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Bio-Ecological Drainage System (BIOECODS) for Flood Management: Case Study: Maharani Janki Kunwar College, Bettiah

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Abstract

This study examines the flooding issues on the M.J.K. College campus in Bettiah, Bihar, which severely disrupts operations during the rainy season, particularly in the southeastern area. To address this, the BIOECODS (Bio-Ecological Drainage System), developed by University Sains Malaysia, is proposed as a sustainable solution. This system utilizes a "control-at-source" approach with components such as grass swales, detention ponds, and wetlands to reduce peak flow, increase lag time, and improve water quality through natural filtration. The findings indicate that BIOECODS provides an environmentally friendly and effective alternative to traditional drainage systems, significantly mitigating flood impacts and enhancing the ecological conditions of the campus. Key recommendations include constructing retention ponds and swale drains and upgrading existing roadways for improved drainage efficiency. Moreover, the study underscores the importance of integrating modern technologies such as real-time hydrological monitoring with IoT-based sensors and machine learning models to optimize system performance. These innovations can adapt the drainage system to variable climatic conditions, making it more effective in stormwater management. Overall, BIOECODS presents a practical and sustainable solution for addressing campus flooding, offering a model for similar challenges in other areas.

1. Introduction

M.J.K. college is situated in Bettiah City, located in the West Champaran district of Bihar, experiences a sub-tropical climate with distinct seasons. According to the Köppen Climate Classification, this climate is classified as "Cwa" (dry-winter humid subtropical climate). M.J.K. College Bettiah was established in 1955, captioning firstly as Bettiah Mahavidyalaya. Now It is a constituent unit of B. R. Ambedkar Bihar University, Muzaffarpur. It is situated in the heart of Bettiah town (West Champaran), Bihar (Figure 1). The summer months of March through June are usually hot, with highs of 30 to 45 degrees Celsius and moderate to high humidity. With precipitation ranging between 1,000 and 1,200 mm, the monsoon season, which runs from June to September, provides the

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majority of the region's yearly rainfall. High humidity, intense rainfall, and the possibility of flooding particularly given the Gandak River's close proximity are the hallmarks of this time of year. With temperatures between 5°C and 20°C, the winter months of October through February offer a more comfortable atmosphere with little precipitation. During the monsoon season flooding and waterlogging are major issues in Bettiah. Due to its proximity to the Gandak River, the city is susceptible to riverine floods. The river may overflow during times of intense precipitation, flooding vast swaths of land and damaging infrastructure, houses, and agriculture. Long-term, intense rainfall upstream or breached embankments frequently make floods more severe. Furthermore, waterlogging is made worse by Bettiah's low-lying terrain, particularly in urban areas with inadequate drainage infrastructure. During the monsoon, water can build up in fields, streets, and even homes, which can cause public health issues like the spread of waterborne illnesses. As a result, Bettiah needs better flood management and drainage infrastructure to address its persistent climate-related issues and flood-prone areas. The meteorological information of the study area is presented in Table 1.

In October 2024, a 20-year-old ring dam near Bettiah breached, leading to inundation in five panchayats and affecting numerous villages. Bihar, including areas around Bettiah, experienced severe floods in July 2021, causing significant damage to property and infrastructure. Bettiah was among the regions impacted by the devastating floods of 2007, which affected large parts of Bihar, leading to loss of life and displacement. Studies indicate that Bihar is one of India's most flood-prone states, with approximately 76% of the population in North Bihar living under the recurring threat of flood devastation. The combination of multi-criteria analysis and analytical hierarchy process (MCA-AHP) in a GIS environment has been utilized to assess flood risk in the state, highlighting the need for effective flood management strategies. In recent years, rising water levels and soil erosion have increased flood threats in West Champaran, including Bettiah. The erosion threatens embankments near Bettiah, creating significant flood risks for surrounding villages. Despite villagers' repeated complaints, responses from authorities have been limited. Efforts to mitigate flood risks in Bettiah have included the construction of embankments and ring dams. However, the breach of such structures, as seen in the 2024 incident, underscores the need for regular maintenance and comprehensive flood management plans. Bettiah's susceptibility to flooding necessitates ongoing attention to infrastructure maintenance, effective flood risk assessment, and the implementation of sustainable flood management strategies to protect lives and property in the region.

Time immemorial, the campus is prone to flooding, especially in the rainy season. This problem is observed more acute in the south-eastern end of the campus and around several blocks of the campus. Therefore, in order to determine the cause of the flooding several spatial and temporal analysis will have to be conducted.

To reduce flooding in MJK college campus, the relatively new concept of integrating stormwater Best Management Practices (BMPs) namely “Control- at-Source” approach; For urban planning and designed to achieve multiple objectives, is the most promising approach in the newly developing urbanizing areas (Ghani et al., 2007). The Figure1 shows an image of the Study area.

Table 1. The meteorological information of the Bettiah City.

Parameter	Values
Climate Classification	Humid subtropical with dry winters (Köppen Cwa)
Average Annual Temperature	Approximately 25.4°C (77.8°F)
Average Annual Precipitation	Approximately 1,330 mm (52.4 inches)
Monsoon Season	June to September
Peak Monsoon Rainfall	July and August, with average precipitation of 380 mm (14.9 inches) and 360 mm (14 inches), respectively
Dry Season	November to April
Average Humidity	Varies seasonally; higher during monsoon months
Sunshine Hours	Mean daily sunshine hours range from 10.9 to 14.2 hours throughout the year
Wind Speed	Generally low; average around 8 km/h (5 mph) during May

Figure 1. Location of Campus and its boundary.

Figure 2 and Figure 3 are shown the water logging and the situation of the M. J. K. College Campus Bettiah of the study area. The Redac USM BIOECODS is a management model designed for the comprehensive and sustainable evaluation and management of natural resources and ecosystems. This method is focused on optimizing resource utilization while ensuring the conservation of biodiversity and ecological sustainability

Figure 2. Situation of M. J. K. College Campus Bettiah.

Figure 3. Water logging of M. J. K. College Campus Bettiah.

This article discusses brief concepts of the “Bio-Ecological Drainage System (BIOECODS)”. This approach is particularly applicable in marine and coastal ecosystems, agriculture, and natural resources. (Zakaria, 2016) focuses on sustainable urban water management systems developed by University Sains Malaysia (USM) researchers to address Malaysia’s critical challenges: flash floods, river pollution, and water scarcity during dry seasons. BIOECODS is introduced as a sustainable alternative to conventional drainage systems that often worsen downstream flooding and pollution. The Bio-Ecological Drainage System (BIOECODS) is a sustainable urban stormwater management approach that adopts a "control at source" strategy in Malaysia. It integrates various components to manage stormwater quantity and quality effectively (Zakaria, 2016). The system comprises elements such as grass swales, subsurface modules, dry and wet ponds, detention ponds, and constructed wetlands, which work together to attenuate peak flow, increase lag time, and improve water quality (Abdurrasheed et al., 2018); (Abdurrasheed et al., 2018); (Zakaria, 2016). BIOECODS employs a combination of surface and subsurface conveyance systems. The surface component uses the Storm Water Management Model (SWMM) for overland flow routing, while the subsurface flow is modeled using the Horton method and the Soil Conservation Service (SCS) curve number method (Abdurrasheed et al., 2018). This integrated approach has shown significant success in managing stormwater, with studies reporting peak flow attenuation of 60-75% and increased lag time of 20 minutes within an area of <28,300 m^2 compared to traditional drainage systems (Benisi Ghadim et al., 2017). One of the key features of BIOECODS is its ability to improve water quality through a complex interaction of physical, chemical, and biological processes (Ayub et al., 2005). The system has demonstrated effectiveness in reducing concentrations of various water quality parameters, including Biochemical Oxygen Demand (BOD5), Chemical Oxygen Demand (COD), and Total Dissolved Solids (TDS), while increasing Dissolved Oxygen (DO) levels (Ayub et al., 2005). This makes BIOECODS an environmentally friendly alternative to traditional hard engineering-based drainage systems, capable of managing both stormwater quantity and quality in urban areas (Zakaria, 2016). A comprehensive review by (García-Haba et al., 2023) examined innovations in sustainable urban drainage systems (SUDS), becoming one of the most cited works in the field (Ngong Deng & Ikhsan, 2024). This reflects the growing interest in green infrastructure approaches to stormwater management. The review found that SUDS research has increased significantly, with publication volume rising by 66% over the past decade (Ngong Deng & Ikhsan, 2024). Coastal urban areas face unique drainage challenges due to marine dynamics, soil conditions, and vulnerability to flooding. A review by (Geraldes et al., 2024) emphasized the need for a multidisciplinary approach to address urban flooding, stormwater pollution, and groundwater salinization in coastal settings. The study recommends adapting existing infrastructure, implementing source control solutions, and involving local populations in drainage management (Geraldes et al., 2024). In Sub-Saharan Africa, green infrastructure-based approaches like SUDS offer potential for addressing climate change impacts and existing drainage deficits. A SWOT analysis revealed that despite barriers such as low prioritization, SUDS could provide valuable flood risk reduction benefits and synergies with urban agriculture and water supply (Mguni et al., 2016). The role of policies, institutions, and regulations (PIR) in stormwater management is an understudied area. A hybrid literature review found that understanding of PIR in relation to urban drainage is fragile, highlighting the need for more research on how PIR affects management options and outcomes (Novaes (Novaes & Marques, 2024). Recent work has also focused on greenhouse gas emissions from integrated urban drainage systems. A review by the IWA/IAHR Joint Committee on Urban Drainage identified the need to enhance existing mathematical models to account for GHG emissions in urban drainage systems (Mannina et al., 2018). In conclusion, these reviews demonstrate the evolving nature of urban drainage research, with increasing emphasis on sustainability, multidisciplinary approaches, and addressing complex challenges in diverse urban contexts. Future research directions may include improving SUDS design and performance through advanced data analytics, enhancing understanding of PIR impacts, and developing more comprehensive models that incorporate factors like GHG emissions. Sustainable Urban Drainage Systems (SUDS) have emerged as a crucial approach to stormwater management in urban areas. These systems aim to mimic natural drainage processes, reduce runoff volume, improve water quality, and provide multiple benefits to urban environments (Griffiths & Chan, 2022); Marchioni (LOBO MARCHIONI & Becciu, 2014). The concept of SUDS has gained significant traction in recent years, with research interest increasing by 66% over the past decade (Ngong Deng & Ikhsan, 2024). SUDS encompass a range of strategies and solutions for distributed stormwater management, including green infrastructure, permeable pavements, and other nature-based solutions (Muwafu et al., 2024); Raimondi (Raimondi et al., 2023). These systems are particularly valuable in highly urbanized areas suffering from the combined effects of impervious surfaces and increased extreme rainfall events due to urbanization and climate change (Raimondi et al., 2023). The integration of SUDS into traditional urban drainage systems can help mitigate flood risk and reduce pollution of receiving water bodies (Raimondi et al., 2023). Interestingly, while SUDS are well-established in many developed countries, they also hold significant potential for addressing drainage challenges in Sub-Saharan African cities (Mguni et al., 2016); (Muwafu et al., 2024). Despite barriers such as low prioritization on the urban agenda and lack of data, SUDS offer valuable opportunities for flood risk reduction and synergies with urban agriculture, amenity, and water supply in these regions (Mguni et al., 2016).

In conclusion, the literature emphasizes the importance of collaborative and interdisciplinary approaches in implementing SUDS (Fryd et al., 2012). While technical aspects are crucial, understanding the socio-governance dynamics at the community level is equally important, particularly given the decentralized nature of SUD (Muwafu et al., 2024). As research in this field continues to evolve, there is a growing focus on developing analytical and probabilistic approaches for modeling SUDS (Raimondi et al., 2023)), as well as exploring the potential of machine learning methods for predicting hydrological responses in SUDS catchments (Yang & Chui, 2021).

2. Materials and Methods

2.1. Study area

This acronym represents a set of biological and ecological factors considered essential in sustainable resource management and biodiversity conservation assessments. This method examines natural systems and assesses their capacity to sustainably provide resources and ecosystem services over the long term. It also suggests strategies to reduce environmental impact and increase productivity. Redac USM BIOECODS provides an integrated approach to ecosystem management and conservation, involving detailed identification and analysis of biodiversity and ecological needs to recommend effective management strategies. Based on scientific principles and environmental data, this approach aids environmental organizations and management entities in making smarter and more sustainable use of natural resources. The Bio-Ecological Drainage System (BIOECODS) and similar approaches developed by the River Engineering and Urban Drainage Research Centre (REDAC) at University Sains Malaysia (USM) are foundational studies in sustainable urban drainage. Designed initially for Malaysia's tropical climate, BIOECODS incorporates components like ecological swales, biofiltration, and detention ponds to manage stormwater at its source, an approach aligned with Sustainable Urban Drainage Systems (SUDS) principles. By using natural processes for water purification and flow control, BIOECODS enhances water quality and reduces flash flood risks in urban areas, an issue exacerbated by conventional, fast-drainage systems that often increase pollution and sediment build-up downstream. Specific studies have focused on pollutant removal efficiency, using techniques such as grassed swales and underground detention, and how they influence water parameters like turbidity and biochemical oxygen demand (BOD). These systems have been beneficial for areas prone to flash flooding, like urban campuses and developing green townships, where BIOECODS has been piloted with notable success in enhancing ecosystem resilience and reducing urban runoff issues.

2.2. Methodology

The main function of BIOECODS is to promote storm water infiltration from impermeable areas (e.g. roof tops, car parks) by using bio-ecological swales. The Ecological Swales are grass-lined channels combined with biofiltration systems to slow down and infiltrate runoff, effectively enhancing water quality. These serve as temporary storage to manage peak flow and reduce flow variability. The second function is to gradually release the storm water through the use of bio-ecological swales, on-line underground bioecological detention storages and bio-ecological dry ponds. Finally, the third function of BIOECODS is to enhance treatment of storm water quality using the treatment train concept by utilizing bio-ecological swales and bio-ecological ponds (e.g. wet pond, wetland) as the storm water moves downstream. Ecological Ponds and Constructed Wetlands; Including wet ponds, detention ponds, and recreational areas, these ponds support water retention, quality improvement, and recreational use. This drainage system also lessens the impact of flooding by safely carrying storm water away from built-up areas into rivers and creeks. Currently there is no proper internal drainage system within the campus. Surrounding the campus, there is a wide Nallah through city wastewater flows. Initially implemented as a pilot project on USM’s 320-acre engineering campus, BIOECODS managed stormwater runoff effectively by minimizing hydrological disruptions and enhancing water quality through natural processes such as infiltration, flow reduction, storage, and purification. Recent BIOECOD’s successfully implemented in the University Sains Malaysia (USM), Malaysia. The USM engineering campus is a good example and motivation for other university campuses and government offices premises.

3. Results and Discussions

The analysis conducted below was achieved solely from Google Earth Pro, and hence the limitations associated with this software are transposed to this article. However, due to the fact that this is a preliminary suggestion, additional precise data will be obtained before a detailed recommendation is submitted. The elevation profile of line 1, 3, 5, 7, 9, 12 are shown in Figure 4, Figure 5, Figure 6, Figure 7, Figure 8 and Figure 9.

Figure 4. Elevation Profile of Line 1.

Figure 5. Elevation Profile of Line 3.

Figure 6. Elevation Profile of Line 5.

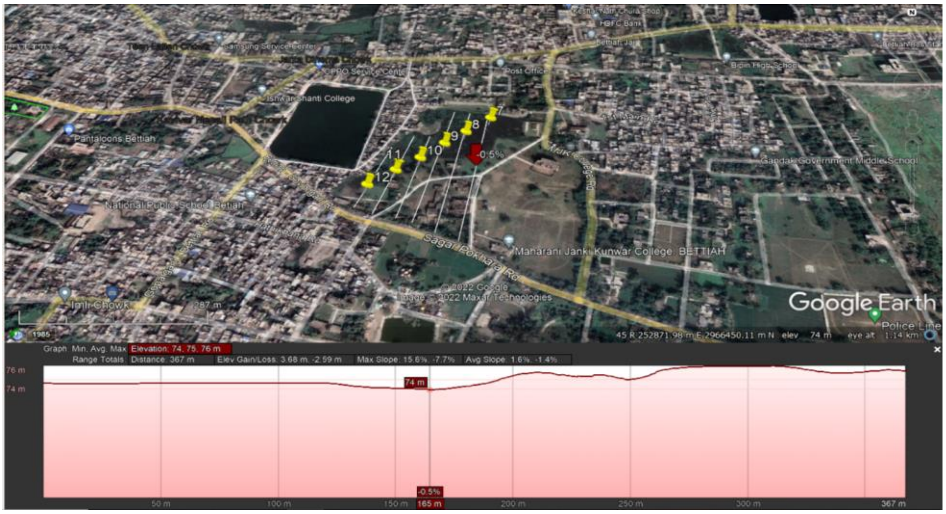

Figure 7. Elevation Profile of Line 7.

Figure 8. Elevation Profile of Line 9.

Figure 9. Elevation Profile of Line 12.

With respect to Figures 2-4, the elevation of the land appears to be sloping toward the southern end of the field. To be more precise the northern half of the lines 1-6 appear to be sloping to the northern end of the campus while the southern half of the lines appear to be sloping towards the south-eastern end of the map. Therefore, it suggests that during the rainfall events, the southern end of the field will flood first if there is inadequate drainage. With respect to Figures 5-7, the MJK Pokhara seems to be higher than some other places in the campus. However, this may be due to the limitation of the software as the software may be representing the heights of the foliage in the pond and not necessarily the height of the water level in the pond. However, if the Pokhara is indeed higher than some other places on the map, then either these places need to be raised or the water has to be diverted away and pumped to a relevant outlet of storage area. The elevation profile of line 13, 15, 17, 19, 20, 22 are shown in Figure10, Figure 11, Figure 12, Figure 13, Figure 14 and Figure 15.

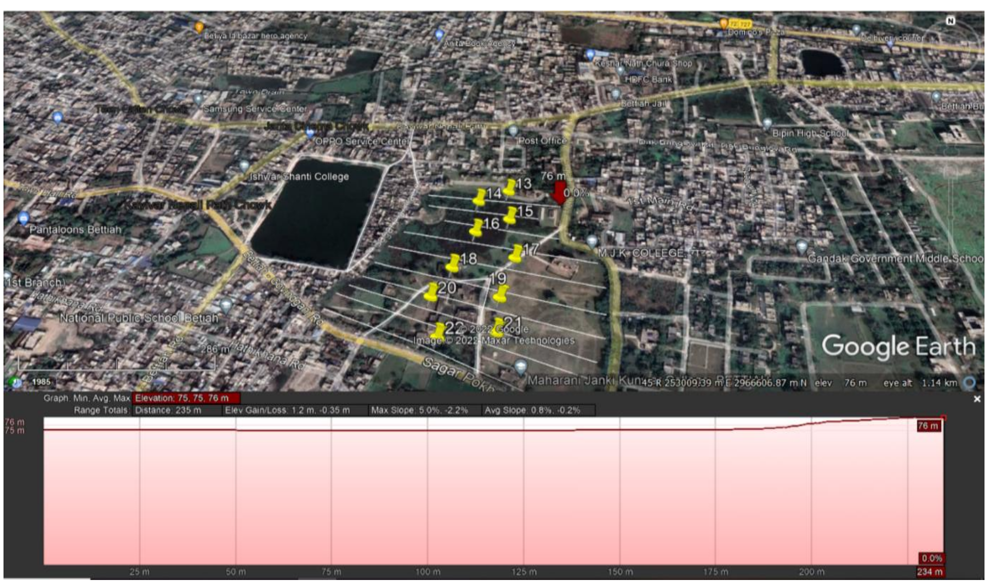

Figure 10. Elevation Profile of Line 13.

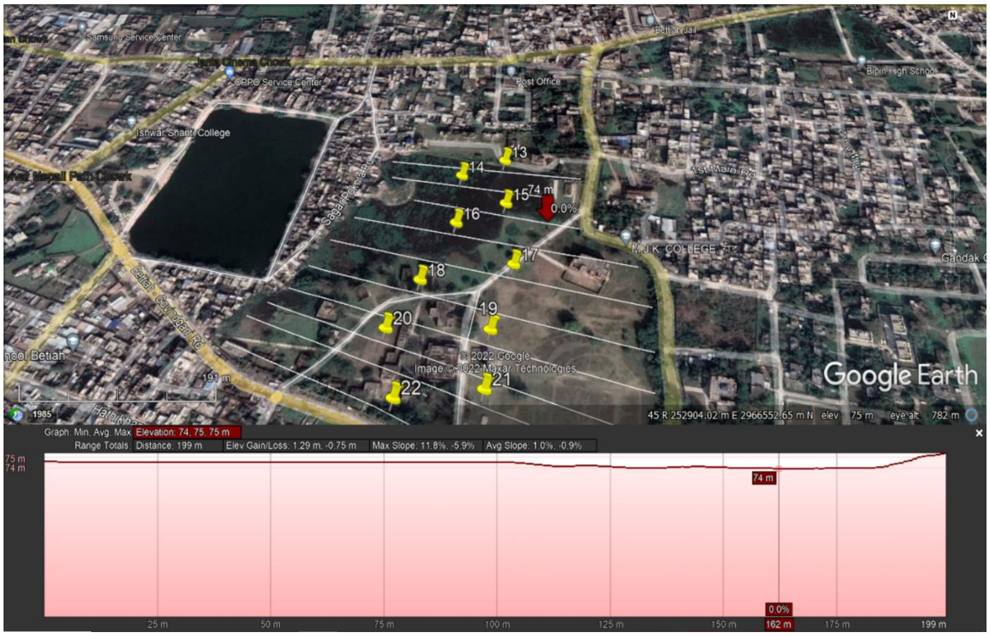

Figure 11. Elevation Profile of Line 15.

Figure 12. Elevation Profile of Line 17.

Figure 13. Elevation Profile of Line 19

Figure 14. Elevation Profile of Line 20

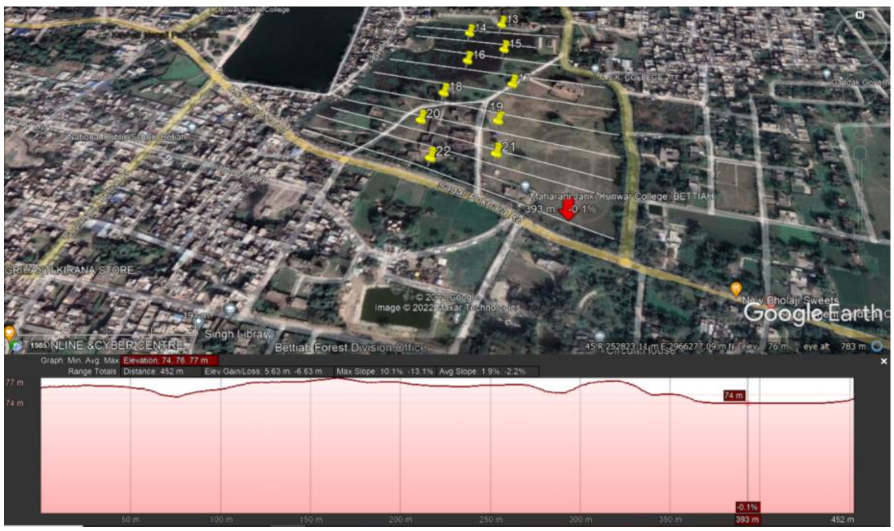

Figure 15. Elevation Profile of Line 22

With respect to figures 8-10, the Pokhara can be observed to be slightly higher than the eastern end of the campus. Hence it suggests that the Pokhara drains to an outlet on the north-eastern end of the campus. Figures 10-13 illustrates that the eastern road is above the surrounding ground level but the western road does not. Therefore, it suggests that this western road is flooding during storm events while the eastern road does not.

Furthermore, Figures 10-13 support figures 2-4, in that the south-eastern end of the campus is significantly lower than the general elevation of the campus, even lower than the Pokhara. Therefore, it further solidifies that severe flooding and ponding will occur on the south-eastern end of the campus. BIOECODS has expanded to various parts of Malaysia and serves as a model for green infrastructure in new urban developments, such as the Kwasa Damansara green township project, which integrates sustainable flood and stormwater management practices.

4. Conclusions

Within the limitations of the spatial analysis conduction in Google Earth Pro, the proposed solution can mitigate flooding in campus if properly constructed. However, further detailed information is required such as the existing topography, soil type, temporal changes and the drainage of the surrounding environment. A drawing of the campus existing drainage system is also required so that improvements and or alterations can be made that would not have significant repercussions elsewhere on the campus or surrounding environment.

The similar BIOECODs approach is highly recommended for MJK college, Bettiah to control flooding and water logging problems. A detailed design is underway and a feasibility report will submit for approval from the authorities. The author successfully implemented the application of soft computing techniques, Gene-Expression Programming (GEP), in water resources management. The capabilities of these techniques have been illustrated by applying them to the prediction of water consumption, rainfall and Manning's roughness and river stage - discharge curve in hydrology (Chaplot, 2021; Chaplot and Birbal, 2021, Chaplot et al., 2021) . The results are very promising, which support the use of these intelligent techniques in prediction of hydraulic and hydrologic variables. Availability of free and easy-to-apply software for a specified method can invite a huge number of its applications by enthusiastic investigators. Few recent works of the author and her collaborators are mentioned in the references.

It is proposed that a retention pond be placed at the south-eastern end of the campus. In doing so, the field will have to be slightly shifted or reduced in size depending on the client's preference. It is also suggested that swale drains be implemented along the roadways and replace other existing drains along the campus. However, it is also recommended that the roads be upgraded simultaneously with the implementation of these swale drains. The swale drains were chosen due to their sustainable nature and there is space for its implementation.

It is also recommended that the north-eastern and south-eastern ends up the campus separated by the road in the centre be graded such that it drains directly into the MJK Pokhara. This will divert the surface run off from filtering back into the blocks. Natural impermeable berms made from soil and clay can also be added around the blocks to prevent storm water from intruding into the blocks. This may be the most feasible solution for the campus. The following suggestions can be added for future studies and implementation strategies:

- Optimization of Bio-Ecological System Performance; Advanced Hydrological Modeling: Employ advanced models like SWMM (Storm Water Management Model) to simulate water flow accurately in BIOECODS systems. Using real-time data to optimize surface and subsurface flow can enhance system efficiency.
- Optimization of Bio-Ecological System Performance; Water Quality Monitoring and Assessment: Consistently monitor water quality parameters, including Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), and Chemical Oxygen Demand (COD), to refine treatment processes and improve downstream water quality.
- Expanding BIOECODS to Urban and Rural Areas; Adaptation to Various Climatic Conditions: Given climate change, further research is needed to adapt BIOECODS for different climates, such as arid, semi-arid, or coastal areas, each requiring unique water management strategies.
- High-Density Urban Areas: In densely populated areas, explore techniques like green roofs, permeable pavements, and underground storage to make BIOECODS effective in limited urban spaces.
- Advances in Monitoring Technology and Artificial Intelligence; IoT Sensors for Real-Time Monitoring: Integrate smart sensors in BIOECODS components to continuously monitor water quality and flow, supporting more effective and responsive stormwater management.

- AI Modeling for Predictive Analysis: Use machine learning models to predict runoff behavior and assess the performance of different BIOECODS components, increasing accuracy and adaptability of the system.

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Conflicts of Interest
The author declares no conflict of interest.

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