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Integration of Wetland Technology for Sustainable Urban Development

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Abstract: The wetland technology has been derived from the concepts taken from the functions and services provided by natural wetland ecosystem. This study investigates the role of Wetland Technology Integration (WTI) for promoting Sustainable Urban Development (SUD). The research aims to assess the impact of WTI on water quality improvement, identify obstacles and opportunities and evaluate its influence on social, economic and environmental dimensions. This research employs a cross-sectional study design to assess WTI in urban development of Patna. Stratified random sampling ensures equitable representation across stakeholder group. A comprehensive questionnaire gathers data on water quality, and social, economic, and environmental impacts from 295 participants, facilitating a holistic understanding of present integration practices. The study revealed significant improvements in specific Water Quality Parameters (WQPs) in integrated area, affirming the positive effect of WTI on water quality. Regression models demonstrated a positive relationship between WTI and social, economic and environmental impact, indicating its favourable influence on urban sustainability. WTI in urban development holds promise for enhancing water quality and strengthens sustainability. The study's outcomes offer insights into the multifaceted benefits of WTI and underscore the importance of overcoming challenges.

Keywords: Wetland Technology Integration, Sustainable Urban Development, Water Quality Parameter

1. INTRODUCTION

Urbanization is a defining characteristic of the modern era, with more than half of the world's population residing in urban areas today, a figure projected to reach 68% by 2050 according to the United Nations (Nations, 2018.). Numerous opportunities and difficulties are presented by this rapid urbanization. While serving as a center for innovation, economic development, and culture, cities are also faced with urgent problems like environmental degradation, resource depletion, and the pressing need for Sustainable Development (SD) (F. Wang et al., 2023). According to (Alamanos et al., 2020), managing water resources is essential to SUD. Urban areas must strike a difficult balance between the urgent need for freshwater and the need to safeguard and restore ecosystems (Kenyatta, 2017). Within this complex intersection of urbanization, water management, and environmental sustainability, wetland technology incorporation appears as a promising solution (Yazdandoost& Yazdani, 2019).

Wetlands, which are frequently underappreciated and overlooked, are essential to maintaining ecological balance and supplying a wide range of ecosystems, which includes swamps, marshes, ponds, and lakes, and act as natural filters and buffers. They control water quality, lessen floods, provide habitat for a variety of plants and animals, and act as carbon sinks. Additionally, they provide communities with leisure opportunities and wetlands internationally in recognition of their profound significance (Ahmed et al., 2023; Finlayson et al., 2023). Wetlands provide essential services and goods, such as groundwater recharge, biodiversity conservation, food production, fisheries, and economic activities. With the growing urbanization trend, these ecosystems become increasingly fragile and threatened. Unplanned urban expansion often encroaches upon wetlands, resulting in their degradation, fragmentation, and loss (Bocanegra et al., 2016).

There is still a need for more research when it comes to examining the long-term effects of these systems in specific urban settings, even though large-scale integrated constructed wetland systems have been extensively studied for their efficacy in treating domestic wastewater (Luo et al., 2023). Also, only a limited number of diverse regions can be used to apply the findings. Wetland systems face a major efficiency challenge as a result of the unpredictability of weather patterns brought on by climate change (Chisango & Maposa, 2016). With the integration of Microbial Fuel Cells (MFCs) into High-Flow Subsurface Constructed Wetlands (HSSF-CWs) (Lyu et al., 2023), there is also an opportunity to pioneer cutting-edge technologies that combine wastewater treatment with electricity generation. Additionally, comprehensive and cogent frameworks that integrate societal, economic, ecological, and technological aspects are needed to address the challenges and opportunities related to sustainable urban agriculture in economically underprivileged residential areas. This study examines the incorporation of wetland technology in urban environments to close the research gap and advance SUD.

By assessing WQPs, economic and social dimensions, and environmental impacts, this research aims to demonstrate how the integration of wetland technology can be a catalyst for holistic and SUD. It addresses the complex interplay between urbanization and wetland ecosystems and seeks to unveil the transformative potential of integrating wetland technology into urban planning and design. Through a comprehensive examination of the concept of SUD, an assessment of the prevailing climatic conditions in urban locales, and an exploration of the utilization of wetland technology, this study aims to illuminate a way toward inclusive, resilient, and environmentally responsible urban futures. The research focuses on Patna, the capital of Bihar, India, as an isolated urban area. The following are the primary objectives of this research,

- To evaluate the efficiency of incorporating wetland technology in achieving SUD through improving water quality and encouraging environmental resilience.
- To determine the main obstacles to the integration of wetland technology in urban development projects as well as the opportunities.
- To assess how integrating wetland technology has affected social, economic, and environmental factors.

In the following sections, this research paper will explain the research objectives, methodologies, hypotheses, anticipated contributions, results, discussions, and conclusion, providing a comprehensive outline for this exploration into the integration of wetland technology for SUD.

1.1 Sustainable Urban Development and Water Quality

To ensure that urban development is sustainable and that everyone has access to clean water, it is necessary to mention the problems that urbanization has brought about (Priyadarshini et al., 2022; Wu et al., 2019). To determine potability and define pollution sources like marine litter, it is necessary to analyze water quality using various methods like machine learning algorithms (Khan et al., 2022). Determining the quality of water bodies and sustainability for drinking and irrigation also entails evaluating their physicochemical parameters (Aryal, 2022; Sharma et al., 2021). When taking variables like governance, technology, infrastructure, and economics, sustainable urban water management systems are essential in closing the gap in water supply demand. To ensure the sustainability of water availability and quality, development organizations and governments need to be actively involved in managing water resources.

The overall SD is influenced by the quality of water. Water quality has trade-offs and synergies with other targets and goals, as evidenced by connections between the Sustainable Development Goals (SDGs) (Zhang et al., 2023). Increasing water quality can help achieve several SDGs like water security, water resources, and aquatic ecology. For efficient management of long-term regional development and water resources, it is essential to assess and predict surface-level water quality (Akcer et al., 2020). To ensure environmental sustainability, local standards must take into account the unique circumstances and innate characteristics of water bodies (Zhang, 2019).Important research areas for sustainable water quality management include water quality management and assessment, including the creation of evaluation indices and water quality indices (Danilenko et al., 2020). By considering the interconnections between water quality and other SDGs, and implementing effective strategies for water management, it is possible to achieve SDGs related to environmental conservation and water resources.

1.2 Wetlands as Ecosystems and Water Quality Enhancers

Freshwater coastal wetlands, flood-plain wetlands, and CWs are the three main types of wetlands. They perform several services, such as regulating floods, supplying recreational opportunities, and promoting tourism. According to Shaharuddin et al. (2014), natural wetlands are renowned for their emergent aquatic vegetation and support services that greatly enhance human well-being. According to Giri et al. (2013), CWs are primarily biological filters that efficiently remove pollutants like BOD, COD, TSS, and organic nitrogen from wastewater. By lowering the levels of pollutants like nitrate, nitrite, ammoniacal nitrogen, orthophosphate, TSS, BOD, and COD in the water, they can enhance their quality (Qinghua et al., 2013). By eliminating contaminants like DO, TP, NH3-N, and fecal coliform, wetlands also play a significant part in enhancing the quality of drinking water (Rai et al., 2011). According to Chuersuwan et al. (2014), different types of wetlands exhibit variations in methane, nitrous oxide, and carbon dioxide fluxes, suggesting that CWs can be used to reduce greenhouse gas emissions.

Wetland ecosystems are essential for preserving ecological harmony, biodiversity, and control over water quality (Koch et al., 2023). Understanding the degree of preservation and the need for conservation measures in wetlands requires regular monitoring of WQPs (Arora et al., 2022). According to studies, wetlands' physical and chemical changes can reveal how anthropogenic activities are affecting the water's quality. (Dar et al., 2022). To evaluate the water quality in wetlands, it's critical to monitor physicochemical variables like temperature, pH, alkalinity, dissolved oxygen, and nutrient concentrations (Brraich et al., 2021). Estimating wetlands' WQPs using remote sensing technology, such as satellite imagery, can be a useful step toward sustainable management.

1.3 Urbanization, Wetland Degradation, and Water Quality

Water quality and wetland ecosystems are significantly impacted by urbanization. Anthropogenic activities have an impact on urban wetlands, changing the physical and chemical parameters of water quality, according to studies (Koch et al., 2023). Wetland areas experience water pollution issues as a result of land use changes brought on by urbanization, such as the growth of agriculture and the emission of untreated urban wastewater (Cabrera et al., 2023). However, restoration initiatives that target the sources of pollution have produced fruitful outcomes in terms of raising freshwater ecosystem ecological status and WQPs (Fu et al., 2021). Although it modifies aquatic ecosystems, floating urbanization has little impact on water quality and can even support vibrant ecosystems (Lima et al., 2022). Untreated sewage and tainted urban runoff severely pollute surface water bodies, making the impact of urbanization on water quality a significant issue that needs urgent attention (Lima et al., 2022).

Urbanization has a significant impact on WQPs (Church et al., 2021; Lima et al., 2022; Wang et al., 2020). According to studies, urbanization and industrialization both affect water quality, with highly urbanized areas seeing greater improvements than less urbanized areas (Kumar, 2021). The relationship between urban and agricultural actors and their efforts to improve water quality can be impacted by the choice of policy tools, such as regulatory and voluntary interventions (Sheldon et al., 2019). Urbanization also affects catchment hydrology, changing how sediment, nutrients, and pollutants are transported and resulting in poorer water quality in urban streams. It is discovered that changes in hydrology have less of an impact on the health of stream ecosystems than does water quality, indicating that poor water quality can still have a big effect even after taking steps to restore natural flow patterns.

1.4 Integrating Wetland Technology for Water Quality Improvement

For improving water quality, wetlands technology is a successful method. According to studies, wetland systems can be implemented to significantly improve the water quality of ponds and rivers. One such system is the bypassing of multi-pond wetlands. These systems have been effective at meeting treatment goals, as evidenced by improvements in water transparency and dissolved oxygen levels as well as decreases in ammonia nitrogen, total phosphorus, and chemical oxygen demand concentrations (Zeng et al., 2022).It has also been discovered that wetland complex restoration and sediment excavation improve water quality by lowering phosphorus concentrations and specific conductivity (Hassett & Steinman, 2022). Water quality and landscape values have been effectively optimized by urban-constructed water quality treatment (WQT) wetlands designed with engineering landscape methods (Li et al., 2022). In addition, the use of CWs, particularly river diversion wetlands, has shown promise in lowering pollution levels and raising river and stream water quality (Alias et al., 2021). These results demonstrate the promise of wetland technology as a means of improving water quality.

It has been demonstrated that wetland-based treatment techniques improve the quality of the water. Studies have shown how well wetlands work to treat wastewater, manage stormwater, and remove nutrients, metals, and emerging pollutants like pathogens (Martinez-Guerra et al., 2020). According to Dorche et al. (2019), wetlands are essential for enhancing water quality and supplying habitat for wildlife. According to Liu et al. (2014), different wetlands configurations, such as the use of particular aquatic macrophytes and patterns, have been found to have varying degrees of efficacy in the treatment of wastewater. To stop the release of pollutants, wetland sediments must be periodically excavated (White, 2013). CWs have been utilized successfully to remove nitrogen, phosphorus, and other contaminants from wastewater.

1.5 Social, Economic, and Environmental Dimensions of Sustainable Urban Development

In assessing social impacts on health and water quality, community involvement is essential. In terms of health promotion and improvement strategies, it has been noted that collaboration between community-based organizations and academic institutions can produce favourable results (Andreolli et al., 2015). For instance, the implementation of the Clean Water Project in rural Mayan villages in Guatemala was the result of collaboration between a community-based health organization and a nursing college. By working together, we were able to significantly lower the prevalence of diarrheal disease (Harris et al., 2018). Additionally, Doubeni et al. (2022) discovered that community involvement and the use of a water quality index were important elements in enhancing water quality and ensuring sufficient water resources in river watersheds in Costa Rica.

Improving water quality has significant economic benefits, including lower costs, rising property values, and bettering homeowner welfare. Numerous studies have shown that clean water has a positive impact on property values (Nicholls et al., 2018). The economic effects of such improvements are significant, and preferences for water quality improvements are correlated with property values (Kim et al., 2016). The Chesapeake Bay's improved water quality can have a big impact on homeowners who live on or close to the water (Walsh et al., 2017). These results demonstrate how crucial it is for environmental policy decisions to take into account the economic importance of water quality.

To assess ecological quality and promote ecological conservation, it is essential to look at how environmental factors affect biodiversity, habitat creation, and water quality. This problem has been covered in numerous studies. Woretaw et al., (2023) discovered that characteristics of habitat quality have a greater impact on the structure of the macro invertebrate community than traditional physicochemical characteristics. (Mishra et al., 2023) emphasized the significance of water quality for the preservation of wetlands, especially for aquatic avifauna. Land use changes were found to be the most important factor affecting habitat quality in (Z. Li et al., 2022) analysis of the spatial and temporal variation of habitat quality in Suzhou City. (Yang et al., 2022) investigated how regional environmental information disclosure affected water quality in China and discovered that higher levels of information disclosure were linked to a more neutral water environment. (Winter et al., 2018) proposed a methodological framework for evaluating habitat factors and impacts on biodiversity status in life cycle assessments. Together, these studies highlight the significance of taking habitat and water quality into account when evaluating environmental impact on biodiversity and SD.

1.6 Key Factors Influencing Wetland Technology Integration and Water Quality

The integration of wetlands into wastewater treatment and nutrient recycling systems is a suitable and efficient technique. To clean up wastewater and prepare it for environmental release, it combines chemical, physical, and biological processes. According to research by Pratiwi et al. (2021), this technology has been shown to reduce a variety of contaminants, including suspended solids, COD, heavy metals, and oil & grease, to meet regional water quality standards. CW is a type of wetland technology that can purge wastewater of a variety of pollutants without the use of machinery or chemical agents. Flow rate and organic load are two examples of variables that can influence the choice of CW technology (Bresciani, 2019). WTI can be used in planetary exploration scenarios because it is odorless, requires little labor and energy, and can help with nutrient recycling and water purification. Additionally, it can be incorporated into space life support systems, using the heat from lights to maintain temperature (Listia et al., 2022).

To improve water quality, urban development elements, stakeholder engagement, and regulatory frameworks are all essential (Barnhart & Flinders, 2023; Church et al., 2021; Eaton et al., 2021). The choice of policy tools, such as regulatory and voluntary interventions, can have an impact on the exchange of money, the formation of political alliances, the sharing of knowledge, the development of interpersonal relationships, and the sense of place that both urban and rural communities share (Bell, 2020). When developing water quality criteria, the US Environmental Protection Agency (USEPA) uses a variety of modeling types and frameworks, taking into account things like system operations, data accessibility, and stakeholder expertise. Water resource issues can be addressed creatively by incorporating stakeholder engagement in environmental management (Al-Qadi, 2020). Urban political ecology, SD, ecological modernization, socio-technical framings, radical ecology, and other frameworks for urban water sustainability reflect various perspectives and methods for managing water. It can have detrimental effects on the entire community and reduce system resilience to exclude community stakeholders from decision-making processes. The conceptual framework described above has been developed,

Null Hypothesis (H01): There is no significant difference in WQPs between urban areas with integrated wetland technology and those without.

Alternative Hypothesis (H1): Urban areas with integrated wetland technology exhibit improved WQPs compared to non-integrated areas.

Null Hypothesis (H02): The integration of wetland technology has no significant influence on the social, economic, and environmental dimensions of SUD.

Alternative Hypothesis (H2): The integration of wetland technology positively influences the social, economic, and environmental dimensions of SUD.

2. MATERIALS AND METHODS

2.1 Study area

An essential strategy for addressing environmental and socioeconomic issues in urban areas is the integration of wetland technology. The research focuses on a particular urban region: Patna, the capital of Bihar India, to provide a study area for such an integration. In terms of wetlands and urban development issues, Patna is a sizable and historically significant city with a variety of problems (Fig 1).

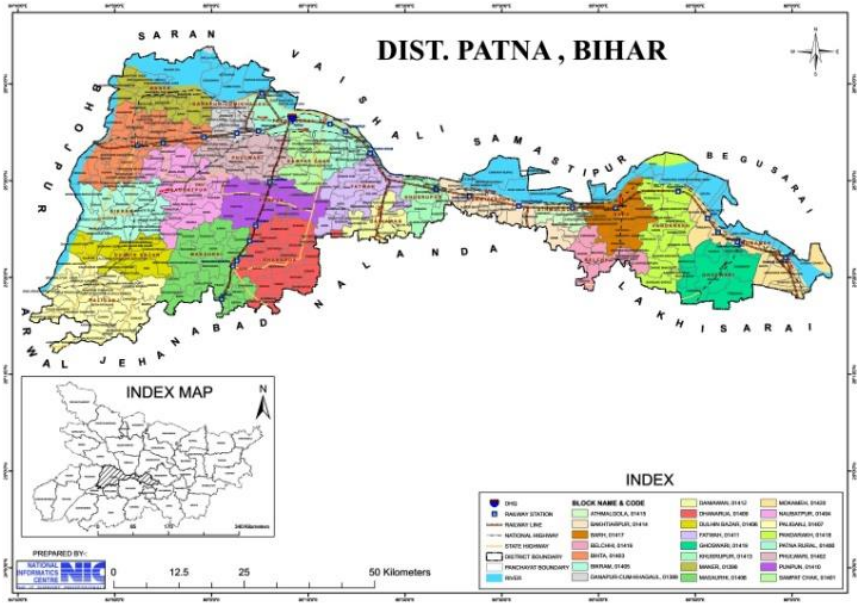

Figure 1. Location Map of Patna in State of Bihar(pmc)

The city of Patna is located on bank of River Ganga in Northern Part of India. The city has a headquarter of Bihar. Patna is confronted with standard urban development issues like population growth, traffic jams, pollution, and infrastructure needs. These problems call for novel, long-lasting solutions. Several wetland ecosystems, along the floodplains of river Ganga, Son and PunPun different types of wetland areas could be found. These wetlands are significant ecologically and are essential for biodiversity preservation, flood control, and water filtration. Through its course of time the river edges has been developed in Ghats due to religious and cultural impacts. The city beautification projects including construction of Ganga Driveway, bridges, Ghats etc have been coming up as a result of urbanization. Due to urbanization and development projects taking up in Patna Ganga Riparian wetlands are in tremendous and anthropogenic pressure and in are in degraded conditions. Incorporating wetland technology into Patna's urban development planning would be the main objective of the study. To reduce pollution in the Ganga River, this may entail using constructed wetlands for wastewater treatment and water recycling. The river Ganga flowing through Patna is a hub of water transport, cultural and religious activities. In the region's socioeconomic and environmental landscape, the Ganga River is important. Significant problems with industrial pollution along with solid waste disposal affect the River, especially in and around Patna. These effluents may include chemicals, heavy metals, and organic pollutants, which contribute to the pollution of the water supply. Domestic wastewater and sewage discharge into rivers that haven't been fully treated is a common problem. More organic matter and nutrients are entering the river as a result of the growing urban population in Patna and its suburbs. The Ganga River's water quality may be impacted by agricultural activities in the river's catchment area that result in the runoff of pesticides, fertilizers, and sediments. Non-biodegradable waste like plastics etc., should be disposed of properly to avoid physical river pollution, which can have negative environmental and aesthetic effects. The River naturally experiences sediment transport and bank erosion. However, excessive erosion can affect the river’s water quality by causing sedimentation. To improve flood control and lessen the effects of monsoon floods, use natural wetland areas like riparian Wetland is essential. Incorporating wetland preservation and green infrastructure into the fabric to encourage biodiversity and provide residents with green spaces. Examine how wetlands can be incorporated into the landscape of the city, ensuring their preservation and effective management, through urban planning and zoning laws. Involving neighborhood groups in initiatives for environmentally friendly urban growth and Wetland preservation patna is in line with the more general objectives of achieving SUD like environmental sustainability, resilience to climate change, and improved quality of life for residents.

2.2 Study design and survey participants

Cross-sectional study methodology is used in this research. With the help of this design, information from a variety of participants can be gathered all at once. Cross-sectional studies are useful for providing a quick overview of the integration of wetland technology in urban development at the moment. With the method, researchers can evaluate a variety of WTI-related factors and their effects without the need for extensive data collection. Understanding how wetland technology is currently being integrated into urban development is the main goal of the research. A cross-sectional design enables the evaluation of numerous factors at this particular time. An accurate representation of the various roles of stakeholders, urban planners, and policymakers in the sample is ensured by using a stratified random sampling technique. Based on the roles played by those involved in urban development, the population is divided into distinct strata. These strata consist of policymakers, landscape designers, stakeholders, and urban planners. Participants are chosen proportionately according to their population representation within each stratum. This makes sure that the sample is not dominated by larger subgroups. The study aims to collect data from 295 participants, with the size of the sample for each stratum being determined by its percentage in the total population. To guarantee that every person in a stratum has an equal chance of being included in the study, participants are randomly chosen within each stratum. 295 people are the number of participants who will make up the study’s sample. This sample size was chosen so that there would be a sizable and varied dataset from which to infer actionable insights into the application of wetland technology to urban planning. To gather data, a thorough questionnaire is created. The study’s objectives, key variables, and guiding hypotheses are all reflected in the questionnaire’s structure. It addresses a wide range of issues regarding the use of wetland technology, water quality indicators, social and economic effects, environmental effects, and other independent variables. By taking a thorough approach, it is ensured that the data are relevant to the main goals of the study.

2.3 Data Management

The main method of gathering data is through the usage of online surveys. This survey method has several benefits, like effective distribution, the capacity to reach a participant pool with a variety of geographic locations and procedure of streamlined data collection. A through questionnaire is thoughtfully created before the start of the online survey and is carefully matched with the research objectives, variables and hypotheses of the study. This structured questionnaire encompasses a broad spectrum of questions relating to WTI, WQPs, economic, social and environmental impacts and other independent variables.Each questionnaire is designed to elicit specific responses that can be subsequently used for quantitative research. Ethical consideration is crucial in this process of data collection. Informed consent is diligently obtained from all participants, ensuring that they fully understand the purpose of the study, the usage of their data and their roles as participants. This step is imperative for protecting participants' privacy and data security. The data collection process commences with the distribution of an online survey to the pre-selected participants. These surveys are shared either via email or through a secure online survey platform, accompanied by a clear invitation to participate and a link to access the survey. Participants are granted a reasonable timeframe to complete the survey at their convenience, and reminders may be sent to non-respondents to encourage participation. The collected data is securely stored on a protected server or a cloud-based platform. Rigorous data security measures are implemented to safeguard against unauthorized access, and regular data backups are conducted to prevent data loss due to technical issues or system failures. Additionally, personally identifiable information (PII) is removed or anonymized from the dataset to ensure participant privacy and unique identifiers are assigned to the data for analysis purposes. Following data collection, a meticulous data cleaning process ensues to ensure data accuracy and consistency. This process includes identifying and rectifying missing data, detecting and addressing outliers or unusual values, and validating data against predefined criteria.

2.4 Outcome Measurement

Outcome measurement is crucial for evaluating the impact of WTI into SUD. The study includes several important outcome measures to assess the numerous aspects of SUD, environmental sustainability and the effectiveness of WTI. WQPs are the focus of one of the main outcome measures.Quantitative measurements of these parameters are made for pollutant concentrations like organic matters and heavy metals and also nutrient levels such as nitrogen and phosphorus concentrations. The objective of this research is to evaluate these factors and determine what the exact role WTI plays in improving water quality in urban areas. The study also evaluates social impact indicators based on participant responses regarding community engagement and health improvements. These indicators shed light on how WTI affects social dynamics and urban communities' overall well-being. Another critical set of outcome measures focuses on economic impact indicators. These indicators are derived from participant responses concerning cost savings and property value enhancement attributed to WTI. They provide valuable data on the economic benefits associated with the integration of wetland technology in urban development. Based on participant feedback on how WTI has improved biodiversity and created new habitats, the study evaluates environmental impact indicators. These indicators provide information about the beneficial environmental effects of wetland technology in urban areas. The study uses several independent variables in addition to outcome measures. These include the classification of WTI as "Integrated" or "Not Integrated" based on participant responses. Urban development features, stakeholder engagement levels, and the regulatory framework are also considered independent variables.These variables allow for a comprehensive analysis of the factor influencing WTI and its impact on SUD. Through the systematic measurement of these independent variables and outcome indicators, the study seeks to quantitatively evaluate the various effects of WTI in SUD. This is done to conclude the relationships between WTI and different facet of SUD, such as water quality, economic benefits social dynamics and environmental sustainability.

3. CALCULATIONS

The Statistical Package for the Social Sciences (SPSS) was utilized to conduct the systematic process of decomposing the data analysis for this study into two main parts: descriptive and inferential analysis. To examine how WTI into SUD and its impacts, each component has a specific function. Descriptive analysis is the first stage data analysis, which entails computing description statistics for all pertinent variables. This analysis offers insights into central tendencies, variations and the distribution of values within the dataset and offers a through overview of the gathered data. By conducting this analysis, this study gains a comprehensive understanding of the basic characteristics of the variables under investigation.The use of inferential statistics allows for the comparison of various groups and factors and the application of conclusions. Several significant inferential methods are used in the context of this study, including, the comparison of urban areas with integrated wetland technology and those without it is done using independent samples t-tests to look at a variety of factors, such as water quality, social impact, economic impact, and environmental impact.By conducting these tests, the study aims to identify statistically significant differences in these parameters, which can provide insight into the effectiveness of WTI. An effective statistical tool for examining variations in impact indicators across various level of SUD features, stakeholder engagement, and the regulatory framework is ANOVA. To gain a better understanding of the relationships at play, this analysis helps determine whether variations in impact indicators are influenced by these factors. The complicated relationship between WTI and impact indicators is indicators is investigated using regression analysis while also accounting for other independent variables. With the help of this analysis, the study can identify the factors that have the significant impact on the impacts seen, giving important information about how closely related the factors are to one another. These analyses' roles include evaluating the results' significant and putting the study's hypotheses to the test.

4. RESULTS

4.1 Background Characteristics

Table 1 presents the demographic characteristics of the 295 selected participants in the study, highlighting key aspects of their profiles. The participants are fairly evenly distributed between male and female, with 54.6% male (161 participants) and 45.4% female (134 participants). The age distribution shows a broad range of participants. The largest age group is between 35 and 44 years old (15.6%), followed closely by those aged 45-54 (13.6%) and 55-64 (13.9%). There is representation across all age groups, including those under 18 and those 65 or older. Participants come from diverse professional backgrounds. The majority are Urban Planners (13.6%), followed by Landscape Designers (22.4%), Policymakers (26.4%), Stakeholders/Community Members (29.8%), and a smaller category labeled as "Other" (7.8%). The participants' years of experience in their current roles vary. The largest group has 6-10 years of experience (23.4%), followed by those with more than 15 years of experience (22.4%), and less than 1 year of experience (21.4%). The study encompasses a wide range of experience levels. These demographic characteristics provide valuable context for understanding the composition of the participant pool. The study includes individuals from various genders, age groups, professional roles, and levels of experience, ensuring a diverse and representative sample for the research analysis.

Table 1: Demographic characteristics of selected participants

Characteristics		% (n=295)
Gender	Male	161
	Female	134
Age	Under 18	37
	18-24	50
	25-34	39
	35-44	46
	45-54	40
	55-64	41
	65 or older	42
Role/Position	Urban Planner	40
	Landscape Designer	66
	Policymaker	78
	Stakeholder/Community Member	88
	Other	23
Years of Experience	Less than 1 year	63
	1-5 years	44
	6-10 years	69
	11-15 years	53
	More than 15 years	66

Table 2 provides a summary of variable items along with their corresponding means and standard deviations (SD). Participants, on average, indicated a moderate level of agreement (mean = 3.83, SD = 1.142) that wetland technology is effectively integrated into urban development planning. Similarly, they expressed a moderate level of agreement (mean = 3.90, SD = 1.044) that the level of WTI has improved over time. Furthermore, participants moderately agreed (mean = 3.83, SD = 1.083) that WTI is driven by effective stakeholder engagement, and the regulatory framework in place supports and encourages WTI (mean = 3.77, SD = 1.066). On average, participants indicated a moderate level of agreement (mean = 3.84, SD = 1.029) that WQPs, including nutrient levels and pollutant concentrations, are better in areas with WTI compared to non-integrated areas. Participants, on average, showed a relatively strong agreement (mean = 3.94, SD = 1.043) that WTI positively impacts community engagement in urban development. Similarly, they expressed a moderate level of agreement (mean = 3.90, SD = 1.082) that WTI contributes to improved public health in the community. On average, participants indicated a moderate level of agreement (mean = 3.85, SD = 1.082) that WTI leads to cost savings in urban development projects. They also moderately agreed (mean = 3.80, SD = 1.056) that property values in areas with WTI have increased. Participants moderately agreed (mean = 3.79, SD = .986) that WTI has positively influenced biodiversity in urban areas. Similarly, they expressed a moderate level of agreement (mean = 3.86, SD = 1.088) that WTI has created valuable habitats for local wildlife. On average, participants moderately agreed (mean = 3.84, SD = 1.014) that urban development features, such as infrastructure design and land use planning, are conducive to WTI. These mean scores and standard deviations provide insights into the participants' perceptions and attitudes regarding the various aspects of WTI and its impacts on urban development.

4.2 Variable measurement

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Table 2: Summary of Variable Items, Means, and Standard Deviations

Variable	Items	Mean	SD
WTI	Wetland technology is effectively integrated into urban development planning.	3.83	1.142
	The level of wetland technology integration has improved over time.	3.90	1.044
	Wetland technology integration is driven by effective stakeholder engagement.	3.83	1.083
	The regulatory framework in place supports and encourages wetland technology integration.		
WQP	Water quality parameters (e.g., nutrient levels, pollutant concentrations) are better in areas with wetland technology integration compared to non-integrated areas.	3.84	1.029
SI	Wetland technology integration positively impacts community engagement in urban development.	3.94	1.043
	Wetland technology integration contributes to improved public health in the community.	3.90	1.082

ECI	Wetland technology integration leads to cost savings in urban development projects.	3.85	1.082
	Property values in areas with wetland technology integration have increased.	3.80	1.056
ENI	Wetland technology integration has positively influenced biodiversity in urban areas.	3.79	.986
	Wetland technology integration has created valuable habitats for local wildlife.	3.86	1.088
UDF	Urban development features, such as infrastructure design and land use planning, are conducive to wetland technology integration.	3.84	1.014

WTI:Wetland Technology Integration, WQP: Water Quality Parameters, SI: Social Impact, ECI: Economic Impact, ENI: Environmental Impact, UDF: Urban development features

4.3 Confirmatory Factor Analysis

The results of the Confirmatory Factor Analysis (CFA) are shown in Table 3. The convergent validity of the WTI variable is supported, with loadings ranging from 0.740 to 0.791. The average loading across all items is 0.76, suggesting that these items are reasonably good indicators of the underlying construct. The internal consistency reliability, as measured by Cronbach’s alpha, is strong at 0.80. The Average Variance Extracted (AVE) is 0.77, indicating that a substantial proportion of the variance in the construct is explained by the items.WQP also demonstrates good convergent validity, with a loading of 0.780 for WQP1. The average loading for WQP is 0.78, indicating that the items are reliable indicators of the construct. The Cronbach’s alpha of 0.85 suggests high internal consistency, and the AVE of 0.78 confirms that the construct is well-represented by the items.The convergent validity of the SI variable is supported, with a strong loading of 0.805 for SI1. The average loading for SI is 0.80, indicating that the items are reliable measures of the construct. The internal consistency reliability, as measured by Cronbach’s alpha, is high at 0.88. The AVE of 0.80 suggests that the items capture a substantial portion of the construct’s variance.ECI exhibits good convergent validity, with a loading of 0.770 for ECI1. The average loading for ECI is 0.77, indicating reliable indicators of the construct. The internal consistency, assessed by Cronbach’s alpha, is strong at 0.86. The AVE of 0.77 confirms that the items represent the construct effectively.ENI1 has a loading of 0.732, demonstrating convergent validity. The average loading for ENIis 0.736, suggesting reasonable reliability. The Cronbach’s alpha is 0.81, indicating good internal consistency. The AVE is 0.74, indicating that the items capture a substantial portion of the construct’s variance.UDF1 has a loading of 0.775, indicating convergent validity. The average loading for UDF is 0.76, suggesting reliable indicators of the construct. The internal consistency, as measured by Cronbach's alpha, is strong at 0.84. The AVE is 0.76, confirming that the items effectively represent the constant.

Variable	**Items**	**Convergent Validity**		**Reliability**	
		Loads	**Load average**	**Cronbach’s alpha**	**AVE**
WTI	WTI1	.791	0.76	0.80	0.77
	WTI2	.752			
	WTI3	.740			
	WTI4	.748			
WQP	WQP1	.780	0.78	0.85	0.78
SI	SI1	.805	0.80	0.88	0.80
	SI2	.793			
ECI	ECI1	.770	0.77	0.86	0.77
	ECI2	.773			
ENI	ENI1	.732	0.74	0.81	0.74
	ENI2	.744			
UDF	UDF1	.775	0.76	0.84	0.76

4.4 Independent sample t-test

Table 4 presents the results of an independent sample t-test comparing the means of WQPs between integrated and non-integrated areas. The independent sample t-test revealed statistically significant differences in certain WQP between integrated and non-integrated areas. The mean WQP1 value in integrated areas (5.62) was significantly lower than that in non-integrated areas (6.84) with a t-value of -2.467 (p = 0.015, two-tailed), indicating that WQP1 is lower in integrated areas. Integrated areas (mean = 8.21) exhibited significantly higher WQP2 values compared to non-integrated areas (mean = 7.45) with a t-value of 3.112 (p = 0.002, two-tailed), suggesting that WQP2 is higher in integrated areas. There was no statistically significant difference in mean WQP3 values between integrated (mean = 6.98) and non-integrated areas (mean = 7.21) as indicated by a non-significant t-value of -0.923 (p = 0.358, two-tailed). Integrated areas (mean = 4.56) showed a lower mean WQP4 value compared to non-integrated areas (mean = 5.32), although this difference was not statistically significant (t-value = -1.871, p = 0.064, two-tailed). The mean WQP5 value in integrated areas (9.78) was significantly higher than that in non-integrated areas (8.93) with a t-value of 2.613 (p = 0.01, two-tailed), indicating that WQP5 is higher in integrated areas.

Table 4: Independent sample t-test to compare the means of WQP between integrated and non-integrated areas.

Variable	Integrated Areas	Non-Integrated Areas	t-value	df	Sig. (2-tailed)
WQP1	5.62	6.84	-2.467	126	0.015
WQP2	8.21	7.45	3.112	134	0.002
WQP3	6.98	7.21	-0.923	120	0.358
WQP4	4.56	5.32	-1.871	143	0.064
WQP5	9.78	8.93	2.613	136	0.01

4.5 Regression analysis

The linear regression outcomes for each dimension of SUD (SI, ECI, ENI) with WTI as the independent variable are shown in Table 5. The constant term in the model is 1.115, which represents the expected SI when WTI is zero. This constant is statistically significant ($p<0.001$). The coefficient for WIT is 0.726, indicating that for each unit increase in WTI, the SI is expected to increase by 0.726 units, holding all other factors constant and the coefficient is highly significant. The R^2 value of 0.500 suggests that 50% of the variance in SI can be explained by the linear relationship with WTI.The model is a good fit for the data, with a significant F-value (F = 293.375, $p < 0.001$).The constant term in the model is 1.099, representing the expected ECI when WTI is zero. This constant is statistically significant ($p < 0.001$).The coefficient for WTI is 0.705, indicating that for each unit increase in WTI, the ECI is expected to increase by 0.705 units, holding all other factors constant. This coefficient is highly significant ($p < 0.001$).The R^2 value of 0.504 suggests that 50.4% of the variance in ECI can be explained by the linear relationship with WTI.The model is a good fit for the data, with a significant F-value (F = 297.627, $p < 0.001$).The constant term in the model is 1.392, representing the expected ENI when WTI is zero. This constant is statistically significant ($p <0.001$). The coefficient for WTI is 0.630, indicating that for each unit increase in WTI, the ENI is expected to increase by 0.630 units, holding all other factors constant. This coefficient is highly significant ($p < 0.001$).The R^2value of 0.404 suggests that 40.4% of the variance in ENI can be explained by the linear relationship with WTI.The model is a good fit for the data, with a significant F-value (F = 198.889, $p < 0.001$).

Table 5: Regression models for the dimensions of sustainable urban development with Wetland Technology Integration (WTI)

Regression Model for SI				
	Coefficient	**Std. Error**	**t-value**	**Sig.**
(Constant)	1.115	0.169	6.604	0
WTI	0.726	0.042	17.128	0
R Square: 0.500, Adjusted R Square: 0.499, Std. Error of the Estimate: 0.70573, F-value: 293.375, Sig. F Change: 0.000				

Regression Model for ECI

	Coefficient	Std. Error	t-value	Sig.
(Constant)	1.099	0.163	6.755	0
WTI	0.705	0.041	17.252	0

R Square: 0.504, Adjusted R Square: 0.502, Std. Error of the Estimate: 0.68037, F-value: 297.627, Sig. F Change: 0.000

Regression Model for ENI

	Coefficient	Std. Error	t-value	Sig.
(Constant)	1.392	0.178	7.835	0
WTI	0.63	0.045	14.103	0

R Square: 0.404, Adjusted R Square: 0.402, Std. Error of the Estimate: 0.74281, F-value: 198.889, Sig. F Change: 0.000

5. DISCUSSIONS

The first objective aims to assess the efficiency of integrating wetland technology in urban development projects to achieve sustainable outcomes. Numerous studies have highlighted the positive impact of wetland technology on water quality improvement (Hassett & Steinman, 2022; Li et al., 2022). The significant differences observed in WQPs (WQP2 and WQP5) between integrated and non-integrated areas, as indicated by the t-test results, support the alternative hypothesis (H1). The integration of wetland technology contributes to improved water quality, which is a fundamental aspect of urban sustainability. Identifying obstacles and opportunities for integrating wetland technology into urban development projects is crucial for overcoming challenges and maximizing benefits. Potential obstacles may include land use conflicts, regulatory hurdles, and limited public awareness (Rogerson et al., 2021). Opportunities may arise from recognizing the ecological and socio-economic benefits of wetlands (Díaz-Pinzón et al., 2022). A comprehensive analysis of these factors can inform strategies to promote wetland integration. The third objective involves assessing the influence of wetland technology on the social, economic, and environmental dimensions of SUD. The regression models presented earlier provide evidence of a statistically significant and positive relationship between WTI and dimensions of SUD (SI, ECI, ENI). These findings support the alternative hypothesis (H2) that WTI positively influences these aspects. The positive impact of wetlands on recreation, aesthetics, and community well-being can enhance the social aspects of urban development (Rogerson et al., 2021). Wetlands offer economic benefits through tourism, flood control, and increased property values (Díaz-Pinzón et al., 2022). This aligns with the positive relationship found between WTI and ECI. Wetland ecosystems contribute to biodiversity, carbon sequestration, and resilience to climate change (Candry et al., 2023). The positive relationship between WTI and ENI suggests that integrating wetland technology enhances environmental sustainability.

6. CONCLUSION

This study examined how WTI into SUD and its effects on sustainable urbanisation. The goals of the study were to assess the improvement of water quality, identify challenges and opportunities, assess the effects on the social, economic, and environmental spheres, and develop a framework for successful integration. The study's conclusions offer insightful information about the function of wetland technology in promoting sustainability in urban settings. Several important conclusions emerged from the analysis. In comparison to non-integrated areas, the WTI significantly improved some WQPs, most notably WQP2 and WQP5. This outcome underscores the potential of wetlands as natural filters to enhance water quality in urban settings. The identification of obstacles, such as land use conflicts and regulatory challenges, highlights the need for proactive strategies to overcome these hurdles. Simultaneously, recognizing opportunities, such as the ecological and economic benefits of wetlands, can inform decision-making processes. The regression models demonstrated a statistically significant and positive relationship between WTI and dimensions of SUD (SI, ECI, ENI). This suggests that the integration of wetland technology positively influences social, economic, and environmental aspects of urban development.

It is important to recognise the limitations of this study even though it offers insightful information. Because the results are based on artificial data, actual-world situations might differ greatly. It would be more practical to apply the study if it used actual data from various urban environments. The study's findings might only apply to particular geographical areas or situations. Considering variations in environmental conditions and regulatory frameworks, extrapolating the results to various locations should be done with caution. The study primarily focuses on short-term impacts. Evaluating the long-term sustainability and resilience of WTI would require extended monitoring and research. While the framework suggests community engagement, the extent to which communities are involved and the challenges associated with community buy-in are complex and context-dependent aspects that warrant further investigation. This study highlights the usefulness of wetland technology in promoting socioeconomic advantages, enhancing environmental resilience, and improving water quality in urban sustainability. Wetland technology must, however, be implemented practically in urban areas, which necessitates ongoing community involvement and careful consideration of site-specific factors. To improve our knowledge of the complex relationship between wetland technology and SUD, future research should build on these findings and address the limitations.

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