awareness in the younger generation. As stated by Fan & Li (2021), such community service projects are fundamental for the cultivation of an environmentally conscious generation.

Participatory monitoring conducted with partners indicates an increase in independence regarding infrastructure maintenance. Awareness of the importance of maintaining inlet channel cleanliness and vegetation health is a key factor in the functional sustainability of the system. The active involvement of all stakeholders from the planning stage ensures the successful adoption of this green technology. This confirms the importance of small-scale Nature-Based Solutions (NBS) and community-based maintenance advocated by Copeland (2016) and Zerei & Shahab (2025). Finally, this project demonstrates that land constraints are not an obstacle to the implementation of ecological water governance. The use of local materials and community involvement minimizes construction costs without compromising hydrological performance. The success at this site is expected to trigger similar replications across various educational institutions in the Bojonegoro Regency.

Conclusion

Based on the implementation outcomes and technical field evaluations, it is concluded that the construction of the rain garden at Dharma Wanita Caruban Kindergarten has successfully established an effective green infrastructure solution for rainwater management. From a technical perspective, the system demonstrates the total elimination of inundation in the school corridor areas within a 24-hour post-rainfall duration. The specialized filter layer design, comprising a mixture of sand, compost, and local soil is functionally proven to facilitate optimal water infiltration while maintaining the school's environmental aesthetics through the strategic selection of adaptive vegetation.

Beyond its hydrological functions, this project significantly improved the partners' level of understanding and competence. Quantitative evaluation indicates a substantial average increase of 55% in partner proficiency, reaching a final competence level of 90% across technical maintenance and educational utilization indicators. The transformation of the school grounds into a "Living Laboratory" has successfully empowered educators to integrate water conservation modules into the early childhood curriculum, with the educational utilization indicator peaking at 95%.

Ultimately, this project demonstrates that civil engineering interventions, specifically through the application of green infrastructure, can be executed within limited spatial constraints with high cost-efficiency. The presence of the rain garden does not merely improve the micro-drainage system at the partner site; it functions as a sustainable pedagogical instrument that fosters environmental consciousness in the younger generation. The community service objectives have been fully realized, ensuring both the technical performance of the infrastructure and the long-term independence of the school community in maintaining its functional sustainability.

Recommendation

The broader replication of this green infrastructure model is highly encouraged across other public facilities within Caruban Village, particularly in locations identified as flood-prone areas. To ensure the long-term success and scalability of such initiatives, the Department of Education is encouraged to integrate Nature-Based Solutions (NBS), such as rain gardens, into the standard school facility guidelines within the Bojonegoro Regency. This includes providing technical workshops for educators to utilize these facilities as outdoor learning laboratories for environmental conservation curricula. Simultaneously, the Local Village Government should consider allocating a portion of the Village Fund for the maintenance and expansion of green infrastructure within residential clusters, while also establishing a specialized community task force to monitor drainage health and village-scale water retention to enhance local climate resilience. Furthermore, establishing continuous communication between higher education institutions and village authorities is essential for providing sustained technical assistance and regular hydrological performance audits. The exploration of potential integration between rainwater harvesting systems and existing rain garden structures is also necessary to maximize water resource management efficiency. The expansion of this regional implementation will ensure that the positive impact on groundwater conservation in the Bojonegoro Regency becomes more significant, measurable, and ecologically impactful.

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