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Green Infrastructure Approaches in Watershed Planning: The Review

Yashaswini N M[1], Pragathi B[2], Revathi M[3], Goutham Prasad M E[4]
[1, 2, 3, 4]UG – Research Scholar, Department of Civil Engineering, RV College of Engineering, Bengaluru – 560059, Karnataka, India
[5]Assistant Professor, Department of Civil Engineering, RV College of Engineering, Bengaluru – 560059, Karnataka, India

Abstract: The 2024 UNESCO assessment predicts that half of the world's population would face water scarcity by 2050. Currently, 3.5 billion people lack basic sanitary facilities, and 2.2 billion people lack access to clean drinking water. Over 1.4 billion people have experienced droughts since 2002, and as a result of climate change, the frequency and severity of water shortages are expected to increase. It is predicted that the number of urban dwellers experiencing water shortage will quadruple by 2050, further taxing both natural habitats and cities. In addition to restricting access to energy, these water constraints are contributing to a rise in food insecurity. Meanwhile, the International Energy Agency (IEA) highlights the ongoing global energy emergency, which has caused fuel prices to soar to record levels, pushing millions into poverty. Addressing these challenges requires holistic solutions, such as effective efficient water management techniques like rainfall collection and groundwater restoration, coupled with a transition to renewable energy sources. This study explores how these combined approaches can enhance resilience, ensuring reliable access to water and energy for vulnerable populations.
Keywords: UNESCO; International Energy Agency (IEA); groundwater restoration; poverty

I. INTRODUCTION

The urgent global issues of water scarcity and energy insecurity underscore the necessity for sustainable development within the built environment. By 2030, the United Nations forecasts a 40% shortfall between global water supply and demand, while energy consumption is projected to increase by more than 50% by 2050, driven by population growth and urban expansion [1]. Urban centers, which account for nearly 70% of global energy use, are also major contributors to greenhouse gas emissions [2]. Resolving these issues is essential for long-term resilience as well as environmental sustainability. The built environment, which includes residential, commercial, and industrial sectors, plays a pivotal role in this challenge. Adopting green building practices—such as integrating renewable energy, implementing water-saving technologies, and utilizing eco-friendly materials—provides an effective approach to substantially decrease resource consumption [3]. Solutions like rainwater harvesting, energy-efficient designs, and eco-friendly materials are no longer just environmental aspirations; they are practical necessities to mitigate the escalating crises. These interventions hold immense potential to redefine urban living and transform homes into self- sufficient, sustainable units.

The development of sustainable building technologies has advanced significantly, but there are still barriers to the general adoption and integration of these techniques into traditional urban development.

Research indicates that although green buildings can result in energy savings of up to 30% in wealthy nations, the impact is less pronounced in regions where the adoption of these techniques is still in its infancy. Bridging these disparities requires a model that is cost-effective, widely accessible, and flexible enough to suit various climatic and socio-economic contexts.

Furthermore, this model addresses urban runoff issues, contributing to a 40% reduction in flood risks in densely populated areas through bioretention and permeable pavements. By focusing on measurable outcomes and scalability, this research emphasizes measurable results and scalability, aiming to improve resource efficiency while offering a replicable framework for sustainable development. It sets the path for ecologically conscious living in line with global sustainability goals like the Sustainable Development Goals of the United Nations. Our project includes sustainable goals such as -

SDG 6: Clean Water and Sanitation SDG 7: Affordable and Clean Energy

SDG 11: Sustainable Cities & Communities SDG 13: Climate Action

This also includes Green Building Rating Systems - Rating systems like IGBC and LEED encourage sustainable water practices such as rainwater harvesting, promoting water conservation and resilience against water scarcity in both local and global contexts [4, 5].

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II. TECHNIQUES FOR CREATING A WATER-SELF-SUFFICIENT HOME

A. Permeable Pavements

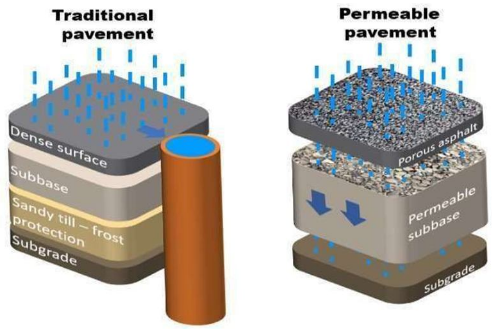

Figure.1: permeable pavement

An effective way to manage rainwater is with permeable pavements, which are designed to allow water to percolate through the surface and into the ground. These pavements are made of materials that allow rainwater to be absorbed into the underlying soil, like interlocking pavers, asphalt, or porous concrete. By reducing surface runoff, permeable pavements help to recharge groundwater and mitigate urban flooding. In addition to increasing groundwater recharge, they also help filter pollutants from precipitation before it enters the groundwater system [6].

B. Swales and Bioretention Areas

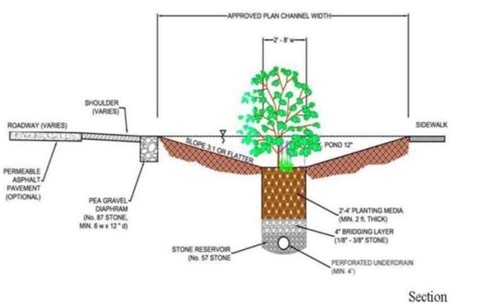

Figure.2: Bioswales

Swales are shallow, vegetated ditches that direct and manage surface water runoff, while bioretention areas (also known as rain gardens) are designed to capture stormwater runoff and encourage infiltration through a soil- media mixture. These features are often planted with vegetation that helps filter and absorb rainwater and the excess will carry out through perforated pipes [7].

C. Cavity Walls with Integrated Rainwater Collection

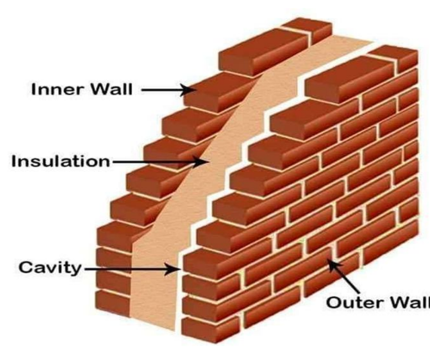

Figure.3: cavity walls

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Cavity walls are a popular building method that involves creating a gap or cavity between two layers of walls. Since rainwater harvesting will involve more pipe connections, we are now concerned about the building's aesthetics. This could be a solution to implement all the pipe connections that can be seen on these cavity walls. Usually connected to a rainwater harvesting system, this system collects rainwater from the roof, channels it into the cavity, and stores it in a tank for later use.

D. Green Roofs with Modular Water Retentions

Figure.4: Green roof

Green roofs consist of vegetation planted over a waterproof membrane, designed to capture and store rainwater through integrated modular water retention systems. This stored water can be repurposed for irrigation or other non-potable uses. In addition to enhancing water collection, this approach contributes to temperature regulation within buildings and improves air quality, while the vegetation plays a role in filtering and absorbing rainwater [8].

E. Greywater Usage: A Sustainable Solution

Greywater, which is relatively clean wastewater from activities like bathing, laundry, and washing, can be repurposed for non-potable uses, providing a sustainable solution for freshwater conservation. Due to its low contamination levels, greywater is well-suited for applications such as irrigation, toilet flushing, and even car washing, reducing dependence on treated water. By reusing treated greywater, both costs are reduced and the environmental footprint is minimized, as it helps ease the strain on sewage infrastructure and supports the preservation of freshwater supplies.

Filtering greywater involves simple methods like mesh screens to remove debris, followed by advanced systems such as biological treatment using microorganisms or UV disinfection to eliminate pathogens [9]. Modern greywater systems integrate these processes, making reuse safe and efficient. For example, urban projects in Australia and India have successfully implemented greywater reuse in housing complexes, conserving millions of liters annually. Greywater reuse is a vital step toward water sustainability, especially in arid and water- stressed regions.

1) Greywater Recycling using a Decentralized Wastewater Treatment System (DEWATS)

DEWATS is a cost-effective and environmentally friendly way to treat greywater in homes. Wastewater from sinks, showers, and washing machines is treated using natural biological processes, allowing the treated water to be used again for non-potable uses including landscaping, flushing and irrigation.

For low-maintenance water filtration and purification, the system usually consists of sedimentation, anaerobic digestion, and artificial wetlands. DEWATS is a very effective system that can remove up to 95% of suspended particles and reduce Biological Oxygen Demand (BOD) by up to 85–90% [10]. It is an economical and environmentally responsible solution that lowers the demand for freshwater in residential settings and encourages water conservation.

2) Usage of DEWATS

Cosumption of water per person per day = 200 liters Consumption of water per person for 365 days = 200 x 365
=73000 liters
DEWATS efficiency = 80 %
Therefore, amount of water that Can be reused after filtration through DEWATS
= 80% X 73000
= 58400 liters
80 % of recycled water can be used for non-portable and miscellaneous purposes inside and outside the house.

F. Raintap

Figure.5: Raintap

- Effortless Rainwater Collection: The Raintap Rainwater Filter collects clean rainwater directly from your roof & Advanced Filtration: Uses a 130-micron nylon mesh screen to filter out dirt, debris, and contaminants [11].
- Zero Electricity Required: Operates purely on gravity, no power needed.
- Easy Maintenance: The mesh screen is easy to clean—just rinse it off.
- Roof Safety: Built-in features prevent water stagnation.
- Universal Fit: Modular design adapts to any roof size, perfect for homes and businesses
- Proven Reliability: Over 25,000 units installed in India and worldwide.
- Cost-Effective & Eco-Friendly: Saves on water bills and benefits the environment.

III. ACHIEVING ENERGY INDEPENDENCE IN HOMES WITH HYBRID ENERGY SYSTEMS

In today's world, dependence on external power grids and fossil fuels has become an escalating issue. As energy demands rise, power shortages become more frequent, and the environmental consequences of conventional energy sources grow, an increasing number of homeowners are turning to sustainable energy solutions. Solar panels typically generate 20-25 kWh/day for a 5kW system under optimal sunlight conditions. Wind turbines, depending on location and wind speeds, can generate 4-10 kWh/day for a 1.5 kW turbine [12].

By combining these two sources, the system ensures a more reliable and consistent power supply. For example, a 5kW solar system producing 25 kWh/day and a 1.5 kW wind turbine generating 9 kWh/day can together produce 34 kWh/day, which is sufficient to meet the average daily energy needs of most homes (typically 15-30 kWh/day).

IV. MODEL DEVELOPMENT

We built a scaled model of a house to showcase innovative and sustainable ways to manage rainwater. We started by creating a detailed plan using AutoCAD, which helped us map out the design and get everything organized. Once the plan was ready, we got to work on building the model. The finished model is a hands-on way to demonstrate practical, eco-friendly solutions for managing water in homes.

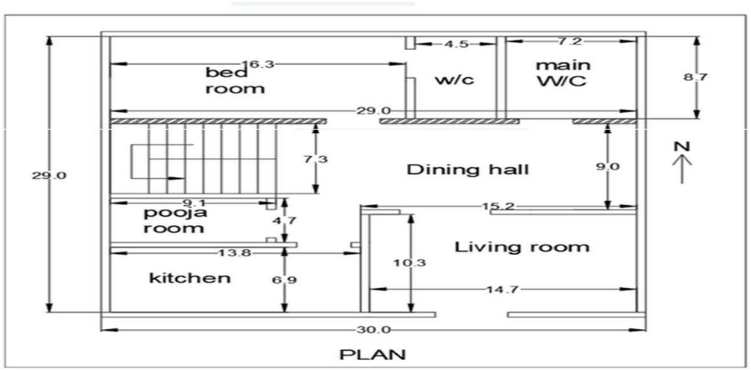

Figure:6: AUTOCAD Plan

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Figure: 7: 3D Model

V. RESULTS & DISCUSSION

Incorporating sustainable practices into the built environment shows promise in tackling energy insecurity and water scarcity. Permeable pavements, swales, and bioretention areas are important techniques that have demonstrated great promise for groundwater recharge and urban runoff mitigation, lowering the risk of flooding in urban areas by about 40%. Water conservation is promoted by systems such as green roofs with modular water retention and cavity walls with integrated rainwater collection, which efficiently capture up to 60% of household water needs. Additionally, innovations like Raintap filters offer cost-effective rainwater harvesting solutions by purifying all the roof rainwater and it is directed to sump, benefiting residential users.

Reusing greywater, made possible by decentralized wastewater treatment systems (DEWATS), has been shown to be a successful strategy for lowering the demand for freshwater. Up to 80% of household greywater can be recycled by DEWATS, saving each person about 58,400 liters a year and substantially lowering the demand on water supplies.

Energy resilience is increased by hybrid energy systems that combine solar and wind technologies. These systems can generate up to 34 kWh per day, which is enough to meet the energy needs of the typical household. These systems also lessen carbon emissions and reliance on fossil fuels, which is in line with international sustainability objectives.

Our research model also emphasizes these interventions' scalability and economic viability. Applications in the real world, like rainwater collection systems and the incorporation of renewable energy, highlight how feasible sustainable solutions are in urban environments. In addition to increasing resource efficiency, these developments help build self-sufficient homes and communities, which opens the door to accomplishing the Sustainable Development Goals (SDGs) pertaining to energy, water, and climate action.

The findings highlight the revolutionary potential of fusing cutting-edge water and energy management techniques with green building technologies. Future research should concentrate on improving these strategies to increase accessibility and adaptability in a range of socioeconomic and climatic conditions.

VI. FUTURE TRENDS AND INNOVATIONS IN SUSTAINABLE HOUSING

A. Smarter Water Management

In the future, homes will incorporate innovative technologies to enhance water conservation. Intelligent systems will track water consumption in real-time, automatically identify leaks, and manage irrigation more effectively. Rainwater harvesting will be optimized with advanced filtration technologies, simplifying the process of storing and utilizing rainwater, even in urban environments. Additionally, greywater recycling will become a standard practice, enabling households to repurpose water from sinks, showers, and washing machines for tasks like gardening and toilet flushing.

B. Better Renewable Energy Systems

Homes will increasingly rely on hybrid energy systems combining solar panels, wind turbines, and micro-hydro generators. These systems will share energy within neighborhoods using smart grids. Emerging solar panel technologies, such as those designed to function on windows or capture sunlight from both surfaces, will further enhance the energy efficiency of homes. Improved battery systems will store excess energy, allowing households to utilize it during the night or on overcast days.

C. Eco-Friendly Building Materials

New materials, like self-repairing concrete and recycled products, will make homes stronger and more environmentally friendly. Prefabricated construction, where parts of a house are built in factories and then assembled on-site, will save time and resources. Adding green elements like rooftop gardens and indoor plants will make homes healthier and more comfortable.

D. Technology for Efficiency

Artificial intelligence (AI) will play a key role in designing homes that optimize energy and water use according to the specific climate conditions. Digital replicas of homes, known as digital twins, will enable homeowners to simulate and refine their systems prior to construction, ensuring improved efficiency and minimizing errors.

E. Support from Policies and Finance

More tax breaks and subsidies will probably be offered by governments to encourage the development of sustainable homes. By implementing sustainable habits, homeowners may be able to earn carbon credits, which they may then exchange for cash. These programs will increase the affordability and desirability of environmentally friendly housing.

VII. CONCLUSION

These advancements offer not only practical and affordable solutions but also lay the foundation for a more sustainable and inclusive future. By taking collective action and widely implementing these approaches, we can create self-sustaining, eco-friendly homes that support the global mission of realizing the United Nations' Sustainable Development Goals.

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