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## FROM BROADCAST TO BROADBAND: OTT PLATFORMS AND THE TRANSFORMATION OF HOME ENTERTAINMENT ECOSYSTEMS

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### ABSTRACT

*The evolution of home entertainment from broadcast-based television to broadband-enabled streaming platforms constitutes a fundamental transformation in contemporary media ecosystems. Traditional broadcasting operated within a linear, schedule-driven framework characterized by centralized content distribution and limited audience agency. In contrast, Over-The-Top (OTT) platforms—such as Netflix, Amazon Prime Video, and Disney+—deliver content via internet infrastructures, enabling on-demand access, personalized viewing, and multi-device consumption. This transition reflects broader processes of digital convergence, wherein distinctions between media formats, distribution channels, and user roles are increasingly blurred.*

**KEYWORDS:** *Distribution, Contemporary, Consumption, Convergence, Personalized.*

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### INTRODUCTION

The evolution of home entertainment from broadcast-based television to broadband-enabled streaming platforms constitutes a fundamental transformation in contemporary media ecosystems. Traditional broadcasting operated within a linear, schedule-driven framework characterized by centralized content distribution and limited audience agency. In contrast, Over-The-Top (OTT) platforms—such as Netflix, Amazon Prime Video, and Disney+—deliver content via internet infrastructures, enabling on-demand access, personalized viewing, and multi-device consumption. This transition reflects broader processes of digital convergence, wherein distinctions between media formats, distribution channels, and user roles are increasingly blurred.

Scholarly discourse situates this shift within the framework of convergence culture, where media consumption becomes participatory, interactive, and dispersed across platforms. According to **Henry Jenkins (2006)**, convergence is not merely technological but also cultural, involving the

active migration of audiences across multiple media environments. OTT platforms exemplify this paradigm by integrating content libraries, recommendation systems, and user interfaces into cohesive digital ecosystems that prioritize user engagement over passive reception. Consequently, audiences are no longer confined to predetermined schedules but exercise temporal autonomy through practices such as binge-watching and selective viewing (Jenner, 2018).

From an economic perspective, the rise of OTT platforms aligns with the logic of platform capitalism, wherein digital intermediaries leverage data analytics and algorithmic infrastructures to mediate content distribution and consumption. **Nick Srnicek (2017)** argues that platforms function as data-driven entities that extract, analyze, and monetize user behavior, thereby reshaping traditional media value chains. In this context, OTT services utilize algorithmic recommendation systems to curate personalized content feeds, influencing audience preferences while simultaneously reinforcing platform dependency. This dual dynamic of empowerment and control underscores the complexity of contemporary media consumption.

Moreover, the transition from broadcast to broadband has significant implications for domestic viewing practices. Historically, television functioned as a collective medium, fostering shared family experiences within the household. However, the proliferation of personal devices and individualized accounts has led to the fragmentation of viewing patterns, with users engaging in solitary and asynchronous consumption (**Lotz, 2017**). This transformation not only alters social interactions within the home but also redefines the cultural significance of television as a communal activity.

Despite extensive research on digital media and streaming technologies, there remains a need for qualitative investigations that capture the lived experiences of users navigating this evolving ecosystem, particularly in emerging markets such as India. The rapid expansion of internet penetration and mobile streaming has accelerated OTT adoption, creating hybrid consumption environments where traditional broadcast media coexist with digital platforms. Understanding how individuals negotiate these overlapping systems is essential for developing a nuanced account of media transformation.

This study, therefore, examines how OTT platforms reconfigure home entertainment ecosystems by analyzing changes in viewing practices, audience agency, and platform-mediated content consumption. It advances the argument that the shift from broadcast to broadband is not a linear replacement but a complex reorganization of media infrastructures, shaped by technological innovation, economic imperatives, and evolving cultural practices.

## **STATEMENT OF PROBLEM**

The rapid expansion of Over-The-Top (OTT) platforms such as Netflix, Amazon Prime Video, and Disney+ has significantly disrupted traditional broadcast-based home entertainment systems; however, the nature and implications of this transformation remain insufficiently understood at the level of lived experience. Existing scholarship has largely emphasized technological advancement and market growth, with limited qualitative attention to how individuals and households interpret and negotiate the coexistence of broadcast and broadband media within everyday contexts. Moreover, while OTT platforms promote user autonomy through on-demand access, their reliance on algorithmic recommendation systems introduces new forms of structured consumption that may constrain choice and shape cultural exposure. This tension

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between perceived freedom and platform-mediated control, coupled with the shift from collective television viewing to individualized, multi-device engagement, generates complex changes in domestic media practices that are not adequately captured in current research, particularly within emerging markets such as India. Consequently, there is a critical need for in-depth qualitative inquiry to examine how OTT platforms reconfigure home entertainment ecosystems across technological, cultural, and social dimensions.

## REVIEW OF LITERATURE

Recent scholarship has increasingly examined the transformation of media consumption through OTT platforms using diverse methodological and theoretical approaches. Amanda D. **Lotz (2021)** investigated the evolution of internet-distributed television and argued that OTT platforms fundamentally restructure audience engagement by prioritizing subscriber retention over mass viewership metrics. Using qualitative industry analysis and audience behavior data, the study demonstrated that platform-driven content strategies emphasize niche targeting and long-term engagement, thereby altering traditional programming logics and reinforcing the shift toward individualized consumption patterns.

**Ramon Lobato (2022)** explored the globalization of streaming services with a focus on regional content flows and platform localization strategies. Through comparative case analysis, the study highlighted how OTT platforms adapt to local cultural contexts while maintaining global distribution infrastructures. The findings indicated that algorithmic recommendation systems play a crucial role in mediating cultural visibility, often privileging platform-generated content hierarchies, thereby reshaping audience exposure and reinforcing asymmetrical power structures within global media ecosystems.

In a qualitative audience study, **Mareike Jenner (2023)** examined binge-watching practices and temporal autonomy in OTT consumption. Drawing on in-depth interviews, the research identified that users perceive binge-watching as both a form of leisure control and an outcome of platform design. The study concluded that while OTT platforms enhance viewer autonomy, they simultaneously encourage prolonged engagement through interface design and narrative structuring, thereby embedding users within continuous consumption cycles.

**David B. Nieborg and Thomas Poell (2024)** analyzed platformization within the cultural industries, emphasizing the role of datafication and algorithmic governance in shaping media production and distribution. Using a political economy framework, the study demonstrated that OTT platforms exert significant control over content visibility, monetization, and audience access. Their findings underscored that platform infrastructures transform creative labor and institutional practices, leading to increased dependency on proprietary algorithms and performance metrics.

Focusing on emerging markets, **Usha M. Rodrigues (2025)** conducted a qualitative investigation into OTT adoption in India, utilizing semi-structured interviews across urban households. The study revealed hybrid consumption patterns in which traditional television and OTT platforms coexist, with users strategically navigating between them based on cost, convenience, and content preferences. It further highlighted the role of mobile-first streaming and regional language content in accelerating OTT penetration, while also identifying persistent digital divides affecting accessibility and user experience.

These studies indicate that OTT platforms not only transform technological infrastructures but also reconfigure cultural practices, audience agency, and media economies. However, a critical gap remains in deeply contextualized qualitative analyses that integrate household-level experiences with broader theoretical frameworks, particularly within rapidly evolving media environments.

## RESEARCH GAP

Despite the expanding body of scholarship on OTT platforms such as Netflix and Amazon Prime Video, existing research remains predominantly oriented toward quantitative assessments of market growth, subscription patterns, and technological innovation, with comparatively limited emphasis on qualitative, experience-centered analyses of media consumption. Current studies insufficiently address how users negotiate hybrid entertainment environments in which traditional broadcast television coexists with algorithm-driven streaming systems. Furthermore, the experiential dimensions of algorithmic recommendation—particularly the tension between perceived user autonomy and platform-mediated control—remain underexplored within household contexts. There is also a notable lack of region-specific qualitative research focusing on emerging markets such as India, where rapid digital adoption intersects with socio-cultural diversity, linguistic plurality, and uneven access to technology. Additionally, limited attention has been given to the transformation of domestic viewing practices, including the shift from collective to individualized consumption and its implications for social interaction within households. Consequently, a critical gap exists in developing a contextually grounded, theoretically integrated qualitative understanding of how OTT platforms reconfigure home entertainment ecosystems across technological, cultural, and social dimensions.

## OBJECTIVES OF THE STUDY

1. To analyze the transformation of household viewing practices from traditional broadcast television to on-demand OTT consumption through platforms such as Netflix and Amazon Prime Video.
2. To examine the role of algorithmic recommendation systems in shaping audience choice, perceived autonomy, and content consumption patterns within OTT environments.
3. To investigate the shift from collective to individualized viewing practices and its implications for domestic media interactions and home entertainment ecosystems.

## PROPOSITIONS OF THE STUDY

Although qualitative research is typically exploratory, the study formulates the following analytically grounded propositions to guide inquiry into OTT-mediated transformations:

**H1:** The adoption of OTT platforms such as Netflix and Amazon Prime Video is associated with a significant shift from scheduled, collective television viewing to individualized, on-demand consumption practices within households.

**H2:** Algorithmic recommendation systems embedded within OTT platforms significantly influence user content choices, thereby shaping viewing behavior despite the perception of increased audience autonomy.

**H3:** The integration of OTT platforms into domestic media environments contributes to the fragmentation of shared viewing experiences, altering traditional patterns of family-based media engagement.

## **METHODOLOGY**

This study adopts a qualitative, exploratory research design to examine how OTT platforms such as Netflix and Amazon Prime Video reconfigure home entertainment ecosystems. A qualitative approach is appropriate as the research seeks to capture subjective experiences, interpretive meanings, and socially embedded media practices that cannot be adequately understood through quantitative measures.

Data were collected using semi-structured, in-depth interviews, allowing participants to articulate their viewing behaviors, preferences, and perceptions of platform-mediated consumption in a flexible yet guided manner. The study employed purposive sampling to select 15–25 participants from urban households, ensuring diversity in age, gender, occupation, and media usage patterns. This sampling strategy facilitated the inclusion of information-rich cases capable of providing nuanced insights into evolving entertainment practices. Data collection continued until thematic saturation was achieved, ensuring analytical adequacy rather than numerical representation.

All interviews were conducted either in person or via digital communication platforms, recorded with informed consent, and transcribed verbatim for analysis. The data were analyzed using thematic analysis following the framework proposed by Braun and Clarke, involving systematic stages of familiarization, open coding, category development, and theme generation. An inductive coding approach was adopted to allow patterns to emerge organically from participant narratives, while also aligning with the study's theoretical framework on platformization and media convergence.

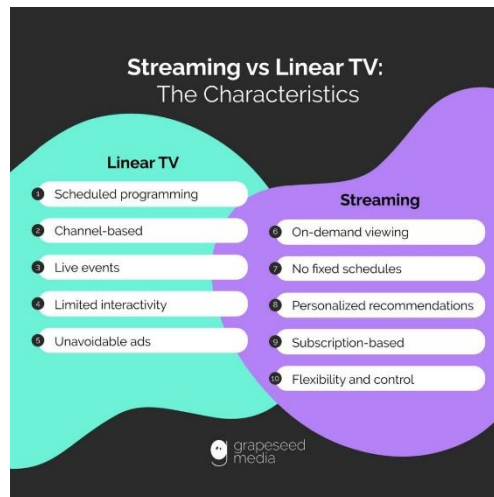
To ensure methodological rigor, the study incorporated strategies such as triangulation through comparison of participant responses, member checking to validate interpretations, and reflexivity to minimize researcher bias. Ethical considerations were strictly maintained, including voluntary participation, confidentiality, and anonymization of personal data. This methodological approach enables a comprehensive and context-sensitive understanding of how OTT platforms transform home entertainment ecosystems at the level of everyday experience.

## **RESULTS AND FINDINGS**

### ***Objective 1: Transformation of Household Viewing Practices***

**Proposition 1:** The adoption of OTT platforms such as Netflix and Amazon Prime Video is associated with a significant shift from scheduled, collective television viewing to individualized, on-demand consumption practices within households.

**Figure 1 :Conceptual Representation of the Shift from Linear Broadcast Viewing to On-Demand OTT Consumption**



**Table 1 :Thematic Analysis of Changing Household Viewing Practices in the OTT Era**

Theme	Key Findings	Interpretation
Shift to On-Demand Viewing	Majority preferred flexible, anytime viewing over fixed schedules	Indicates decline of linear broadcast dominance
Binge-Watching Behavior	Frequent consumption of multiple episodes in one sitting	Reflects temporal autonomy and immersive engagement
Hybrid Consumption	Continued use of TV for news/sports alongside OTT	Demonstrates coexistence rather than complete replacement

Table 1 presents a thematic synthesis of the transformation in household viewing practices associated with the adoption of OTT platforms such as Netflix and Amazon Prime Video. The findings indicate a marked transition from rigid, schedule-bound television consumption to flexible, on-demand viewing, reflecting a broader decline in the dominance of linear broadcast models. Participants consistently emphasized the value of temporal autonomy, enabling them to access content according to individual convenience rather than institutional programming schedules. Furthermore, the prevalence of binge-watching behavior underscores a shift toward immersive and continuous engagement, facilitated by platform design and content structuring. Despite these changes, the persistence of traditional television for specific genres such as news and live sports reveals a hybrid consumption pattern, wherein broadcast and broadband media coexist within the domestic environment. Collectively, these findings demonstrate that the transformation of viewing practices is not characterized by outright replacement but by a negotiated integration of new and traditional media forms.

The findings for the objective 1 explains that the proposition is supported. The findings clearly demonstrate a shift from scheduled, collective viewing to individualized, on-demand consumption, confirming the transformation of viewing practices.

**Objective 2: Influence of Algorithmic Recommendation Systems**

**Proposition 2** :Algorithmic recommendation systems embedded within OTT platforms significantly influence user content choices, thereby shaping viewing behavior despite the perception of increased audience autonomy.

**Figure 2 :Conceptual Model of Algorithmic Recommendation Systems Influencing OTT Content Consumption**



**Table 2: Thematic Analysis of Algorithmic Recommendation Influence on OTT Content Consumption**

Theme	Key Findings	Interpretation
Dependence on Recommendations	Users relied heavily on suggested content	Algorithms act as primary gatekeepers of content discovery
Perceived Convenience	Reduced search effort and quicker decision-making	Enhances user satisfaction and platform engagement
Content Narrowing	Repetitive and limited genre exposure	Suggests algorithmic bias and potential cultural limitation

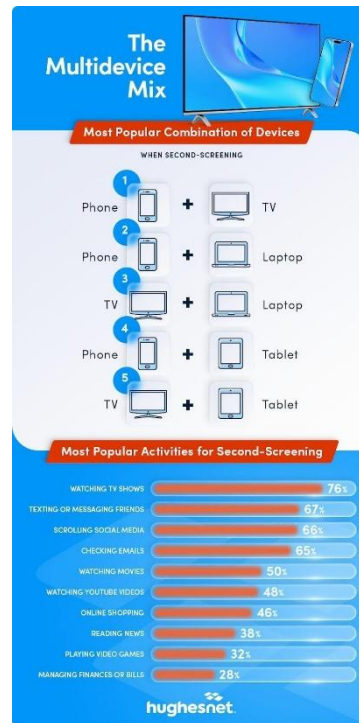
Table 2 delineates the role of algorithmic recommendation systems in shaping user engagement within OTT platforms such as Netflix and Amazon Prime Video. The findings reveal a substantial dependence on platform-generated suggestions, indicating that algorithms function as primary gatekeepers in the content discovery process. This reliance reduces the need for active search, thereby enhancing perceived convenience and expediting decision-making, which in turn contributes to sustained user engagement and platform retention. However, the data also highlight a critical limitation: the tendency of recommendation systems to reinforce repetitive viewing patterns, leading to narrowed genre exposure. This phenomenon suggests the presence of algorithmic bias, wherein user preferences are continually looped, potentially restricting cultural diversity and limiting exploratory consumption. Overall, the table illustrates the dual nature of algorithmic mediation, simultaneously facilitating ease of access while constraining the breadth of content engagement.

The results reveal that the above proposition is supported with nuances. While users perceive autonomy, the findings indicate strong reliance on algorithmic recommendations, suggesting that autonomy is structured rather than absolute.

**Objective 3: Shift from Collective to Individualized Viewing**

**Proposition 3 :**The integration of OTT platforms into domestic media environments contributes to the fragmentation of shared viewing experiences, altering traditional patterns of family-based media engagement.

**Figure 3 :Illustration of the Transition from Collective Family Viewing to Individualized Multi-Device Consumption**



**Table 3: Thematic Analysis of Individualized and Collective Viewing Dynamics in OTT Consumption**

Theme	Key Findings	Interpretation
Individual Device Usage	Increased viewing on smartphones and personal devices	Indicates personalization and portability of media
Decline in Family Viewing	Reduced shared viewing time among family members	Weakening of collective cultural experiences
Selective Co-Viewing	Occasional shared viewing for major releases	Suggests partial retention of communal practices

Table 3 examines the transformation of domestic viewing patterns in the context of OTT platform adoption, particularly through services such as Netflix and Amazon Prime Video. The findings indicate a substantial increase in individual device usage, with participants predominantly accessing content through smartphones and personal screens, reflecting enhanced personalization and portability of media consumption. This shift has contributed to a noticeable decline in shared family viewing, thereby weakening traditional forms of collective cultural engagement within the household. However, the persistence of selective co-viewing—especially for highly anticipated or culturally significant content—suggests that communal viewing practices have not entirely disappeared but have been restructured into more occasional and intentional forms. The results demonstrate a transition toward individualized media engagement, accompanied by a partial yet meaningful retention of collective viewing experiences within evolving home entertainment ecosystems.

Based on the findings, it is informed that the proposition is partially supported. Although fragmentation of family viewing is evident, the persistence of selective co-viewing indicates that collective practices have not been eliminated.

### **MAJOR FINDINGS**

The study reveals that the transition from broadcast television to OTT platforms such as Netflix and Amazon Prime Video constitutes a structural reconfiguration of home entertainment rather than a simple technological substitution. First, viewing practices have shifted decisively toward on-demand, user-controlled consumption, with binge-watching emerging as a normalized mode of engagement. This reflects a broader reorientation from schedule-bound viewing to temporal autonomy, enabling audiences to curate their own media routines.

Second, algorithmic recommendation systems have become central to content discovery, significantly shaping user preferences and engagement patterns. While participants perceive these systems as enhancing convenience and efficiency, they also contribute to constrained exposure through repetitive suggestions, indicating a tension between perceived choice and algorithmic control.

Third, domestic viewing dynamics have undergone notable transformation, with individualized consumption via personal devices increasingly replacing collective family viewing. This fragmentation of shared experiences suggests a redefinition of the social function of television within households, although selective co-viewing for specific content persists, indicating partial continuity of communal practices.

Finally, the findings highlight the emergence of a hybrid media ecosystem in which traditional broadcast television continues to coexist with OTT platforms, particularly for live and event-based content. Collectively, these results demonstrate that OTT adoption reshapes technological access, audience agency, and cultural practices simultaneously, producing a complex and negotiated media environment rather than a complete displacement of earlier systems.

### **DISCUSSION**

The findings of this study substantiate the argument that the transition from broadcast to broadband constitutes a systemic reconfiguration of home entertainment ecosystems rather than a linear process of technological replacement. The observed shift toward on-demand viewing aligns with theoretical perspectives on media convergence, wherein audiences exercise increased temporal flexibility and control over content selection. However, this autonomy is not absolute; rather, it is embedded within platform architectures governed by algorithmic recommendation systems. In this regard, the findings corroborate the notion of platformization, which posits that digital platforms such as Netflix and Amazon Prime Video simultaneously enable and structure user behavior through data-driven interfaces.

The prevalence of binge-watching further illustrates the reorganization of temporal engagement with media. While participants perceive binge-watching as a manifestation of personal choice and leisure optimization, it also reflects the strategic design of serialized content and auto-play functionalities that encourage prolonged consumption. This duality supports existing arguments within the political economy of media, particularly those advanced by Nick Srnicek, who emphasizes that platform economies are oriented toward maximizing user retention and engagement through continuous interaction. Thus, user agency operates within a framework that subtly directs attention and consumption patterns.

Moreover, the findings on algorithmic recommendation systems highlight a critical tension between convenience and constraint. Although participants acknowledge the efficiency of personalized content suggestions, the tendency toward repetitive recommendations suggests the formation of “filter bubbles,” limiting exposure to diverse genres and perspectives. This observation extends prior scholarship by demonstrating that algorithmic governance not only shapes individual preferences but also has broader cultural implications, including the potential homogenization of media consumption.

The transformation of domestic viewing practices provides further insight into the socio-cultural impact of OTT adoption. The shift from collective television viewing to individualized, multi-device consumption reflects broader processes of media privatization and personalization. This fragmentation of viewing experiences challenges traditional notions of television as a shared cultural medium, leading to reduced synchronous engagement within households. Nevertheless, the persistence of selective co-viewing indicates that communal practices are not entirely displaced but are instead reconstituted around specific content events, suggesting a hybridization of social viewing patterns.

Importantly, the continued relevance of traditional broadcast television for live content such as news and sports underscores the coexistence of legacy and digital media systems. This hybrid consumption model complicates deterministic narratives of digital disruption by demonstrating that older media forms retain functional and cultural significance within contemporary ecosystems. Such findings are particularly salient in emerging markets, where infrastructural variability and diverse audience preferences contribute to differentiated patterns of media adoption.

In analytical terms, the study advances the understanding of OTT platforms by integrating user-level experiences with broader theoretical frameworks of convergence, platformization, and media economics. To enhance scholarly rigor, future discussions could further incorporate comparative analysis across demographic segments and include longitudinal perspectives to capture evolving consumption trajectories. Overall, the discussion affirms that OTT platforms reshape not only how content is delivered but also how it is experienced, interpreted, and socially embedded within everyday life.

## **CONCLUSION**

The study concludes that the transition from broadcast television to OTT platforms such as Netflix and Amazon Prime Video constitutes a fundamental reconfiguration of home entertainment ecosystems, characterized by a shift toward on-demand, personalized, and multi-device consumption. While this transformation enhances temporal autonomy and user engagement, it simultaneously embeds viewers within algorithmically structured environments that shape content discovery and limit exposure. The findings further indicate a redefinition of domestic viewing practices, marked by the decline of collective television experiences and the rise of individualized consumption, alongside the continued coexistence of traditional broadcast media within a hybrid ecosystem. However, the study is constrained by its qualitative design and limited sample size, which restrict generalizability, as well as its urban-centric focus and reliance on self-reported data, which may introduce bias. Additionally, the cross-sectional nature of the research limits the ability to capture evolving consumption patterns over time, and the absence of industry-level data restricts a more comprehensive analysis of platform dynamics. Despite these limitations, the study offers a contextually grounded and theoretically informed understanding of

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the complex interplay between technology, audience behavior, and media systems in the digital era.

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## AI-DRIVEN DIGITAL TRANSFORMATION AND CONSUMER BEHAVIOUR IN ONLINE SHOPPING

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### ABSTRACT

*Artificial intelligence (AI) is rapidly altering the digital marketing environment, redefining the way consumers engage with online purchasing platforms. AI-driven technologies, including predictive analytics, chatbots, recommendation systems, and personalized advertising, have had a substantial impact on consumer decision-making processes. The purpose of this investigation is to investigate the influence of AI-driven digital transformation on consumer behavior in online purchasing environments. By synthesising recent literature and theoretical frameworks, the paper explores how AI enhances personalisation, trust, engagement, and purchase intent among online consumers. The study adopts a conceptual research approach, drawing on recent empirical evidence to build a comprehensive understanding of AI-driven consumer interactions. The findings suggest that AI-driven digital transformation not only improves user experience but also reshapes consumer expectations, decision-making patterns, and brand relationships. This paper adds to the expanding body of research on AI in digital marketing by providing insights into emerging trends, key challenges, and future research directions related to the analysis of AI-driven consumer behaviour.*

**KEYWORDS:** *Artificial Intelligence, Digital Transformation, Consumer Behaviour, Online Shopping, E-Commerce, Ai Marketing.*

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### INTRODUCTION

The rapid expansion of digital technologies has profoundly reshaped the global retail environment, making online shopping one of the dominant modes of consumer purchasing (Kumar, 2021; Verhoef, 2015). In recent years, Artificial Intelligence (AI) has become a major catalyst for digital transformation across multiple industries, especially within digital marketing and e-commerce (Huang & Rust, 2021; Davenport, 2020). AI-enabled systems allow organisations to process large volumes of data, anticipate consumer preferences, automate

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customer interactions, and create highly personalised experiences, thus reshaping traditional marketing practices (**Chatterjee, 2021; Jarek & Mazurek, 2019**).

AI-driven digital transformation goes beyond mere technological advancement; it has important behavioural implications as well. Modern consumers increasingly interact with intelligent systems, such as recommendation algorithms, voice-enabled assistants, chatbots, and AI-based search platforms, which influence their purchasing journeys (**Kaplan & Haenlein, 2019; Huang & Rust, 2021**). These technologies play a crucial role in shaping how consumers identify products, compare options, and ultimately make purchase decisions (**Grewal, 2021**). As a result, examining the relationship between AI and consumer behaviour has become highly relevant for both academic research and industry applications (**Puntoni, 2021**).

This study seeks to examine how AI-enabled digital transformation influences consumer behaviour in online shopping environments. By analysing recent advancements in AI-powered digital marketing, the paper offers a comprehensive understanding of how intelligent technologies influence consumer engagement, trust formation, and purchase intentions (**Dwivedi, 2021; Huang & Rust, 2021**).

## Research Objectives

1. To analyse the role of AI in facilitating digital transformation within online shopping environments.
2. To analyse how AI-powered digital marketing influences consumer behaviour.
3. To explore the impact of AI on consumer trust, engagement, and purchase intention.
4. To identify emerging trends and challenges in AI-driven consumer ecosystems.

## Research Methodology

This study employs a conceptual research design, supported by a comprehensive review of recent literature drawn from peer-reviewed journals, conference proceedings, and major scholarly databases such as Scopus, Web of Science, and Google Scholar.

## Literature Review

### AI and Digital Transformation

AI-driven digital transformation can be defined as the incorporation of intelligent technologies into organisational processes to improve operational efficiency, deliver personalised experiences, and enable data-driven decision making (**Verhoef, 2021**). By utilising AI, companies can analyse real-time consumer data, automate customer interactions, and generate predictive insights that guide strategic actions. Research indicates that organisations embracing AI-led transformation experience higher levels of customer engagement and greater effectiveness in their marketing initiatives (**Bughin, 2019**).

Recent research shows that the adoption of artificial intelligence (AI) in e-commerce platforms is increasing rapidly, largely due to advancements in machine learning, natural language processing, and big data analytics (**Dwivedi, 2023**). These technological developments allow organisations to create dynamic and intelligent marketing systems that continuously adapt to changing consumer behaviour patterns.

### **AI in Digital Marketing**

Artificial Intelligence (AI) has substantially reshaped digital marketing by enabling greater automation, enhanced personalisation, and more accurate predictive targeting strategies. AI-driven recommendation systems, widely used by platforms such as Amazon and Netflix, have had a strong impact on consumer engagement and purchasing behaviour (**Gentsch, 2019**). The provision of personalised content enhances its relevance for users, resulting in higher conversion rates and greater customer satisfaction.

Another significant application of AI in digital marketing is the deployment of chatbots and virtual assistants, which enable real-time customer engagement and provide instant support (**Huang & Rust, 2021**). These technologies enhance responsiveness while reducing operational costs, thereby improving the overall customer experience and strengthening brand loyalty.

Additionally, predictive analytics allows marketers to anticipate consumer preferences and design targeted campaigns accordingly. Empirical studies indicate that predictive marketing strategies play a significant role in enhancing purchase intentions and fostering long-term customer retention (**Kumar, 2020**).

### **Consumer Behaviour in Online Shopping**

Consumer behaviour in digital environments is influenced by various factors, including trust, perceived usefulness, convenience, and the level of personalisation provided by online platforms (**Gefen, 2003**). The Technology Acceptance Model (TAM) and the Unified Theory of Acceptance and Use of Technology (UTAUT) have been extensively applied in prior studies to explain patterns of technology adoption and usage in digital environments.

In online shopping, consumer behaviour is increasingly shaped by digital stimuli such as customer reviews, targeted advertisements, and algorithm-based recommendations. These digital cues help consumers reduce perceived risks and make more informed evaluations regarding product reliability and credibility (**Lemon & Verhoef, 2016**).

### **AI and Consumer Behaviour**

Recent research indicates that artificial intelligence (AI) significantly reshapes consumer decision-making by serving as an intelligent intermediary between consumers and products (**Davenport, 2020**). AI-enabled personalisation increases the perceived relevance of content and product offerings, thereby influencing both the cognitive and emotional responses of consumers throughout the decision-making process.

Nevertheless, the growing adoption of AI has generated concerns related to data privacy, algorithmic bias, and the possible reduction of individual decision-making autonomy (**Martin & Murphy, 2017**). Within this context, trust plays a pivotal role in the acceptance of AI. Consumers are more inclined to use AI-based platforms when their transparency and reliability are clearly evident.

Moreover, AI fosters higher levels of consumer engagement by facilitating interactive and immersive experiences, which help to strengthen brand relationships (**Huang & Rust, 2021**). This transition from purely transactional interactions to more experience-oriented forms of consumption underscores the transformative influence of AI on modern consumer behaviour.

### AI-Led Digital Transformation in Online Shopping Platforms

Artificial Intelligence (AI) has emerged as a key driver in reshaping the operations and ongoing development of online shopping platforms. Unlike earlier stages of digital transformation that focused mainly on automation and connectivity, the current phase is increasingly driven by intelligent technologies. AI allows online platforms to analyse large amounts of user data, predict behavioural patterns, and provide adaptive, responsive shopping experiences. Consequently, online retail is transitioning from a static, transaction-oriented model to a more dynamic and data-driven ecosystem (Verhoef, 2021).

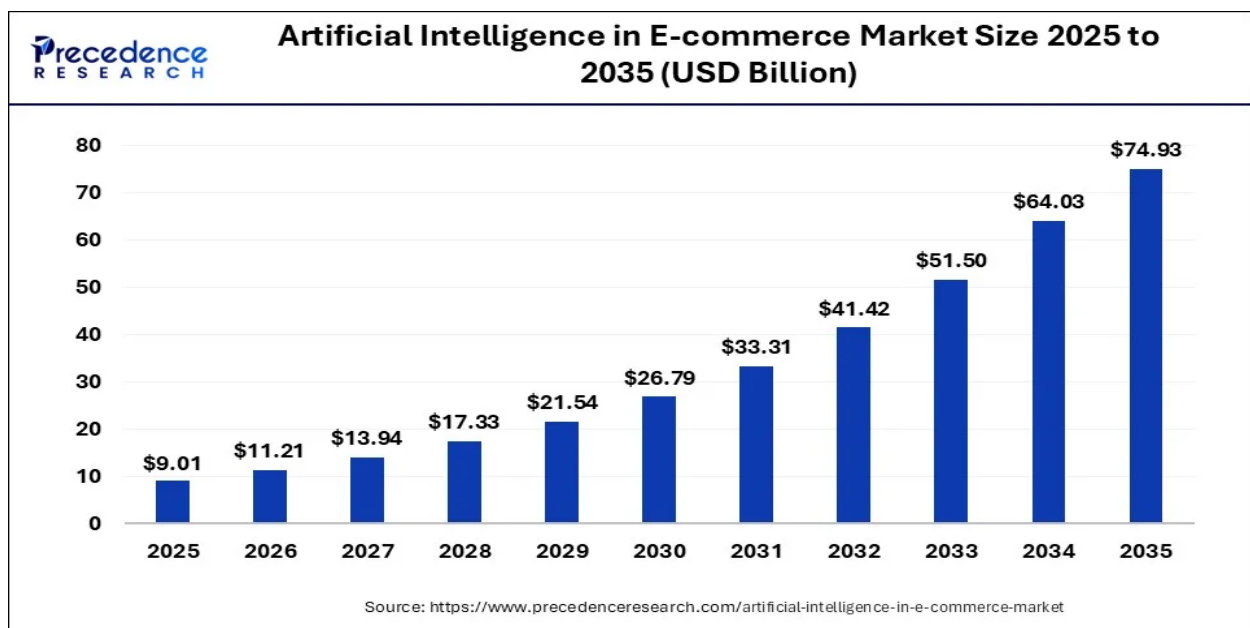
#### Expansion of AI Adoption in Online Shopping

The increasing integration of Artificial Intelligence into online shopping is evident from rising global adoption patterns. Industry analyses indicate that AI-driven functionalities such as intelligent recommendations, virtual assistants, and automated customer support have become standard features across many leading e-commerce platforms.

Empirical shopping data further highlights the expanding influence of AI on consumer behaviour. AI-supported online shopping events have generated substantial sales volumes, while user traffic originating from AI-powered shopping tools has shown significant growth in recent years.

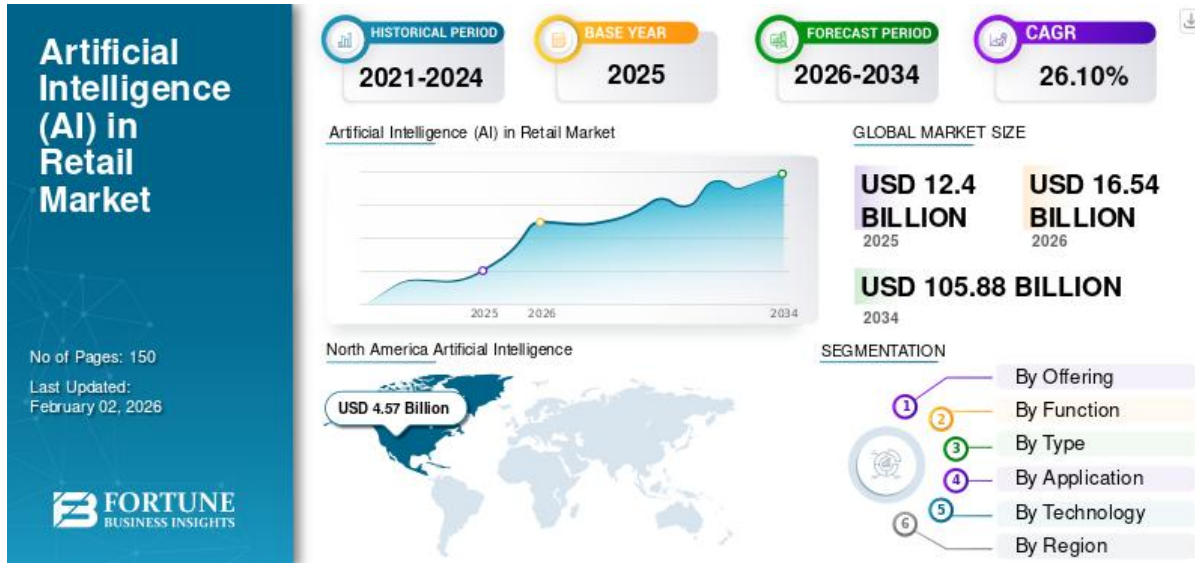
Collectively, these developments suggest that AI is rapidly evolving into a core structural element of online shopping ecosystems rather than merely serving as an additional technological enhancement.

Recent market evaluations indicate that the global AI-enabled online shopping ecosystem was valued at approximately USD 14.03 billion in 2025 and is projected to grow substantially in the years ahead. Estimates suggest that the market may reach nearly USD 70–75 billion by 2035, reflecting a compound annual growth rate (CAGR) of about 17.60% over the period 2026–2035. These forecasts highlight the increasing strategic importance of Artificial Intelligence in shaping the future of online consumer environments.



### AI Adoption Growth Rate in Online Shopping

The global market for Artificial Intelligence (AI) in the retail sector was valued at about USD 12.40 billion in 2025 and is expected to grow considerably during the forecast period. Projections suggest that the market will increase from nearly USD 16.54 billion in 2026 to around USD 105.88 billion by 2034, representing a compound annual growth rate (CAGR) of approximately 26.10%. From a regional perspective, North America held the largest share of the global market in 2025, accounting for about 36.90%. Within this region, the United States is projected to record strong growth, with the AI retail market expected to reach an estimated value of USD 17.76 billion by 2032.

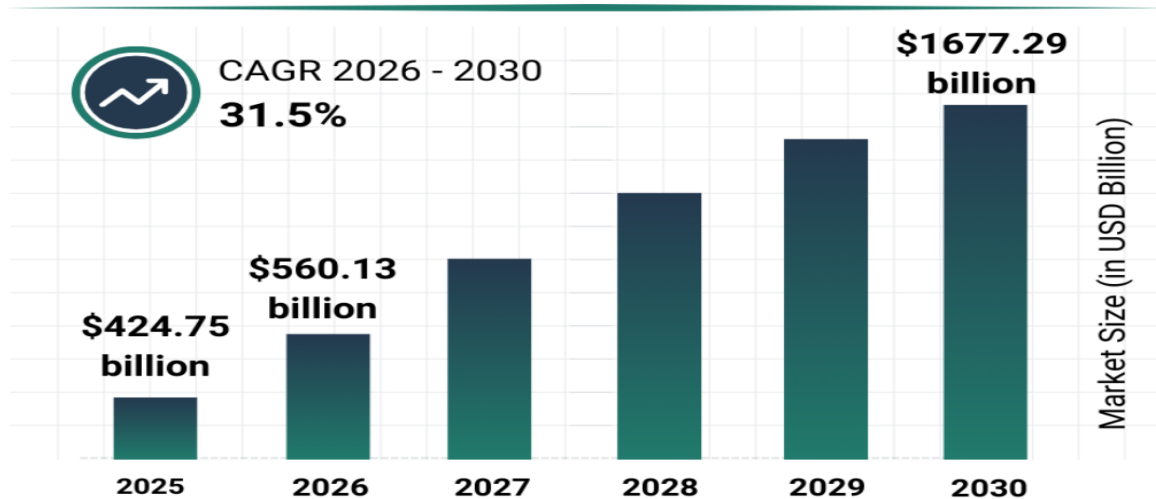


### Artificial Intelligence (AI) in the Digital Transformation Market Overview

#### Strategic Importance of AI in Digital Transformation

Artificial Intelligence is increasingly being recognised as a central force driving digital transformation across a wide range of sectors. In contrast to earlier phases of digitalisation that primarily emphasized automation and improved connectivity, the current phase is largely shaped by intelligent technologies. AI allows organisations to interpret complex data patterns, support automated decision-making, and build responsive digital systems, thereby positioning it as a critical enabler of sustained and long-term transformation.

## Artificial Intelligence (AI) In Digital Transformation Market Report 2026



### Artificial Intelligence (AI) in the Digital Transformation Market Overview

The Artificial Intelligence (AI) market within the digital transformation landscape has experienced rapid growth in recent years and is projected to increase from about USD 424.75 billion in 2025 to nearly USD 560.13 billion in 2026, representing a compound annual growth rate (CAGR) of 31.9%. The strong growth observed during this period can be linked to multiple contributing factors, including widespread enterprise digitisation efforts, early adoption of automation technologies, the increasing reliance on data-driven decision-making, rapid expansion of cloud computing, and the growing demand for improved operational efficiency.

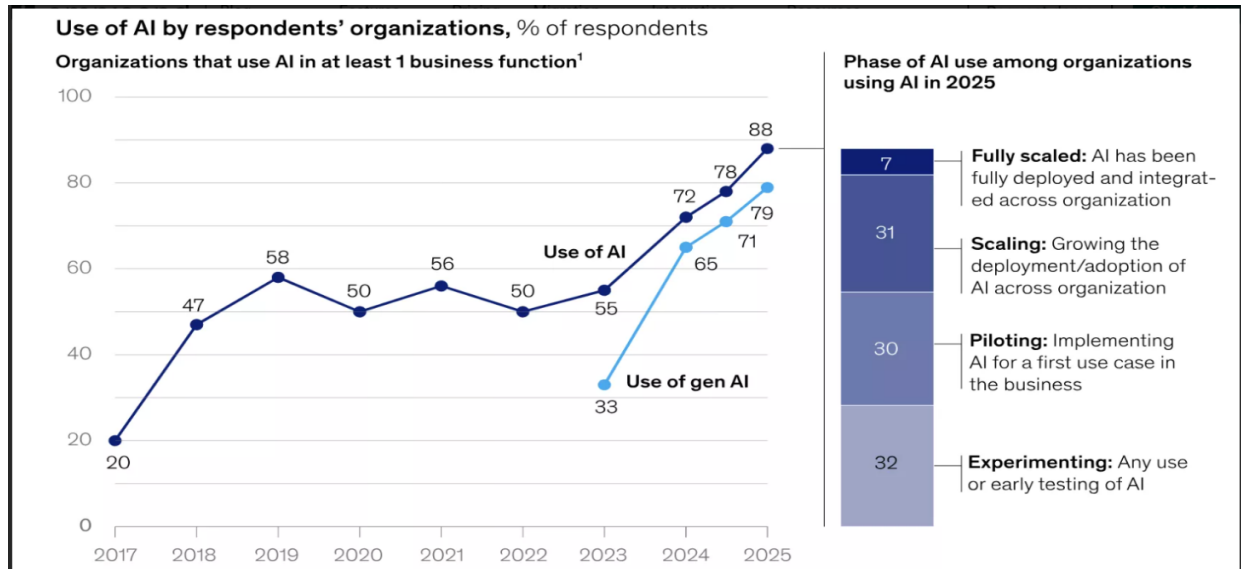
### Influence of AI-Powered Digital Marketing on Consumer Behaviour

#### Personalisation and Behavioural Targeting

Artificial Intelligence has played a transformative role in digital marketing by facilitating advanced levels of personalisation. AI-powered recommendation systems examine users' browsing behaviour, past purchases, and interaction patterns to generate customised product suggestions. Such personalised engagement minimises cognitive effort during the decision-making process and enhances the efficiency of consumer choices, thereby shaping purchasing behaviour.

Furthermore, AI-enabled personalisation increases the perceived relevance of marketing content and strengthens user engagement, which ultimately contributes to higher levels of customer satisfaction and a greater likelihood of purchase.

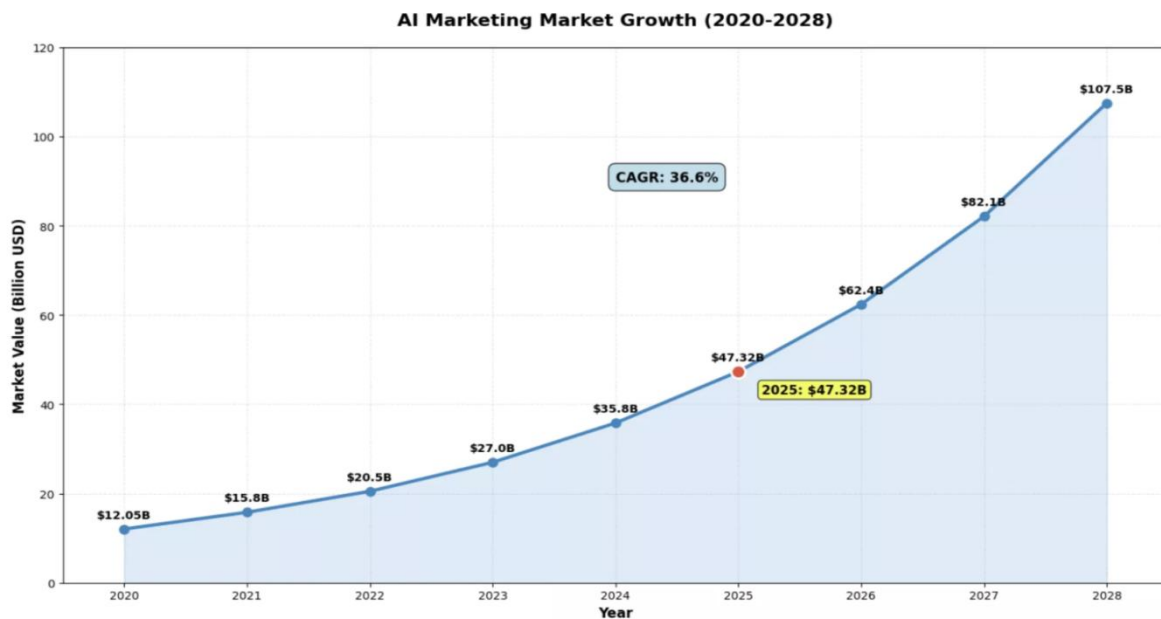
**AI Marketing Industry Growth**



**Table Title: Adoption and Strategic Importance of AI in Marketing and Business Functions**

Stat No	Key Insight	Percentage / Value	Critical Insights
1.	Organisations using AI in at least one business function	88%	AI is now widely adopted and no longer limited to early adopters.
2.	CMOs expecting AI to reshape their role by 2026	65%	Marketing leadership is shifting toward data-driven and tech-enabled roles.
3.	Firms using AI for personalised experiences	73%	Personalisation is a key reason behind rapid AI adoption in marketing.
4.	Firms planning to increase AI budgets	92%	Organisations see AI as a long-term strategic investment.
5.	Marketers automating repetitive tasks using AI	43%	AI is helping improve efficiency by reducing manual workload
6.	Companies already using AI in marketing	50%	AI adoption in marketing is already mainstream but still expanding
7.	Firms planning to increase AI spending next year	78%	Investment momentum suggests continued growth in AI-led marketing.
8.	AI marketing industry valuation (2025)	\$47.32	The market size reflects the growing economic importance of AI in marketing.

**Source:** Compiled from recent industry reports including McKinsey AI surveys, CMO outlook studies, and global AI marketing market analyses (2025–2026).



Source: omniscend.com

### Expansion of the AI Marketing Industry

- AI marketing industry valued at **\$47.3 billion in 2025**
- Projected to exceed **\$107 billion by 2028**
- Over **80% of marketers actively use AI tools**

These figures highlight a clear transition from conventional digital marketing practices toward more advanced, AI-driven marketing ecosystems.

### Impact of AI on Consumer Trust, Engagement, and Purchase Intention

#### AI and Consumer Trust

Artificial Intelligence performs a complex role in influencing consumer trust within online shopping environments. On one side, AI-driven tools such as chatbots and recommendation systems contribute positively to trust by providing accurate information, personalised guidance, and instant assistance. Empirical evidence suggests that factors like chatbot responsiveness, perceived usefulness, and service quality play a significant role in strengthening trust toward online platforms (Illescas-Manzano, 2024).

Trust also functions as an important mediating variable between AI interactions and consumer behaviour. Studies based on the Technology Acceptance Model (TAM) show that consumers' perceptions of the usefulness and reliability of AI tools play a significant role in shaping their attitudes towards, and trust in, AI-enabled shopping environments (Nagy & Hajdu, 2022).

In a broader sense, trust serves as a psychological link connecting AI functionality with user acceptance. When AI systems are viewed as transparent, supportive, and human-like in their interactions, they tend to foster higher levels of trust and sustained user engagement.

## AI and Consumer Engagement

Artificial Intelligence has considerably redefined how brands communicate with consumers in digital spaces. Technologies such as chatbots, virtual assistants, and generative AI interfaces have enabled interactions that are faster, more personalised, and ongoing in nature. In contrast to traditional customer service systems, AI-enabled engagement tools enable real-time interaction across multiple digital channels, such as websites, mobile applications, and social media platforms, allowing brands to maintain continuous connectivity with their audiences.

A key contribution of AI is its ability to facilitate continuous engagement. AI-based chatbots and conversational systems operate around the clock, enabling users to obtain assistance without delays typically associated with human support. This constant availability enhances user convenience and reflects the growing expectation among modern consumers for immediate responses and frictionless digital experiences.

In addition, AI enhances engagement by delivering highly personalised interactions. By examining user browsing habits, purchase records, and behavioural patterns, AI systems generate customised responses and recommendations tailored to individual preferences. Such personalised interactions foster a more engaging and immersive shopping journey, encouraging users to spend more time on digital platforms and build stronger connections with brands.

Another important benefit of AI-driven engagement is enhanced responsiveness. AI-powered support tools significantly minimise response times when compared with traditional service channels. Prompt and efficient replies help sustain higher engagement levels, as consumers are more likely to continue interacting with brands when their concerns are addressed quickly and effectively.

## Quantitative Insights into AI and Consumer Engagement

- Research findings indicate that the use of AI chatbots can increase customer satisfaction by nearly 18 percentage points, underscoring their significant role in enhancing user engagement and overall service quality (**Sutantri, 2025**).
- Organisations that adopt AI chatbot technologies report approximately 24% higher customer satisfaction levels, while nearly 80% of users describe their experiences as positive, indicating increasing consumer acceptance of AI-enabled interactions (**Envive AI Insights, 2024**).
- AI-powered conversational systems are capable of resolving customer issues up to 92% more quickly, enabling organisations to deliver more efficient responses and sustain higher levels of user engagement (**Master of Code, 2024**).
- Studies indicate that AI chatbots can shorten response times by more than 99% when compared with traditional customer support systems, resulting in faster and more seamless user interactions (**Sutantri, 2025**).
- Evidence suggests that during peak online shopping periods, the adoption of AI-based chat services has grown by more than 40% on a year-on-year basis, indicating an increasing reliance on AI-driven customer assistance (**Reuters, 2025**).

- AI-enabled support systems have been shown to increase first-contact resolution rates by over 60%, thereby minimising repeated queries and enhancing the overall user experience (**Envive AI Insights, 2024**).

### **AI and Purchase Intention**

One of the most widely examined outcomes of AI adoption is its effect on consumers' purchase intentions. AI-enabled tools help reduce decision-related uncertainty by providing personalised recommendations, rapid responses, and contextually relevant product information. Empirical evidence suggests that AI-driven personalisation enhances purchase intention by increasing perceived relevance and usefulness among consumers (**AngKhuong, 2025**).

Chatbots, in particular, play a critical role in transforming browsing activity into actual purchasing behaviour. Studies conducted in online shopping contexts indicate that interactions with AI chatbots significantly increase purchase likelihood by enhancing consumer confidence and lowering perceived risks (**Dave & Machhar, 2025**).

Behavioural analytics findings further indicate that consumers who engage with AI-driven chat tools generally spend more and achieve higher conversion rates than those who shop without AI assistance. This pattern highlights the tangible commercial value of AI-supported decision-making in digital retail environments (**Rep AI Report, 2025**).

AI increases purchase intention by enhancing confidence, minimising effort, and offering personalised shopping experiences.

### **Emerging Trends and Challenges in AI-Driven Consumer Ecosystems**

#### **Emerging Trends in AI Commerce**

Artificial Intelligence is progressively reshaping digital commerce by introducing advanced technological capabilities that change how consumers interact with online shopping platforms. The progression of AI in this domain has moved beyond basic automation and is now advancing toward predictive, conversational, and autonomous systems. A number of emerging developments illustrate how AI is shaping the future trajectory of online retail and influencing evolving patterns of digital consumer behaviour.

#### **Generative AI in Digital Commerce**

Generative Artificial Intelligence is redefining how brands develop content, interact with customers, and deliver personalised experiences. Contemporary AI tools are capable of producing product descriptions, marketing materials, and conversational responses in real time, thereby making digital marketing more scalable and responsive. Existing research indicates that generative AI plays a significant role in enhancing content personalisation and overall customer experience, particularly within online retail settings (**Dwivedi, 2023**).

Industry analyses further suggest that organisations adopting generative AI report higher levels of customer engagement along with improved operational efficiency, particularly in content-centric customer journeys (**McKinsey, 2024**). These trends imply that generative AI is increasingly emerging as a core component of AI-driven commercial ecosystems.

### **Rise of AI Shopping Assistants and Agents**

AI-driven shopping assistants have emerged as one of the most prominent manifestations of intelligent commerce. These systems support consumers in discovering products, evaluating alternatives, and making well-informed decisions through conversational interfaces. Existing research indicates that such conversational agents improve decision convenience and lower cognitive effort during the online shopping process (**Huang & Rust, 2021**).

Recent market projections suggest that AI-powered shopping agents are likely to become widely adopted within the current decade, supported by the growth of voice commerce and conversational AI ecosystems (**Salesforce, 2024**). This trend signals a gradual shift from traditional search-oriented shopping models toward more assistance-driven forms of digital consumption.

### **Conversational and Voice Commerce**

Conversational commerce is emerging as a major trend, largely fuelled by ongoing developments in natural language processing and voice recognition technologies. AI-enabled voice assistants and chat-based interfaces enable consumers to search, evaluate, and purchase products through natural, dialogue-based interactions. Existing research suggests that such conversational interfaces increase user engagement and enhance shopping convenience by facilitating more intuitive and user-friendly interactions (**Grewal, 2021**).

Voice commerce, in particular, is witnessing increasing adoption as smart speakers and mobile voice assistants become more widely used. Research indicates that conversational AI enhances accessibility and improves overall user experience, particularly among mobile-first consumers (**PwC, 2023**).

### **Predictive and Hyper-Personalised Commerce**

Predictive analytics is driving a transition from reactive to proactive models of commerce. Contemporary AI systems are capable of anticipating consumer preferences by analysing behavioural data, browsing activities, and prior purchase patterns. This predictive functionality enables digital platforms to suggest relevant products even before users actively search for them. Existing research suggests that predictive personalisation enhances customer satisfaction and improves conversion rates by increasing the perceived relevance of recommendations (**Verhoef, 2021**).

Hyper-personalisation, enabled by Artificial Intelligence and big data analytics, is transforming digital experiences by providing highly customised product recommendations and promotional offers. This development is expected to significantly influence future consumer expectations within online shopping environments (**Kumar, 2020**).

### **Challenges in AI-Driven Consumer Ecosystems**

Although Artificial Intelligence has greatly improved digital consumer experiences, it has also brought forward a range of complex challenges that affect both adoption and long-term sustainability. These issues are not limited to technological constraints but also encompass ethical, psychological, and regulatory concerns. Recognising and addressing these barriers is crucial for the development of responsible and sustainable AI-driven consumer ecosystems.

## **Privacy and Data Security Concerns**

One of the most commonly emphasised challenges in AI-driven ecosystems is the issue of data privacy. AI technologies depend heavily on extensive consumer data, such as browsing patterns, purchase histories, and individual preferences. The scale of this data collection often gives rise to concerns regarding surveillance, potential misuse, and the risk of data breaches. Existing research suggests that privacy-related apprehensions play a significant role in shaping consumer resistance toward AI-enabled services, particularly within online shopping contexts (**Martin & Murphy, 2017**).

Recent research further indicates that consumers are increasingly seeking greater transparency in the ways their data is collected and utilised by AI systems. Ambiguities in data governance and management practices can weaken consumer trust and lower their willingness to interact with AI-enabled platforms (**Dwivedi, 2023**).

## **Algorithmic Bias and Fairness**

Algorithmic bias constitutes another major challenge in the context of AI ecosystems. Because AI models are developed using historical datasets, they may unintentionally reproduce or intensify pre-existing societal biases. In the context of digital commerce, such biases can result in inequitable product recommendations, exclusionary targeting practices, or even discriminatory pricing outcomes.

Academic literature indicates that algorithmic bias can compromise fairness and inclusivity, thereby creating ethical concerns for organisations implementing AI technologies (**O'Neil, 2016**). Subsequent research on AI governance further highlights the importance of designing fairness-oriented AI systems to minimise discriminatory effects and promote more equitable digital experiences (**Floridi, 2018**).

## **Lack of Transparency and Explain ability**

AI systems are frequently described as “black boxes” due to the limited transparency of their decision-making processes. This lack of interpretability makes it challenging for users to understand the rationale behind specific recommendations or automated outcomes. Prior studies indicate that explainability plays a crucial role in the acceptance of AI, as people are more likely to trust systems that provide transparent and easily understandable explanations for their results (**Rai, 2020**).

Within consumer ecosystems, opaque AI-driven decisions can generate scepticism and discourage adoption, particularly in sensitive contexts such as financial transactions or personalised pricing models (**Glikson & Woolley, 2020**).

## **Regulatory and Ethical Governance Challenges**

The rapid evolution of AI technologies has progressed faster than the development of corresponding regulatory frameworks, leading to uncertainty for both organisations and consumers. In response, governments and global institutions are increasingly working toward establishing ethical AI standards that address issues such as transparency, accountability, and data protection rights.

Previous studies indicate that the lack of clear and well-established regulatory frameworks can create legal uncertainty and restrict the wider adoption of AI, particularly in cross-border digital

commerce contexts (**Jobin, 2019**). Emerging governance approaches to AI emphasise responsible innovation, highlighting the importance of ethical system design and adherence to evolving international regulatory frameworks (**European Commission, 2023**).

## CONCLUSION

Artificial Intelligence has become a transformative force in redefining the online shopping landscape by altering how consumers engage with digital platforms. Capabilities such as personalised recommendations, intelligent search functions, and automated support systems have made the shopping experience more intuitive and adaptive. By processing behavioural data in real time, AI enables platforms to deliver customised interactions that closely match individual preferences. As a result, online shopping has evolved from a purely transactional process into a more interactive and experience-driven activity.

In addition to enhancing convenience, AI has influenced important behavioural aspects, including consumer engagement, trust, and decision-making. Rapid response mechanisms, conversational interfaces, and predictive recommendations help minimise friction within the shopping journey and contribute to higher satisfaction levels. However, the increasing dependence on AI also raises concerns regarding data privacy, transparency, and ethical use. These challenges are critical in shaping consumer trust and the long-term acceptance of AI-driven platforms.

Looking ahead, the role of AI in online retail is expected to grow further as technologies become more advanced and increasingly integrated into everyday digital interactions. For organisations, the primary challenge is not merely adopting advanced AI solutions but implementing them in a responsible and consumer-centric manner. Maintaining an appropriate balance between technological progress and ethical responsibilities will be essential for building sustainable and trustworthy digital shopping ecosystems in the future.

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## HAND-PULLED RICKSHAW PULLERS IN KOLKATA: EXPLORING THEIR SOCIO-ECONOMIC STATUS

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### ABSTRACT

*Hand-pulled rickshaws were introduced in Kolkata during the British period and after serving local residents for a long period of time, they are facing the problem of marginalization. In the present age of globalization and urban growth, this type of transport has been an integral part of the city's socio-economic fabric. This is a pollution-free, human-driven mode of transport. The people, predominantly migrants from states like Bihar, Jharkhand, Odisha and other rural areas of West Bengal are mainly work as rickshaw pullers and are dependent on this occupation due to lack of formal education and alternative employment opportunities in Kolkata. The present study aims to find out the basic socio-economic characters of hand-pulled rickshaw pullers in Kolkata and also tries to evaluate the reasons behind its marginalization in recent days. The present study combines **both qualitative and quantitative** approaches, with an emphasis on **fieldwork, direct observation and primary data collection and analysis**. The primary survey was conducted on 100 hand-pulled rickshaw pullers (all male) in selected localities of Kolkata like **Burrabazar, North Kolkata, Bhawanipore, Sobhabazar and College Street**. This research highlights the intricate dynamics of the social and economic structure of hand-pulled rickshaw pullers in Kolkata, aiming to provide a comprehensive understanding of their present situation in society as well as their daily struggles.*

**KEYWORDS:** *Rickshaw, Pullers, Migrants, Marginalization, Inclusion.*

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### INTRODUCTION

Rickshaws are very effective, eco-friendly and easily available mode of transport in India. It is mainly a human-powered transport and was first seen in Japan in 1868 (Nandi, Bhattacharyya & Banerjee, 2015). In Indian cities and villages, people often rely on rickshaws as a more convenient mode of transport for movement within a short distance. In India, we can observe two major forms of this human-powered transport -hand-pulled rickshaws and cycle rickshaws.

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Among these two, the hand-pulled rickshaw, being the poorest version and found only in Kolkata in West Bengal.

Hand-pulled rickshaw pullers in Kolkata are facing the problem of marginalization though it has been an integral part of the city's socio-economic fabric since the pre-colonial period. The people, predominantly migrants from states like Bihar, Jharkhand and Odisha, and also from the surrounding rural areas of other districts of West Bengal. They usually came to Kolkata to find suitable jobs and are often work as rickshaw pullers which needs high physical labor and almost no specific skill. Thus, it is easy to work in this profession due to lack of formal education and alternative employment opportunities for those migrants in present days. This is one important reason, why these pullers are facing the problem of marginalization.

The present study revolves around the socio-economic condition of hand-pulled rickshaw pullers in Kolkata and also finds out the reason behind its marginalization in recent days. Based on primary survey, the study also recommends some measures to improve the situation of hand-pulled rickshaw pullers in Kolkata.

## **Objectives and methodology**

Main objectives of the study are-

1. To examine the socio-economic condition of hand-pulled rickshaw pullers in Kolkata and
2. To investigate the reasons of marginalization of hand-pulled rickshaw pullers in Kolkata

The methodology of research outlines the research design, tools, and techniques used to study the socio-economic aspects of hand-pulled rickshaw pullers in Kolkata. The present study combines **both qualitative and quantitative** approaches, with an emphasis on **fieldwork, direct observation and primary data collection and analysis**. The primary survey was conducted on 100 hand-pulled rickshaw pullers (all male) in selected localities of Kolkata like **Burrabazar, North Kolkata, Bhawanipore, Sobhabazar and College Street**.

This research tries to throw light towards the intricate dynamics of the social and economic structure of hand-pulled rickshaw pullers in Kolkata, aiming to provide a comprehensive understanding of their present situation in society as well as their daily struggles. Through participant observation, interviews and interaction with the rickshaw pullers, this study reveals the facts behind the marginalization of hand-pulled rickshaw pullers of Kolkata.

## **Socio-cultural significance of hand-pulled rickshaws in Kolkata**

The rickshaw was first invented in Japan in 1869, which later spread to China in 1874. In India, these were introduced by the British East India Company in different cities like Shimla and Kolkata (Ghosal; Saha, 2025). In Shimla, the British East India Company first introduced the hand-pulled rickshaws, which later came to the streets of colonial Calcutta (Present Kolkata). This type of transport is a cultural icon of Kolkata since colonial period, which is documented in many Bengali films and documentaries to show the socio-cultural situation of colonial Kolkata. Thus, this hand-pulled rickshaws have a special significance in Kolkata's history and culture. This type of transport was an essential system of transport in colonial Kolkata, when the city was expanding northwards covering the narrow streets of North Kolkata. Thus, during the early 20<sup>th</sup> century, most of the local residents of Kolkata depended on hand-pulled rickshaws to navigate narrow and congested streets, especially during floods or emergencies. It can be said that, for more than a century, Kolkata's cityscape and streetscapes were dominated by hand-pulled

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rickshaws. In Bengali, it was known as *tana rickshaw*, the hand-pulled rickshaws are one of the heritage transports of Kolkata.

Historically, hand-pulled rickshaws were introduced during the colonial era as a symbol of urban mobility. For many years, they served as the single mode of transport for passengers and goods for their movement in narrow lanes of Kolkata. During heavy rains, especially in areas prone to water logging, except hand-pulled rickshaws, no other vehicle can operate effectively. Till today, in some narrow streets in North Kolkata, this is the main reason why these hand-pulled rickshaws are still operating. West Bengal Government attempted a ban on these hand-pulled rickshaws in 2005 on the issues of modernity and urban development, which faced much criticism of not making an alternate livelihood pattern for these rickshaw pullers before banning their primary occupation. However, with support from local people, hand-pulled rickshaws continue to function under legal protection as a means of livelihood, symbolizing the complex intersection of tradition, poverty, heritage conservation as well as urban development in Kolkata.

In Kolkata, the hand-pulled rickshaws operate in certain congested part of the central Kolkata within the jurisdiction of the Kolkata Metropolitan Corporation. Halder and Basu (1982), in their work estimated that the number of hand-pulled rickshaws in Kolkata ranging between 24,000 and 70,000. Recent research report suggests that, about 3,500 hand-pulled rickshaws are still operating on a daily basis in different parts of Kolkata which is declined from 6000 in numbers during 1919 (Santra, 2024). Although modern traffic rules in Kolkata in 2006 banned these hand-pulled rickshaws from major roads but still one can see this type of transport in the narrow streets of North Kolkata.

The British introduced these rickshaws to Kolkata, replacing the ornate palanquins (pulled by 2-4 people) used by the high-class people. It involved one human manually pulling another, i.e., the colonial master-slave power dynamics was represented in this shift of transport. In 1919, the British enacted the Calcutta Hackney Carriage Act, which authorized the use of hand-pulled rickshaws in Kolkata for passenger movement within a short route. These rickshaws thus became the alternative to palanquins for high-class people. However, due to some specific reasons, though this unique mode of transport is still operating as a lasting legacy of Kolkata, but the pullers are facing the problem of marginalization.

## Literature Reviews

In most of the urban cities, according to urban policy makers, there is need to promote non-motorized modes of transport like bicycles, cycle rickshaws or even walking as they are more inclusive and non-polluting (Tiwari, 2007). As a mode of transport, rickshaws are the most important and convenient mode of movement within the narrow streets of urban area for daily commuting. Due to easily accessible and cheap fare, rickshaws are invaluable for the city's transportation and economic activities (Basu et. al., 2022; Hossain & Susilo, 2014). Rickshaw plays a critical role in transportation in city areas of many east Asian countries like India and Bangladesh. In Bangladesh, the rickshaw has one front wheel and two rear wheels and can carry two passengers except for the puller. In some cases, rickshaws are also used for carry goods up to 250 kg (Replogle, 1991). Some research in Bangladesh reveals that, among poor people, rickshaw pulling has become a popular informal economic activity in urban areas due to its low initial investment, low maintenance and as it requires no specific skill to operate. Many people are engaged in this sector across the many Asian countries (Karim & Salam, 2019; Basu et. al., 2022).

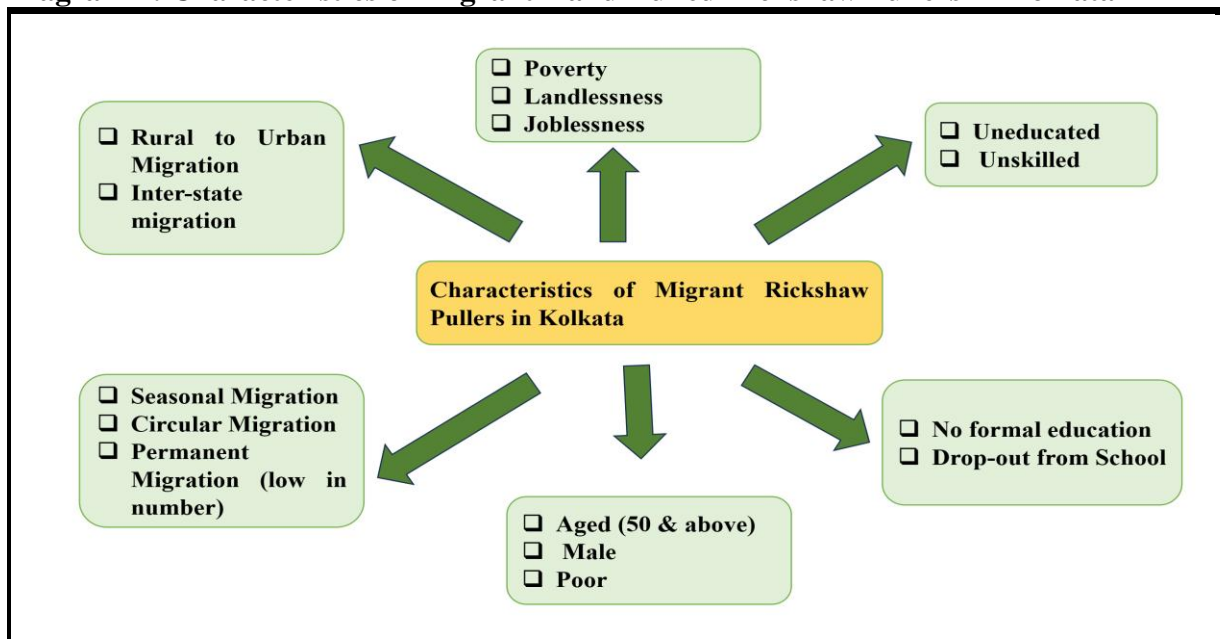
The city of Kolkata enjoys some specific iconic symbols since the early 20th century. Among them, hand-pulled rickshaw is one important tangible heritage of this city. In spite of that, the person who bears all the load of pulling the rickshaw and the passenger remain marginalized due to many reasons. The city of Kolkata is the only city, which enjoys highly mechanized modern modes of transport like the metro rail alongside hand-pulled rickshaws (i.e., a primitive form of human-powered vehicle). For shorter distances and in narrow lanes and by-lanes, the rickshaws have emerged as a significant and popular mode of informal mobility (Samanta & Roy, 2013).

Most of the pullers are migrants from Bihar and Jharkhand to Kolkata, who are forced to take this profession due to interplay of different push and pull factors (Seal, 2026). On August 6, 2006, the three-Judge Bench of the Supreme Court banned the hand-pulled rickshaws in the eco-sensitive zone of Matheran Hill Station in Maharashtra and declared as “inhuman” while holding that such an inhuman practice needs to be abolished (Saha, 2025). The role played by the non-motorized mode of transport is highly significant in case of urban sustainability like Kolkata as it links to the environmental sustainability. The economic issues related to the hand-pulled rickshaw pullers made the survival of this eco-friendly mode of transport a problematic one (Whitelegg & William, 2000).

**Socio-economic condition of hand-pulled rickshaw pullers in Kolkata**

Hand-pulled rickshaws are a unique mode of transport in Kolkata after its initiation in British India. This type of transport system is still operated in certain parts of Kolkata, particularly in older areas like North Kolkata and around the large old markets. These rickshaws are manually pulled by a rickshaw-puller, usually barefoot in older days and often belonging to poor migrant communities from Bihar, Jharkhand, or rural Bengal. The socio-economic condition of these rickshaw-pullers reveals the fact that, these people are still very poor and due to unskilled and uneducated characters, they are unable to change their profession.

**Diagram 1: Characteristics of Migrant Hand-Pulled Rickshaw Pullers in Kolkata**



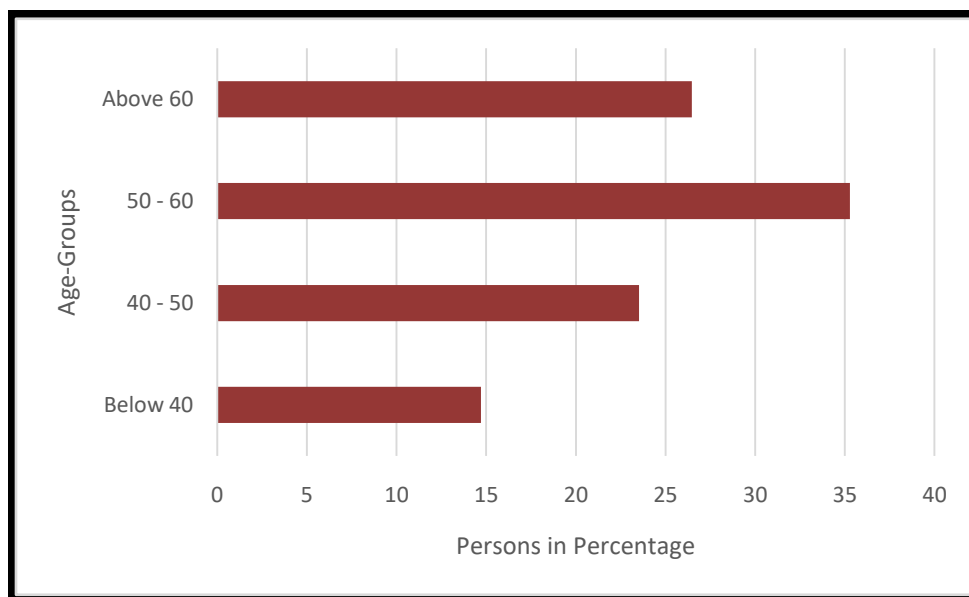
Source: Compiled by researchers

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### Age Structure of Hand-Pulled Rickshaw Pullers in Kolkata

People came from different remote villages in Bihar, Jharkhand, Odisha and other districts of West Bengal and started working as hand-pulled rickshaw pullers in Kolkata. The study shows that, these people started their profession approximately 10 – 15 years back and today, they have very minimum possibility to change their profession due to their no educational attainment and lack of skill. These pullers are older people and some of them have brought their sons or cousins in this profession. But this new generation pullers are not happy in this profession due to very low income and they are trying to join in other type of jobs. Some of them are working in some private firms or work as casual labour in construction site to earn more money for their livelihood.

**Diagram 2: Age Structure of Hand-Pulled Rickshaw Pullers in Kolkata**



The study reveals that, a considerable percentage of hand-pulled rickshaw pullers in Kolkata belongs to older age group, specifically recording 35 percent of respondents are in 50 – 60 age groups, while about 26 percent persons are of the higher age groups (above 60 years) and came in this profession for more than 10 years. The below 40 age group comprises less number of people as these are mostly literate and are willing to engage in any other occupation which are comparatively high paid jobs. These comparatively young people can acquire skill that are necessary for other jobs and are still searching for their better livelihoods. Remaining 24 percent pullers belong to 40-50 age-groups and also eager to change their profession as the income in this work is uncertain and very low.

### Educational Status of Hand-Pulled Rickshaw Pullers in Kolkata

The average level of education of hand-pulled rickshaw pullers in Kolkata is generally very low, reflecting their socio-economic background, migration type, drop out from formal education and early entry into the labour force. Most belong to economically poor rural areas of Bihar, Jharkhand and West Bengal, where access to quality schooling is limited and majority are forced to leave their school due to family's financial condition.

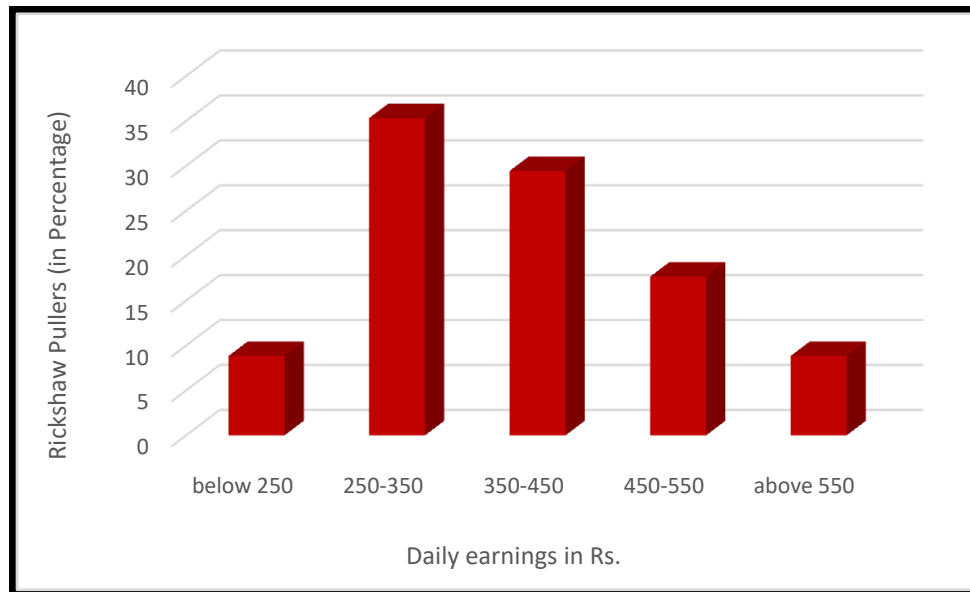
The study explains the educational status of hand-pulled rickshaw pullers in Kolkata. Most of these rickshaw pullers have come from very poor families both in terms of household income level and land productivity. In both these respects, rickshaw pullers belong to one of the most deprived social categories. They are mostly uneducated (58%) or semi-educated, having never completed primary level education (17%), only 2.5% have passed the secondary level. All others either completed primary school but did not continue (9%) or did not complete secondary education (13%). It is interesting to note that the rickshaw pullers who have joined the occupation relatively recently (over the last five years) have come from relatively higher educational backgrounds than those who have been pulling rickshaw for 15 years or more, representing two socially distinct waves of migrants. Two-thirds of recent rickshaw pullers are uneducated or semieducated, compared to 83% among older generation of pullers.

**Table 1: Educational Status of Hand-Pulled Rickshaw Pullers in Kolkata**

Education Level	Approx. % of Pullers	Characteristics
No Schooling	40–50%	Mostly older Rickshaw pullers, who came from very poor rural areas and working for more than 15 years.
Primary (Class 1–5)	25–30%	Dropped out from school due to poverty and came to Kolkata with relatives and friends and joined as rickshaw puller.
Middle School (Class 6–8)	10–15%	Usually, younger generation in this profession and some still continue schooling.
Secondary & Above	<5%	Very rare category and most of them came to this profession due to job loss or migration crisis and trying to find other jobs in this city.

### **Income structure of hand pulled rikshaw puller in Kolkata**

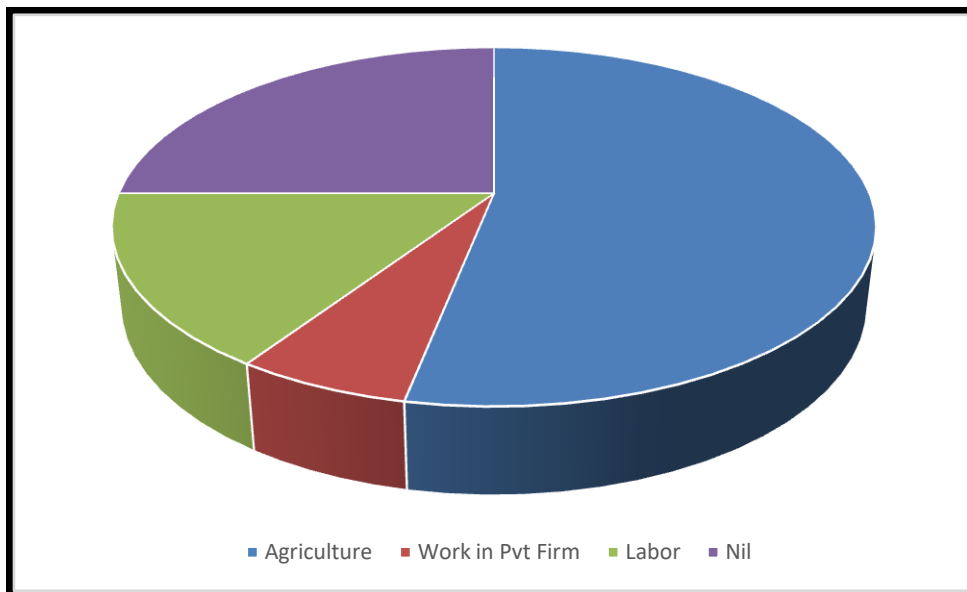
The income of hand-pulled rickshaw pullers in Kolkata is largely **weather dependent, irregular and low**. Most pullers operate on a **rental basis**, i.e., they pay a daily or weekly or monthly charge to the rickshaw owner. Their **daily earnings** ranges between ₹250 – ₹450 on normal days. During peak season, like Puja time, exam period, school hours etc, their earnings ranges between ₹500 – ₹600, while during lean periods, extreme heat, or their time of poor health their earnings may ranges between ₹150 – ₹200 per day. The study shows that, 35 percent respondents earn daily ranging between Rs. 250 – Rs. 350, while 29 percent earn between Rs. 350 – Rs. 450. The study also reveals that, only 9 percent rickshaw pullers earn more than Rs. 550 daily.

**Diagram 3: Daily Income Structure of Hand-Pulled Rickshaw Pullers in Kolkata****Other source of income**

As most of these rickshaw pullers are migrant workers, they have their agricultural land in their home villages. These people work as rickshaw pullers in Kolkata and send money to their home. The study reveals that, about 50 percent of the respondents have their other source of income in their villages, where they earn livelihood from agricultural field. Remaining 15 percent rickshaw pullers work as casual labours in different sectors in and around Kolkata, some (6percent) work in factories and other private firms, while the rest 24 percent purely depend on the hand-pulled rickshaws. These 24 percent are uneducated and unskilled aged persons mainly, who do not have the possibility to engage in any other activities for their livelihood.

The rickshaw-pullers are poor because they more than 4 members in their family, while only one or two earning members in each family. In some cases, the rickshaw puller have to support his whole family with 6 members. Though majority of pullers have their agricultural land in the village, but due to very low capital investment and low production, the whole family face poor situation.

**Diagram 4: Other Sources of Income for Hand-Pulled Rickshaw Pullers**



However, the following table reveals the basic socio-economic features of hand-pulled rickshaw pullers in Kolkata.

**Table 2: Basic Socio-Economic Features of Rickshaw Pullers in Kolkata**

Indicator	Status
Age- structure	Mainly older people of more than 60 years age, very few young generation people
Education	Low literacy, most of the pullers are illiterate while few are continuing their education
Housing type	Mainly pavement dwellings and slum areas
Skill level	Mainly unskilled
Income	Unstable and very low income
Reasons for a smaller number of passengers	Passengers prefer auto rickshaw or e-rickshaw for a speedy movement
Other Source of Income	About half have agriculture field in villages, some work as casual labor and some have no other income source
Healthcare	Inadequate
Social Status	Very low, marginalized
Acceptance of new generation	Not accepted by young people due to unstable and low income
Current Trend	Declining trend, facing extinction

**Reasons for socio-economic marginalization of hand-pulled rickshaws in Kolkata**

Rickshaw pulling provides livelihood to many people, though earnings are meager and irregular, which is also often dependent on daily demand. As this is human-powered local transport, thus weather condition is highly important to run this type of transport efficiently. It is very difficult for the person, who are pulling the rickshaw during days of heavy rains and high heat. In Kolkata, during the British period, this type of transport was treated as a the most convenient for the-then middle-class Bengali people, but with the development of urban society in the 21<sup>st</sup> century, this type of transport has become back-dated. During the age of high-speed metro-rail as a means of commuting, this low-speed rickshaws face neglect and the pullers suffer from lack of

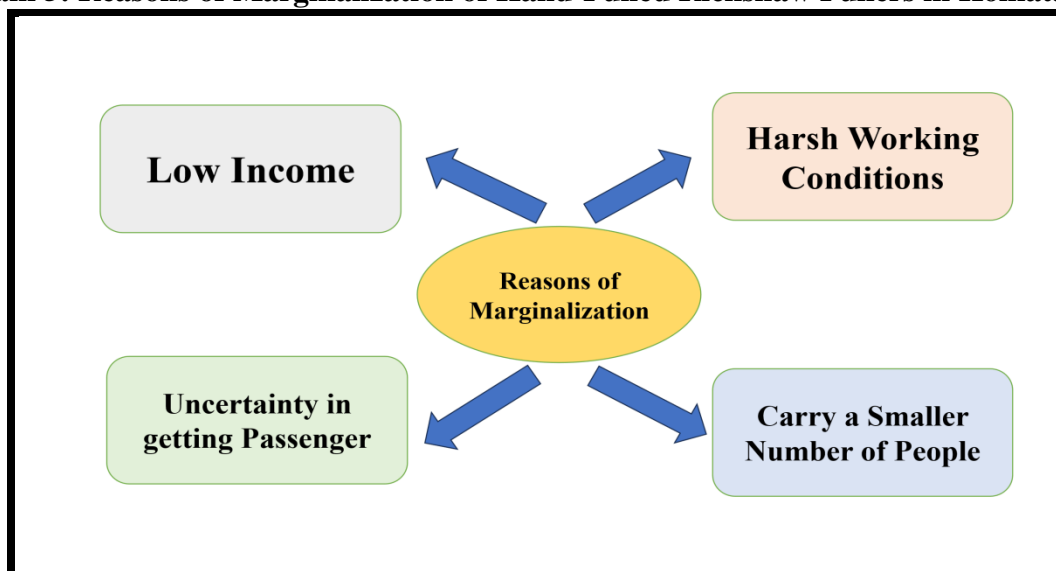
work. Under such challenging situation, they are facing social neglect and financially poor condition highlighting socio-economic disparities.

The government declaration about rickshaws that, these cause traffic congestion in modern high-speed society and also constitute an exploitative use of human labor and “not in alignment with the image of a modern society” (Samanta & Roy, 2013). But, those people who are the pullers of hand-pulled rickshaws are still depend on this type of work due to lack of any alternate option for their livelihood. Kolkata is a city of many activities and developments. It is the first city in India to construct a metro rail and also the only city, with many licensed hand-pulled rickshaws (called *tana rickshaw* in Bengali) as a mode of public transport. Calcutta (present Kolkata) was the capital of British India, which played a highly significant role in the development of public transportation inside the city.

The type of labour used to operate the hand-pulled rickshaws are also play significant role in making this type of transport a marginalized one. It is interesting to note that, pulling a rickshaw does not require skill and only it requires hard physical labour. Thus, mainly unemployed and unskilled labors find this type of work helpful for them. The migrant labors, who came from villages of surrounding states to Kolkata started this type of work in this city during the British period. They do not undergo any training or require a driver’s license to operate. Most rickshaw pullers do not even know the names of the roads, nor do they understand the various traffic symbols. This is because they are mostly illiterate and speak their own language instead of the local Bengali. Most of the rickshaw pullers rent the rickshaw from owners, who own *khataals* (rickshaw garages). This arrangement evolved because many rickshaw pullers are either too poor or seasonal migrants, plying the rickshaws only for a few months when their agricultural fields in their villages remain fallow.

The combination of economic insecurity and occupational uncertainty- are two important reasons of the hand-pulled rickshaw pullers in Kolkata, which force these people towards marginalization. If we further analyze their situation, four interconnected problems can be come out.

**Diagram 5: Reasons of Marginalization of Hand-Pulled Rickshaw Pullers in Kolkata**



As the rate per ride is very low till today, thus most hand-pulled rickshaw pullers earn very little on a daily basis, but they have to give a certain amount to the rickshaw owner daily or monthly basis. This force these pullers to live in a very tough situation. Combined effect of low speed, weather conditions, competition from auto-rickshaws, e-rickshaws and app-based transport create a situation that, majority of passengers prefer to take other mode of transport than hand-pulled rickshaws. This uncertainty in passenger also makes it hard for the rickshaw pullers to cover basic needs, repay debts, or send money to families in villages. As it is human-driven transport, thus the job demands extreme physical labour to pull the rickshaw along with the passengers by their hand often in intense heat, heavy rain, or during floods. Other mode of transport (even a e-rickshaw or an auto rickshaw) can carry 4-6 people at once, but a hand-pulled rickshaw can only carry one or at most two.

To keep pace with the high rate of urbanization, high-speed modern transport system, modernization, progress and globalization, hand-pulled rickshaws are lagging far behind due to its low speed, unsophisticated nature of pulling and poor financial condition of pullers. Inhuman working conditions, health risks, limited access to social security or welfare programs and declining demand due to modern transport options are other reasons for marginalization of this once cultural icon of the city. This contrasting picture in socio-cultural dimension of Kolkata's cityscape raises many questions about urban inequality, social disparity, economic drawbacks and the need for inclusive policies to ensure dignified livelihoods.

## CONCLUSION

In the age of globalization and high-speed transport, the rickshaw is currently undervalued and under-utilized means of transport. The socio-economic condition of hand-pulled rickshaw pullers in Kolkata is a complex issue combining physical exploitation, **economic instability and social neglect**. These rickshaw-pullers represent an extinct chapter of Kolkata's tradition, however, their existence reveals the gaps in urban socio-economic policy and strategy including inclusive development, equality in society and social justice. There is an urgent need for **alternative livelihood support** to ensure their basic rights and well-being. According to Samanta and Roy (2013), the important reason for increasing the number of rickshaws in many Asian cities is the increasing local demand for movement. But besides this, the other reasons are also there that, the increasing migration rate of uneducated and unskilled rural people to cities and urban rural market. For these people, rickshaw pulling is the easiest option for initiating a livelihood in cities. Rural unemployment is, therefore, one of the reasons for the flourishing rickshaw profession in the cities of India (Samanta & Roy, 2013).

However, over the years, the number of hand-pulled rickshaws is likely to decrease significantly as younger educated generations are finding this profession as low-paying but physical labor-intensive occupation. On the contrary, the aged pullers are still work and the speed has become slow resulting in decreasing its demand among local residents. As this is a mode of livelihood for poor people, where dependency ratio is about 4-6. Thus, with abolition of this occupation, many families may face problems. Thus, government should reframe the urban transport related policies. Future schemes may incorporate **skill development programs** and **financial aid** to these rickshaw pullers for alternative livelihoods.

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**CONSTRUCTED WETLANDS FOR WASTEWATER REUSE AND  
RENEWABLE-ENERGY-DRIVEN IRRIGATION IN  
TRINIDAD AND TOBAGO, WEST INDIES**

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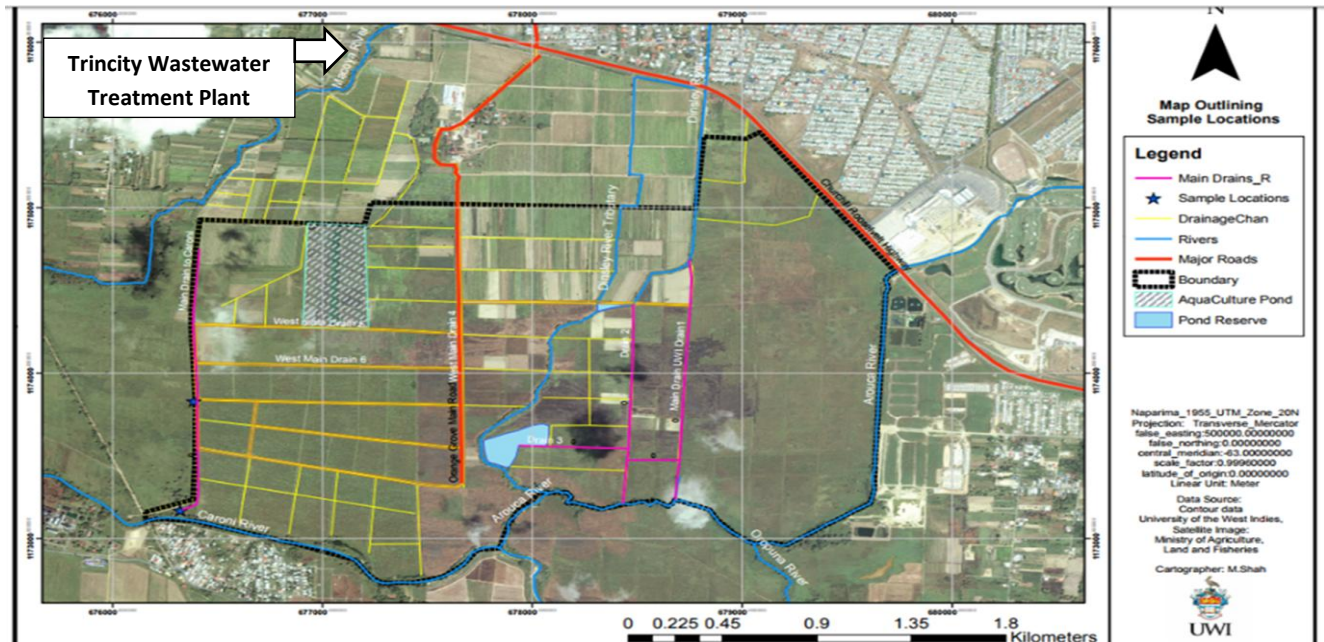
**ABSTRACT**

*Constructed Wetlands are engineered systems designed to imitate natural wetlands for wastewater treatment. They utilise soil, plants and microbes to filter out pollutants and use macrophytes to absorb nutrients. This study adopts a mixed-methods research design to evaluate pollutant removal efficiencies and wastewater reuse potential using integrated nature-based solutions (NbS) and renewable energy solutions. Removal of key water quality parameters (BOD<sub>5</sub>, COD, TSS, NH<sub>4</sub>-N, PO<sub>4</sub><sup>3-</sup> and E. coli) was assessed by varying geotextile membrane types and biofilter media in experimental treatment rigs. Treatment performance was compared for reclaimed water (RW), conventional irrigation water (CW), and secondary effluent (SW) using a Wastewater Reuse (WWR) prototype. Horizontal flow constructed wetlands planted with *Phragmites australis* was designed with a cross-sectional area of 3.75 m<sup>2</sup>, hydraulic loading rate of 0.8 m<sup>3</sup> m<sup>-2</sup> day<sup>-1</sup>, and flow rate of 3 m<sup>3</sup> day<sup>-1</sup>, operating at retention times of 24–120 h. Field trials achieved average removal efficiencies of 75.99% (BOD), 76.16% (COD), 57.34% (TDS), 62.08% (nitrate), 58.03% (phosphate), and 57.83% (potassium). The study further evaluated a solar-powered automated drip irrigation system to quantify water savings, energy consumption, and crop yield outcomes. Knowledge, Attitudes, Practices, and Willingness to Pay were assessed to inform national wastewater reuse standards, supporting sustainable Water-Energy-Food-Ecosystems nexus.*

**KEYWORDS:** *Wastewater Reuse; Constructed Wetlands; Geotextiles; Solar-Powered Irrigation; Water Quality; WEFE Nexus.*

## 1.INTRODUCTION

This study aimed to investigate the risks and hazards associated with treated wastewater and agrochemicals, and to assess water quality for irrigation and crop quality at the proposed site for the Orange Grove Food Crop Project in Tacarigua, Trinidad and Tobago, West Indies, which is adjacent to the Trincity municipal wastewater treatment plant (WWTP) (see Figure 1).



**Figure 1.** Map of Orange Grove Food Crop Project located near the Trincity Wastewater Treatment Plant, Trinidad and Tobago, West Indies.

### 1.1 AIM OF THE STUDY

The overarching aim of this study is to evaluate integrated nature-based and technological solutions for safe wastewater reuse in agriculture by assessing pollutant removal performance, irrigation efficiency, and resource recovery within constructed wetland and solar-powered irrigation systems.

### 1.2 SPECIFIC OBJECTIVES

To achieve this aim, the research study pursues the following specific objectives:

- To quantify the removal efficiencies of key water quality parameters (including BODs, COD, TSS,  $\text{NH}_4\text{-N}$ ,  $\text{PO}_4^{3-}$ , and E. coli) by assessing the influence of different geotextile membrane types and biofilter media configurations in experimental biofilter rigs treating reclaimed water (RW), conventional irrigation water (CW), and secondary effluent (SW).
- To evaluate the treatment performance and hydraulic behaviour of vertical flow constructed wetland (VFCW) systems, comparing alternative configurations in terms of media

composition, depth, and vegetation, to identify cost-effective designs suitable for decentralised domestic wastewater treatment and potential reuse in irrigation.

- To assess the effectiveness of a solar-powered automated drip irrigation (SPADI) system, by quantifying water savings, energy consumption (kWh/day), and crop yield responses (biomass, marketable yield, and water use efficiency) for lettuce and kale under controlled experimental conditions.

The project site, the Orange Grove Food Crop Project, located in Trinidad, West Indies, offers a semi-controlled environment with a uniform soil type. This allows for experimental assessments, ensuring that produce will not enter the market until it is confirmed safe for consumption. Additionally, the site is prepared for equipment installation, including demonstration plots equipped with monitoring components, and has baseline soil property information available.

Lettuce (*Lactucasativa*) and kale (*Brassica oleracea* var. *acephala*) have been selected as the crop for this study due to its sensitivity to irrigation water quality issues. As the most commonly consumed raw vegetable, lettuce has a leafy structure that may protect pathogens from light and desiccation, promoting their persistence (Pettersen et al., 2001). The choice of this crop was also influenced by its growth rate, given that the total data collection timeline was 18 months.

This study will examine the water-energy-food-ecosystems (WEFE) nexus, highlighting the connections between crop production risks, renewable energy, and the reuse of treated wastewater in agriculture. It aims to identify research gaps related to emerging pollutants that are insufficiently addressed in current regulations. Furthermore, it will assess how findings related to permeable geotextile membranes and filter materials (biochar and chitosan) could influence future wastewater management practices and explore the potential implications of these findings for policymakers in integrating agricultural practices with renewable energy solutions.

## 2. REVIEW OF LITERATURE

Agricultural use of reclaimed municipal wastewater has become a notable and economically viable alternative water resource (Drechsel et al., 2015; Eslamian, 2016). This practice is implemented on about 20 million of the 200 million hectares of globally irrigated land (Jaramillo & Restrepo, 2017), positioning agriculture as the largest user of reclaimed water (Lazarova et al., 2013) and a sector exhibiting significant economic benefits (Younos & Parece, 2016). The application of reclaimed water for crop irrigation presents multiple advantages, including mitigating stress on freshwater resources (Eslamian, 2016; Parsons et al., 2010), providing nutrients that minimize the need for synthetic fertilizers (Lyu et al., 2016; Pedrero et al., 2013b; Vicente-Sanchez et al., 2014; Vivaldi et al., 2015), and generating higher crop yields compared to freshwater irrigation (Vergine et al., 2016; Vivaldi et al., 2015). However, improper management of water reclamation can lead to negative consequences for the environment and human health (Eslamian, 2016; Lazarova et al., 2013). The most widely recognized risk is the potential introduction of pathogens into the food supply chain (Castro Ibanez et al., 2015; Lopez-Galvez et al., 2016b). Furthermore, increased salinity can adversely affect crops and soil quality (Pedrero et al., 2008; Pedrero et al., 2010), while phytotoxic elements can inhibit plant growth and reduce crop yields (Parsons et al., 2010; Pedrero, 2010). High levels of sodicity can also deteriorate soil structure (Pedrero & Asano, 2008; Pedrero et al., 2010). Contaminant removal is achieved through various processes: Sorption, where contaminants adhere to soil particles and organic matter; Biodegradation, in which microorganisms decompose organic contaminants into

less harmful compounds; Phytoremediation, where plants absorb and accumulate contaminants or aid in their breakdown through root exudates; Photodegradation, which involves the breakdown of certain contaminants through light-induced chemical reactions; and Volatilization, where some contaminants transfer from water to air through evaporation.

### 3 METHODOLOGY

#### WWR-Prototype Design Experimental Setup

The research methodology incorporates Caribbean case studies and employs a mixed-methods approach with both quantitative and qualitative techniques. Two experimental setups, the constructed vertical flow wetland and gravity biofilter systems, will be tested with the selected crops. Three types of influent water will be utilized: reclaimed water (RW) from the WWR prototype, conventional irrigation water (CW), and secondary effluent (SW) from the Trincity wastewater treatment plant (WWTP), with RW produced by treating SW. The WWR prototype comprised three experimental reclaimed wastewater storage tanks/pipes, with one dedicated to reclaimed wastewater and engineered layers of granular material and geotextile membranes designed to collect treated wastewater. The laboratory setup enabled flow and water-quality measurements (see Figure 2). The three storage tanks/pipes were used to evaluate the water quality of the inflow (SW) and outflow (RW). The designs varied as follows: (i) without a geotextile membrane, (ii) with an upper geotextile membrane, and (iii) with both upper and lower geotextile membranes. Weekly monitoring of water quality parameters, including nutrients, biochemical oxygen demand, chemical oxygen demand, and suspended solids, was conducted to determine removal efficiencies (see Tables 1 and 2).

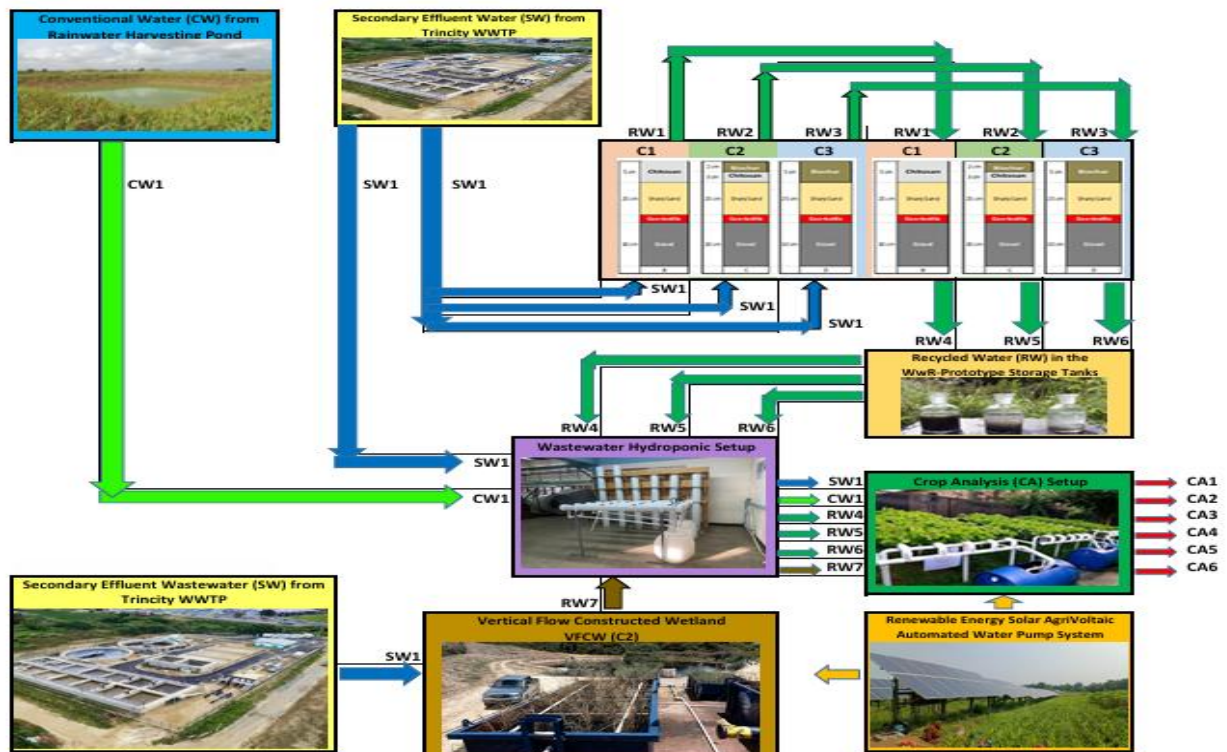


Figure 2. Flow Chart of Experimental Setup and Methodology at the University of the West Indies, St. Augustine Campus, Trinidad and Tobago

Experiments aimed to evaluate contaminant retention and the effectiveness of geotextile membranes and filters. The results would demonstrate the system's efficiency in removing contaminants from secondary effluent. The WWR-Prototype incorporates a permeable geotextile membrane and utilizes a combination of water treatment technologies, including biochar, chitosan, and gravel. Chitosan, derived from chitin found in marine organisms and fungi, along with biochar from biomass pyrolysis, enhances contaminant removal through sorption of heavy metals.

The geotextile membrane and bio-filter media systems were constructed using plastic water tanks/pipes with dimensions of 350 mm × 350 mm × 780 mm (length × width × depth). Geotextile membranes, which are porous fabrics used in agriculture, were fabricated using natural materials, such as jute and coir. They are eco-friendly, biodegradable, and sustainable.

### 3.1 Crop Experimental Setup

The cultivation of lettuce (*Lactucasativa*) and Kale (*Brassica oleracea* var. *acephala*) is scheduled to occur over a 90-day period spanning from January to March 2025. This will take place in 72.0 m<sup>2</sup> grow boxes situated adjacent to municipal wastewater treatment plant (WWTP) facilities in Orange Grove, Tacarigua. The project site coordinates were 10.63678° N (10° 38' 12" N) latitude and -61.37686° W (61° 22' 37" W) longitude. Lettuce and kale were selected for this study because of their pronounced susceptibility to salinity stress, which substantially influences growth patterns and nutritional content (Kim et al., 2008). Moreover, as raw vegetables are the most frequently consumed, lettuce is an excellent model for assessing safe agricultural production practices. The leafy structure of lettuce and kale may offer protection against pathogens by shielding them from light exposure and desiccation, potentially facilitating their continued survival (Pettersen et al., 2001).

### 3.2 Irrigation Water Sources and Methods

The irrigation process utilised three water types: i) reclaimed water (RW) from the WWR prototype, using secondary effluent from a wastewater treatment plant, ii) conventional irrigation water (CW), and iii) secondary effluent (SW) from the Trincity WWTP. RW was produced by processing SW using a WWR prototype. CW, supplied by the Orange Grove irrigation community, is a blend of various sources: the Caroni River (88.7%), Macoya River (3.0%), Dinsley River (6.7%), and Tantrill River (1.6%). CW is mainly used for agronomic quality control owing to its suitable salinity levels. SW was obtained from the Trincity WWTP after undergoing treatment involving pretreatment steps, double-stage activated sludge with extended aeration, and secondary clarification. The experiment combined three water types (RW, CW, and SW) with two types of leafy vegetable crops, namely lettuce and kale (L and K), resulting in six treatments: RW-L, RW-K, CW-L, CW-K, SW-L, and SW-SK, each with four lettuce and kale plant replicates. Using a randomized design, 144 lettuce and kale plants were planted per treatment plot (12 plants/m<sup>2</sup> spacing) on ridges, totalling 864 lettuce and kale plants in the entire area.

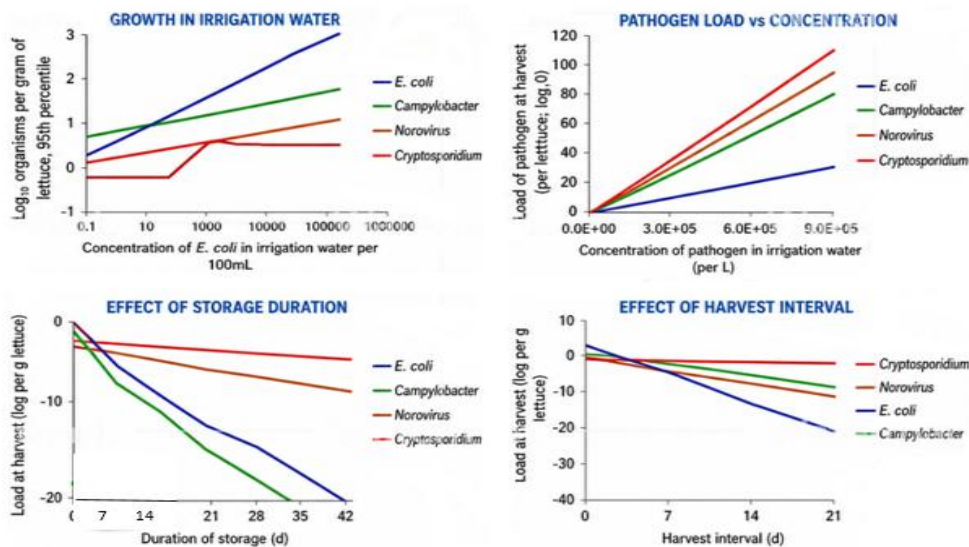
### 3.3 Irrigation Water Quality Analysis

Physicochemical analyses were conducted for different irrigation water types. Bi-weekly grab samples (eight in total) were collected during the experimental period using clean, non-sterile bottles (not for microbiological analyses). The bottles were rinsed and filled with water before collection from the various sites. After transportation to the laboratory, samples were stored at

Five Degrees Celsius prior to processing. A closed hydroponic system was set up, which saved more water and fertilizers than an open system. The three types of water used were conventional water (CW), secondary water/treated wastewater from the water treatment plant (SW), and recycled treated wastewater (RW). These waters were pumped through the growing zone to flow over the lettuce plant roots. The water-saving effect of this system has been confirmed by many studies. A potential problem of the closed hydroponic system is the accumulation of salt ions, mainly sodium (Na) and chlorine (Cl). Increased salt concentration can lead to decreased plant photosynthesis and transpiration rates. Elevated salt levels may cause a reduction in plant weight and apparent toxicity effects caused by chlorine (Cl).

Wastewater quality parameters measured included, physicochemical parameters such as pH, Conductivity, Total Dissolved Solids (TDS), Dissolved Oxygen (DO) and Temperature. Chemical parameters measured were Nitrate, Ammonia, Phosphorus, Potassium, Chloride and COD. The bacteriological parameter measured was faecal coliform.

These parameters were selected based on their importance in wastewater treatment and reuse for irrigation. Temperature and pH help to understand the operating conditions of the system. TDS, Conductivity, and DO provide the primary indications of the chemical constituents in wastewater. Nitrates, potassium, and phosphorus are essential nutrients for crop growth. This study aimed to determine the availability of chemical parameters in the final effluent. Ammonia was measured because of its toxic nature, which can affect biological life and treatment system performance at high levels. Chemical oxygen demand was measured to quantify organic loading, as high organic content depletes oxygen in the receiving environment. COD measures the total amount of oxygen needed to break down both organic and inorganic matter in water. BOD was measured to quantify the amount of oxygen. BOD measures the amount of oxygen that microorganisms need to break down organic matter in water. It is desirable that the final effluent has low organic loading. Faecal coliform was used as an indicator of faecal pollution, representing the level of biological pollution loading (see Figure 3).

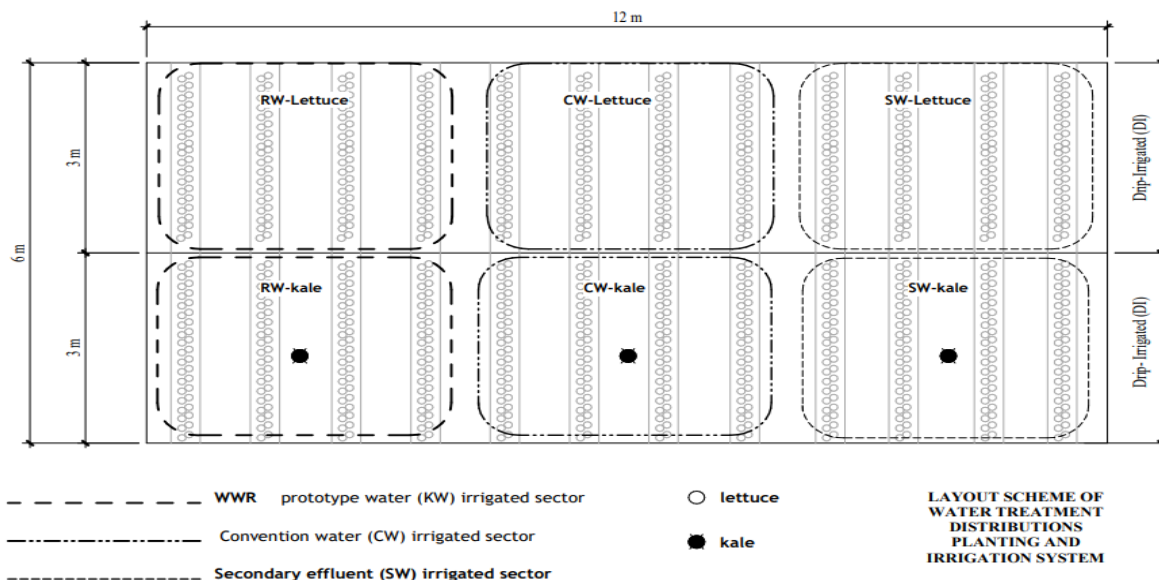


**Figure 3. Graphs (i) to (iv) Showing Modelled Pathogen Survival Rates in Water and on Vegetables(Adapted from Pond, K. et al. (2007), B17005 Review of the Use of Water in UK Agriculture)**

### 3.4 Agronomic/ Crop Quality Analyses (Lettuce and Kale)

For analysing agronomic quality, microbial analyses are performed whereby sampling of lettuces and kale are performed at their growth stage 49, according to the BBCH scale (Meier, 2001), when the produce reaches commercial size. Each sample consisted of a whole lettuce/kale head cut from its base, with soil removed. Fresh (whole lettuce/kale) and commercial (cleaned lettuce/kale, without outer leaves) weights were measured on-site immediately after harvesting and drying the lettuce with paper towels to avoid inaccuracies due to plant water losses and external moisture. Lettuces/kale were dried for at least two days at 65 °C to measure dry weight. The percentage of water content in lettuces/kale was calculated based on fresh and dry weight values. To analyse C concentrations, macronutrients (total N, NO<sub>3</sub><sup>-</sup>, PO<sub>4</sub><sup>3-</sup>, K, Ca, Mg), micronutrients, phytotoxic elements (B, Cl<sup>-</sup>, Na), and metals, lettuce leaves underwent a cleaning preparation process. This process consisted of detergent washing (Alconox 0.1%), rinsing with tap water, cleaning with 0.005% hydrogen chloride (HCl) solution, and rinsing with distilled water. Cleaned samples were then drained by leaving them on filter paper. Subsequently, they were oven-dried at 65 °C for at least two days. Dried samples were blended and digested in nitric perchloric acid (2:1).

- (i) Field sampling: Collect soil and plant samples from different parts of the field.
- (ii) Laboratory analysis: Analyse soil for nutrient content, pH, organic matter, and other properties.
- (iii) Plant analysis: Assess plant health, growth parameters, and yield.
- (iv) Pest and disease assessment: Check for signs of pests and diseases.
- (v) Data Interpretation: Use agronomic data to make decisions on fertilization, irrigation, and pest control.



**Figure 4. Schematic Layout of Planting and Irrigation Distribution Layout in the Field**

### 3.5 Vertical Flow Constructed Wetland System Experimental Setup

The vertical flow-constructed wetland system experimental setup wetlands tested two crop types (lettuce and kale) using three water sources: reclaimed water (RW), conventional irrigation water (CW), and secondary effluent (SW) from the Trincity Wastewater Treatment Plant, and is designed for a single household, has a surface area of 16 m<sup>2</sup> and a total depth of 1.4 m. It consists of a 0.2 m drainage layer, a 1.0 m filter sand layer, and a 0.2 m insulation layer, with a 0.2 m embankment to prevent water intrusion. The filter bed is enclosed by a 0.5 mm thick geotextile membrane protection, with common reed (*P. Australis*) planted at four (4) plants/m<sup>2</sup> using seedlings or rhizomes (See Figure 5).

A vertical flow constructed wetland (VFCW) is an engineered system that treats wastewater by filtering it through layers of sand, gravel, and other permeable materials, with the liquid collected at the base. VFCWs effectively treat agricultural wastewater by mimicking natural wetland processes through the use of vegetation, soil, and microbes. They utilize physical, biological, and chemical mechanisms to remove pollutants. VFCWs require proper lining and filter materials.

Design specifications of vertical flow constructed wetlands and design guidelines for efficient wastewater treatment

- (i) Depth: 0.5 1 meter.
- (ii) Surface area based on wastewater volume and treatment goals.
- (iii) Flow rate: Ensure adequate contact time with the filter medium.
- (iv) Plant selection: Use deep-rooted wetland plants to enhance permeability and microbial support.
- (v) Maintenance access: Include access points for solid removal and vegetation management.

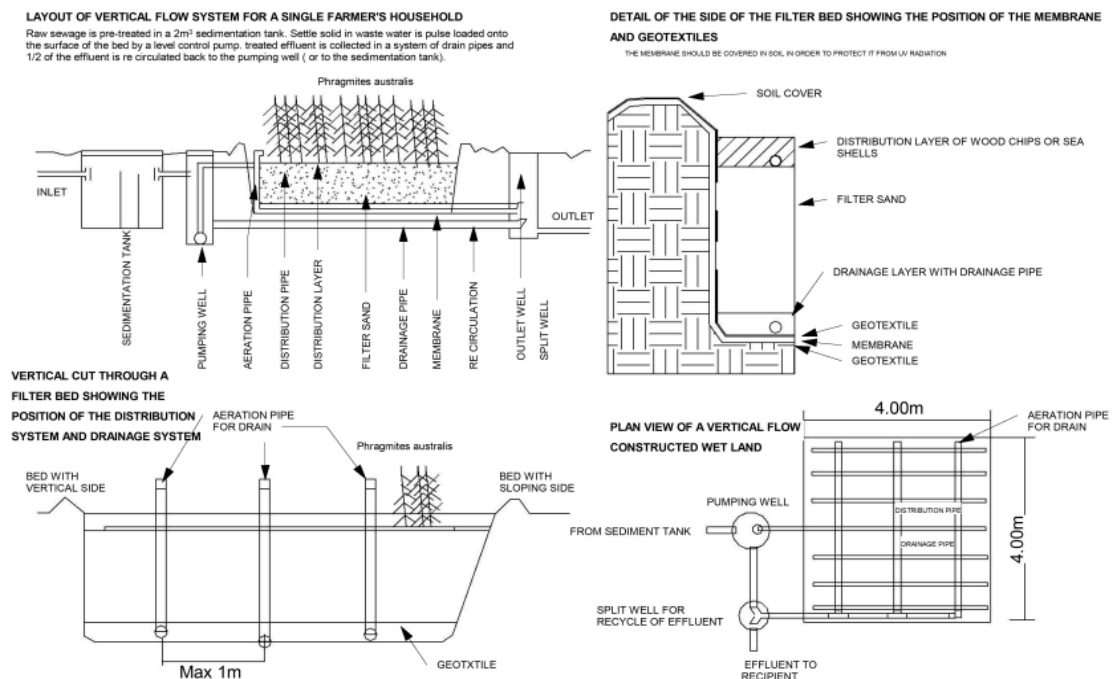


Figure 5. Schematic Diagram Showing Layout of Vertical Flow Constructed Wetland System

### 3.6 Horizontal Flow Constructed Wetland System Experimental Setup

A horizontal free-surface flow constructed wetland (HFCW) experimental setup (See Figure 6) was developed at the Fluids Laboratory, University of the West Indies, St. Augustine, Trinidad and Tobago, to treat greywater generated and collected from bathrooms, kitchens, and laundries of households within the Orange Grove, Tacarigua community. An HFSF wetland was chosen over vertical subsurface flow system because it requires less complex construction, allows direct plant growth on the water surface, and is more adaptable to fluctuating greywater loads in urban communities with limited resources (Alao et al., 2021; Raphael et al., 2023; Mustapha et al., 2018).

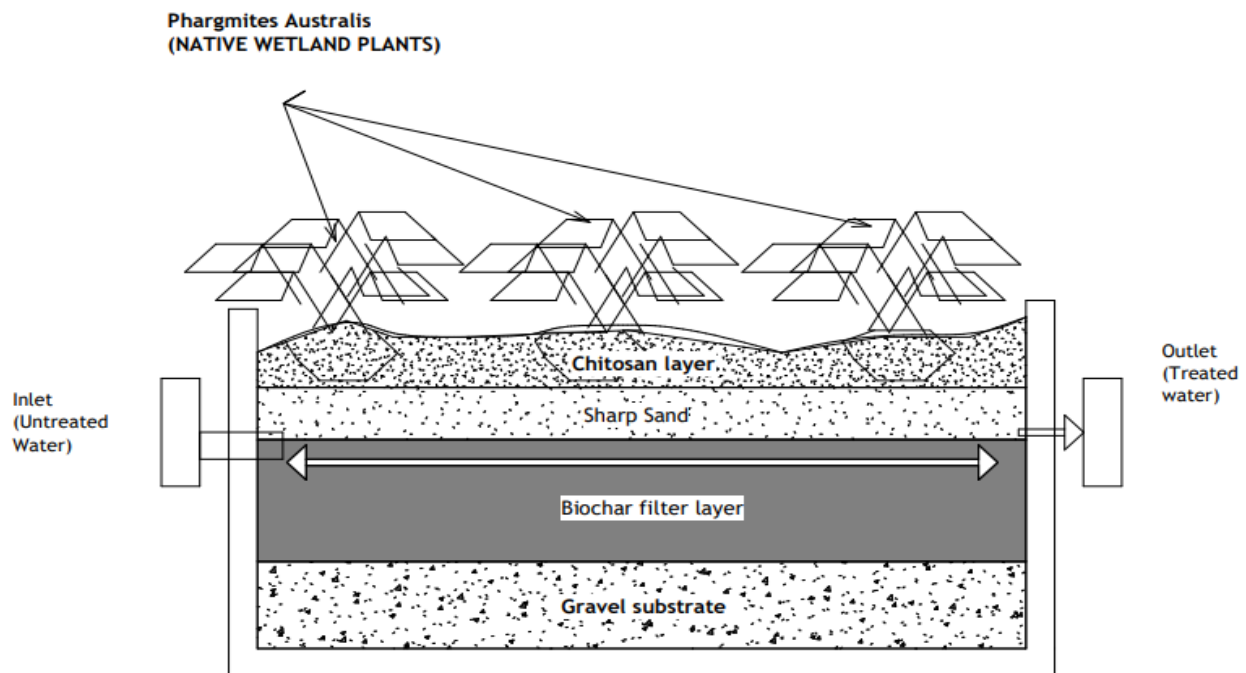
The HFCW wetland system for open-air conditions, shown in Figure 6, was constructed with dimensions of 12 m × 1 m × 1 m in length, width, and depth, respectively, in accordance with the recommended design ranges for horizontal flow constructed wetlands, which specify depths of 0.3–1.0 m and length-to-width ratios of 10:1 to 20:1 (Kadlec and Wallace, 2009; Vymazal, 2011). The system components comprised an inlet, a 1.5-m detention basin, and three treatment cells lined in sequence with an impermeable polymer to prevent seepage, and all were maintained under open-air conditions.

The HFSF was operated with three types of water CW, SW, and RW and a minimum hydraulic loading rate (HLR) of 0.20 m/day mg/L, which falls within the recommended design and operational ranges of 0.10–0.40 m/day for horizontal flow wetlands in warm climates (Arden and Ma, 2018; Rahman et al., 2023) and was selected to represent low-flow conditions for evaluating the influence of the hydraulic rate on the efficiency of pollutant removal.

*Phragmites australis*, which stands upright and is rooted, was used as the treatment vegetation because of its rapid growth, high nutrient uptake efficiency, tolerance to varying pollutant loads, and proven performance in tropical constructed wetlands for greywater treatment. It was then allowed to stabilize for three months before continuous operation for four months. To account for any potential environmental influence on the performance of the wetland, the ambient temperature and rainfall were recorded throughout the period of operation.

The effectiveness of treatment was evaluated by monitoring water quality parameters, including biochemical oxygen demand (BOD), total phosphorus, and total suspended solids. Sampling was performed following the procedures outlined by APHA, AWWA, and WEF (2012). The volumes of the influent and effluent were measured volumetrically every two to three days to calculate the average daily discharge for each unit in the system for a detailed performance analysis of the constructed wetland for the three wastewater types (CW, SW, and RW).

The field dimension of the constructed wetland was 250 x 150 x 80 cm with a slope of 0.01 (1 %). The wetland media consisted of a gravel bed underlain on an impermeable concrete surface. The bed was filled to a height of 50 cm with coarse rock, medium gravel, fine gravel, gravelly sand, and coarse sand. The top portion of the wetland unit was filled with local sandy clay loam soil to support vegetation. This process depicted in Figure 6.



**Figure 6. Experimental Setup of Horizontal (Cross) Flow Constructed Wetland System – Planted Horizontal Flow Constructed Wetland Setup**

### 3.7 Sample Collection / Laboratory Testing

Samples were collected bi-weekly from the influent and effluent of the HFSF constructed wetland unit operated at each hydraulic loading rate. The collections were done by means of plastic containers that had been sterilized and rinsed with the greywater sample before use. These samples were collected for analysis after three months, to ensure the stability of the operation of the system. The concentrations of biochemical oxygen demand ( $BOD_5$ ), total phosphate (TP), total suspended solids (TSS), and ammonium nitrogen ( $NH_4-N$ ) were determined according to the Standard Methods for the Examination of Water and Wastewater (APHA, AWWA, and WEF, 2012), corresponding to Methods 5210 B, 4500-P, 2540 D, and 4500-NH<sub>3</sub>, respectively. All analyses were performed in triplicate ( $n = 3$ ) to ensure the precision of measurements, as no replicate treatment units were constructed; temporal replication was achieved through repeated bi-weekly sampling during the study period. The influent and effluent wastewater flows were measured for each HFSF unit, enabling the calculation of the daily mean discharge. Pollutant mass loading and removal efficiency were subsequently estimated using the measured flow and concentration data.

### 3.8 Solar Powered Automated Pump System for Drip Irrigation

A solar-powered automated pump system for drip irrigation utilizing a pump and solar panels was employed to irrigate lettuce and kale crops. This system efficiently delivers water directly to plant roots, thereby minimizing water losses from evaporation and runoff. In addition to water conservation, it reduces reliance on non-renewable energy sources.

- Solar Power Calculated for Pumping
- Motor Power = 2.0 – 3.7 kW

The Solar PV Array is used for Irrigation purposes. This system delivers approximately 140 m<sup>3</sup> of water per day from a total head of 10 m. Comparing this energy need with the theoretical Hydraulic Power, and assuming the pump works 8 hrs/day, and only 60% of the Peak Solar Power utilized, then

$$P_{\text{hydraulic}} = \frac{140 \times 0.6}{8 \times 3600} (10 \times 1000 \times 9.81) = 286 \text{ W}$$

Supply and installation of a 3.0 kW solar photovoltaic (PV) panel (monocrystalline) system array. Installation requires mounting and securing to metal structures on the ground of adequate strength and design to withstand the load of modules and high wind velocities of up to 150 km/h. Provision of a 6 kW pure sine wave inverter and a 6 kW solar hybrid system split-phase 120 V/240 V, 60 Hz, 5.1 kW lithium-ion battery bank controller system (deep-cycle lead acid [AGM] type with an appropriate 12 V battery system rating). The use of solar power ensures a sustainable and cost-effective irrigation method, which is crucial for regions experiencing water scarcity owing to climate change.

### 3.9 Rule of Thumb for Solar Water Pumping

A common rule of thumb is that a 1000 W<sub>p</sub> (1 kW<sub>p</sub>) solar water pump can draw and pump approximately 40 m<sup>3</sup> of water per day from a source that is up to 10 m deep. We find that the hydraulic energy is 1.09 kWh per day. Assuming eight hours of sunshine, 80% motor-pump efficiency, and 10% pipe loss, the required electric power would be 0.19 kW. In other words, a large safety margin is assumed. Typically, 40 m<sup>3</sup> of water per day is sufficient to irrigate up to one hectare of land planted with regular crops.

The aim was to find an affordable pump and minimize costs by avoiding the use of batteries. The use of a DC pump avoided the cost of DC/AC conversion. The drawback is that DC motors have a shorter life than AC motors. Marine pumps were found to be a good choice; however, many were designed only for low heads. The actual pump can deliver approximately 15 m<sup>3</sup>/h or 4 L/s at zero head. It can operate at a head of 5–6 m; however, the flow rate is lower, although sufficient for the purpose. In this case, the motor was assumed to have a life of approximately one year. However, the profit from irrigation could cover the cost of motor replacement. In total, the pumping system cost less than USD 1,000. No electronic controllers were used; only a simple circuit breaker was used. The pump can irrigate approximately half a hectare (5000 m<sup>2</sup>). A flow rate of 4 m<sup>3</sup>/h for six hours will provide approximately 50 m<sup>3</sup>/hectare/day.

### 3.10 Statistical Analysis

Statistical analysis of water and crop quality data was conducted using analysis of variance (ANOVA). Statistical Package for the Social Sciences (SPSS Version 19) was used to analyse the results. A combination of qualitative and quantitative data will be gathered from n respondents throughout Trinidad and Tobago using convenience sampling. The sample size, n, was determined using Kish's formula. A KAP survey will be implemented to assess stakeholders' knowledge of treated wastewater, their attitudes towards its reuse, and current practices. The target population of the study consisted of 223 farmers. To achieve a 95% confidence level, Kish's formula was used to calculate the sample size, as described by Assaf and Al Hejji (2006). Based on this calculation, questionnaires were distributed to at least 59 farmers within the catchment area to maintain a 95% confidence level:

$$n = n^1 / [ 1 + (n^1 / N)]$$

where:

All Farmers (Registered/ Non-Registered)	
$n^1 = S^2/V^2 = (0.5)^2 / (0.06)^2 = 69.44$ $N = 223$ $n = 69.44 / [1 + (69.44/ 223)] = 52.95$	Allowing for the addition of a non-responsive rate of 5 to 15 % and using a 12% rate (Ameer, 2005; Amoako, 2011): $12/100 * 52.95 = 6.35 = 6.0$ Total Farmers, $n = 53 + 6 = 59$

N = Total number of population,

n = Sample size from a finite population,

$n^1 =$  Sample size from infinite population =  $S^2/V^2$

S = is the variance of the population elements, and V is the standard error of the sampling population (S=0.5, V=0.06).

Statistical analysis will also present gaps where innovation can be achieved. Wastewater reuse in the agricultural sector has economic benefits that can improve farmers' livelihoods. Jiménez et al. (2011) reported a doubling of revenue with wastewater reuse in the sector. Michetti et al. (2019) warned that dissonance between demand and supply affects expenditure and market stability.

### 3.10.1 Statistical Analysis using t Tests

Table 1 shows the BOD, COD, Total dissolved solids, Nitrate, Phosphate, and Potassium value comparison of raw and treated wastewater analysis using t test. The table shows comparison of mean, Standard deviation, Standard error mean. The two-tailed P value equals 0.0029. By conventional criteria, this difference is considered to be very statistically significant. The mean of raw water minus treated water equals 124.60. 95 % confidence interval is obtained with difference from 55.12 to 194.08. Intermediate values used in calculations were  $t = 4.0569$ ,  $df = 9$ , and standard error of difference = 30.713. The two-tailed P value for COD comparison equals 0.0011. By conventional criteria, this difference is considered to be very statistically significant. The mean of raw water minus treated water equals 228.280. 95 % confidence interval of this difference: From 119.345 to 337.215 intermediate values used in calculations are  $t = 4.7405$ ,  $df = 9$ , and standard error of difference = 48.156 (Table 2). The two-tailed P value for TDS is less than 0.0001. By conventional criteria, this difference is considered to be extremely statistically significant. The mean of raw water minus treated water equals 603.33. 95 % confidence interval of this difference is from 488.90 to 717.77. Intermediate values used in calculations are  $t = 11.7473$ ,  $df = 10$ , and standard error of difference = 51.359.

The two-tailed P value for nitrate equals 0.0003. By conventional criteria, this difference is considered to be extremely statistically significant. The mean of raw water minus treated water equals 16.17. 95 % confidence interval is obtained with a difference from 9.66 to 22.67. Intermediate values used in calculations are  $t = 5.6239$ ,  $df = 9$ , and standard error of difference = 2.875. The two-tailed P value for phosphate equals 0.0767. By conventional criteria, this difference is considered to be not quite statistically significant. The mean of raw water minus treated water equals 3.1863. 95 % confidence interval is obtained of difference from -0.4202 to 6.7929. Intermediate values used in calculations are  $t = 1.9986$ ,  $df = 9$ , and standard error of difference = 1.594. The two-tailed P value for Potassium equals 0.0023. By conventional criteria,

this difference is considered to be very statistically significant. The mean of raw water minus treated water equals 6.5917. 95 % confidence interval of difference from 3.0554 to 10.1280 is obtained. Intermediate values used in calculations:  $t = 4.2167$ ,  $df = 9$ , and standard error of difference = 1.563.

After t test analysis, it was observed that every parameter before and after treatment is showing a 95 % confidence interval which means the constructed wetland is showing higher removal efficiency for all the selected parameters. Nitrification and denitrification are the main processes for nitrogen removal from wastewater. Denitrification is an anaerobic heterotrophic microbial process often limited by the presence of oxygen (O<sub>2</sub>) and the availability of labile carbon substrates. Nitrification is an aerobic chemoautotrophic process (Ong et al. 2011). The major processes responsible for phosphorus removal in SFWC are typically by adsorption, precipitation, and plant up-take rates. The frequent filtration materials used in SFCW are gravel, which is commonly good in absorption compared to the plant roots (Vymazal 2004). Phosphorus is an important nutrient required for plant growth and is usually act as a limiting factor for vegetative productivity. Phosphorus is transformed in the wetland by a complicated biogeochemical cycle. Accordingly, most of the researchers claimed that wetlands are not efficient in phosphorus reduction (Kadlec and Knight 1996; Adeniran et al. 2012; Akratos et al. 2008).

**Table 1. BOD, COD, and TDS value comparison using t test**

Sl. No.	Group	BOD		COD		TDS	
		Raw	Treated	Raw	Treated	Raw	Treated
1	Mean	155.00	30.40	287.600	59.320	1050.00	446.67
2	Standard Deviation (SD)	68.02	2.19	106.516	6.922	118.32	42.74
3	SEM	27.77	0.98	43.485	3.096	48.30	17.45
4	N	6	5	6	5	6	6

**Table 2. Nitrate, Phosphate, and Potassium Value comparison using t test**

Sl. No.	Group	Nitrate		Phosphate		Potassium	
		Raw	Treated	Raw	Treated	Raw	Treated
1	Mean	30.17	14.00	6.0183	2.8320	12.1917	5.6000
2	Standard Deviation (SD)	5.64	3.32	3.1317	1.8271	2.9665	1.9987
3	SEM	2.30	1.48	1.2785	0.8171	1.2111	0.8939
4	N	6	5	6	5	6	5

#### 4. REVIEW FINDINGS

##### Irrigation Water

The water reclamation system of the WWR prototype was expected to exhibit removal efficiencies for EC, SAR, turbidity, and TSS. Removal efficiencies for nutrients of agronomic interest, i.e. The removal efficiency for PO<sub>4</sub><sup>3-</sup> concentration was analysed. Removal efficiency for PO<sub>4</sub><sup>3-</sup> concentration will be analysed. The removal efficiency of E. coli is expected to be obtained. Concentrations of other metals and metalloids were determined whether under or over the detection limit. The presence of culturable E. coli will be assessed for significant differences

amongst the different types of irrigation water. In this regard, storage and conveyance of CW through open-air reservoirs and canals, respectively, renders this water source prone to contamination before reaching the end user. In this regard, storage and conveyance of CW through open-air reservoirs and canals, respectively, render this water source prone to contamination before reaching the end user.

**Table 3. Expected Results for Wastewater Quality**

WATER VARIABLE	QUALITY	UNITS	EXPECTED RESULTS	NO RESTRICTION FOR IRRIGATION	SEVERE RESTRICTION FOR IRRIGATION
Faecal Coliform		Count/ 100 ml		-	< 1000
Nitrate-N		mg/L	<5	< 5	>30
Nitrogen (NO <sub>3</sub> -N)		mg/L	<5	<5	
pH		-	7.42	6.5 – 8.4	<6.5 &>8.4
Electrical Conductivity		mmho/cm	<0.7	< 0.7	>3.0
Total Dissolved Solids		mg/L	<450	450	>2,000
Total Suspended Solids		mg/L	NIL	NIL	>100
Sodium (Na)		SAR	<3		
Boron (B)		mg/L	<0.7	0.7	3.0
Chloride (Cl)		mg/L	<4	3.0	40.0
Turbidity		NTU		< 2 - 5	-
Dissolved Oxygen		mg/L		2 - 4	-
Biological Oxygen Demand(BOD), 5 days @ 27 deg. C		mg/L	2.64	10 - 30	30
Chemical Oxygen Demand (COD)		mg/L	7.2		250
Temperature		Deg. C		20 - 30	-
Oil and Grease		mg/L	2		10
Pesticides			≤ 0.01		
True Colour Units		TCU	1		5
Iron (Fe)		mg/L	NIL		3
Nickel (Ni)		mg/L	NIL		3
Chromium (Cr)		mg/L	NIL		2
Colony Forming Units (CFU) Bacteria			NIL		NIL
LC 50 (Bio Assay Test)			>96%		90%

#### 4.1 Horizontal Flow Constructed Wetland System

**Table 4.** The Expected Results of a Performance Data (mean +1 S.D.) of Single House Horizontal Flow Constructed Wetland System for Water Catchment Area of 12,000 persons, and farming acreage of 355 acres.

System	Parameter	Inlet	Outlet	Removal Efficiency (%)
Horizontal Flow System (Without Circulation)	TSS	85±28	8±3	91
	BOD	254±123	19±4	92
	NH <sub>4</sub> -N	105±45	23±17	78
	NO <sub>2</sub> + NO <sub>3</sub> -N	<0.1	40±13	-
	Total N	125±51	72±28	43
	Total P	17.2±7.0	13.0±6.6	25
Horizontal Flow System (With 100% Recirculation)	TSS	68±22	3±1	96
	BOD	100±35	11±3	89
	NH <sub>4</sub> -N	45±13	7±1	85
	NO <sub>2</sub> + NO <sub>3</sub> -N	0.13±0.00	36±4	-
	Total N	57±13	44±5	23
	Total P	5.2±1.7	5.7±1.2	0

NB: The inlet samples were collected as grab samples after the effluent water exits from the sump containing treated wastewater that meets the surface water quality regulations for rivers and water channels (WHO, 2011). This is for a water catchment area of 12,000 people and a farming acreage of 355 acres.

#### 4.2 Influent Wastewater Characterization

The influent treated wastewater (SW) is characterized by Table 5.

**Table 5: Properties of Influent Wastewater (SW)**

Sl. No.	Parameter	Concentrations in mg/l		
		Min	Max	Mean
1	Biological Oxygen Demand (BOD)	101	3390	643.2308
2	Chemical Oxygen Demand (COD)	315	1823	674.923
3	Total Nitrogen (TN)	2.28	196	60.37231
4	Total Phosphorous (TP)	0.06	32.6	14.01385

The parameters Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Nitrogen (TN) and Total Phosphorus (TP) were determined based on standard methods. The analysis was done immediately after sample collection, otherwise were properly stored. Low values of BOD, COD occur during heavy rainfall which indicates clear dilution effect.

#### 4.3 Organics and Nutrient Removal in PAGES

The constructed wetland tank was filled with water for a period of one month until well establishment of the wetland plant species, PhragmiteAustalis. The treated wastewater (SW) was

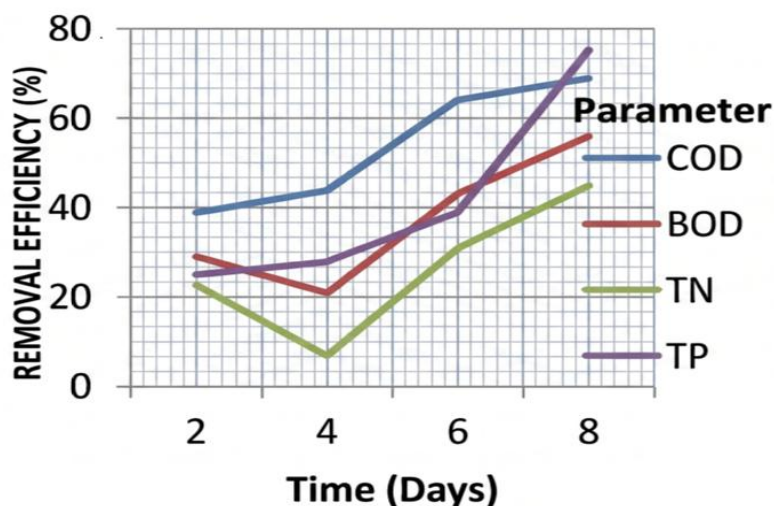
applied after one month. The systems were operated under four different hydraulic conditions by varying hydraulic residence time as 2, 4, 6 and 8 days (Table 6).

**Table 6. Results of Pilot Scale Constructed Wetland Tank**

Parameter	Outlet at Hydraulic Retention Time (HRT) at n Days							
	Inlet	2 Days	Inlet	4 Days	Inlet	6 Days	Inlet	8 Days
COD	174	105	176	98	179	64	161	49
BOD	48	34	42	33	39	22	36	16
TN	0.30	0.23	0.28	0.26	0.32	0.22	0.22	0.12
TP	2.25	1.68	2.22	1.59	2.27	1.38	2.19	2.19

The COD removal efficiencies were 39, 44, 64, and 69% for HRT of 2, 4, 6, 8 days, respectively. The BOD removal efficiencies were 29, 21, 43, and 56% for HRT of 2, 4, 6, 8 days, respectively. The TN removal efficiencies were 23, 7, 31, and 45% for HRT of 2, 4, 6, 8 days, respectively. The TP removal efficiencies were 25, 28, 39, and 75% for HRT of 2, 4, 6, 8 days, respectively.

As shown in Figure 8, there was a slight difference (5%) in removal between HRT of 2 days and 4 days. As the HRT increased to 6 days, there was 19% increase in COD removal when compared to COD removal at 4 days. The COD removal was doubled when there was an increase in HRT from 4 days to 8 days. BOD removal dynamics slightly differs from COD removal dynamics. There was 8% decrease in efficiency when HRT increased from 2 days to 4 days. The removal efficiency doubled at 6 days HRT and it further increased to 56% at 8 days HRT.



**Figure 8. Organic and Nutrient Removal in Phragmites australis HFCW (Adapted from Abou-Elala, S. I., Golinelli, G., El-Tabl, A. S., & Hellal, M. S., 2014).**

There was a two-thirds (2/3) decrease in TN removal efficiency when HRT increased from 2 days to 4 days and 1/3 increase at 6 days HRT. The TN removal efficiency further increased to 45% at 8 days HRT. There was only 3% increase in TP removal efficiency when there was an increase in HRT from 2 days to 4 days. And there was 11% increase at 6 days HRT compared to 4 days HRT. But the TP removal efficiency reached 75% at 8 days HRT.

Similar study to determine the effectiveness of constructed wetlands to treat tertiary effluent wastewater generated from studies involving Paşaköy Advanced Biological Wastewater

Treatment Plant, Cecen, F. et al., (2011), showed that TP removal efficiency (60%) might be due to use of gravel substrate. TP removal rates increased when the HRT was prolonged. But, increasing HRT from 2 days to 4 days did not improve the efficiency in terms of N and P removal.

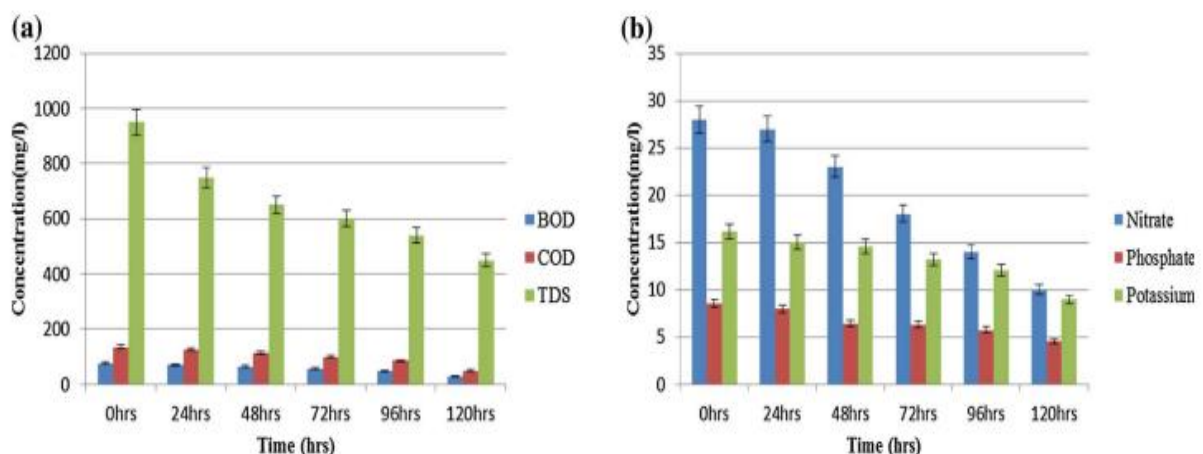
There was an increasing trend in COD removal efficiency as the HRT increased from 2 days to 6 days. Further increase in HRT to 8 days did not change the COD removal efficiency. There was an increasing trend in BOD removal efficiency as the HRT increased from 2 days to 8 days as it doubled from 25% to 52% even as the effluent BOD concentration followed the trend of influent BOD concentration.

Solano et al, (2004) presented results of treatment efficiency of a pilot-scale subsurface flow constructed wetland planted with *Phragmites australis* remove BOD, COD, and TSS. The TN removal efficiency decreased at 4 days HRT but increased at 6 days. There was only slight increase (2%) in removal efficiency when HRT increased from 6 days to 8 days. There was an increasing trend in TP removal efficiency as the HRT increased from 2 days to 8 days but there was a slight decrease (2%) at 4 days HRT which may probably be attributed to decrease in influent TP concentration (Figure 8).

*Phragmites australis* were able to establish successfully in wastewater treatment as reported by Calheiros et al, (2008). The treatment performance as reported by Calheiros et al, (2008) was higher than the present study as the former use two-stage HSFCW in series planted with *Phragmites australis*.

#### 4.4 Horizontal Flow Constructed Wetland (HFCW) Field Trial Results

Figure 7a and 7b shows the reduction in concentration of various parameters with respect to time. As the detention time increases, the reduction percentage is also increased, a detention period of 5 days is given for the constructed wetland. The removal efficiencies of various parameters after 5<sup>th</sup> day were 63.16 % for BOD, 62.96 % for COD, 52.63 % for TDS, 64.29 % for Nitrate, 46.60 % for Phosphate, 44.27 % for Potassium.



**Figure 7. Reduction in Concentration from Influent and Effluent of Wastewater. (a) BOD (Biological Oxygen Demand), COD (Chemical Oxygen Demand) and TDS (Total Dissolved Solids), (b) Nitrate, Phosphate, and Potassium (Adapted from Karpagam, M., and S. Sivasubramanian, 2015).**

The interactions between abiotic and biotic components as well as external factors could influence the treatment efficiency of CW systems. Several parameters including CW physical configurations, hydraulics, substrates, plant species diversity, dissolved oxygen (DO) level, climatic conditions (e.g., temperature/season) etc. impact the pollutant removal performance of CW systems (Zhu et al., 2014; Herrera-Cárdenas et al., 2016). The pollutant removal efficiency varies with a change of CW system configurations as reported by Chen et al. (2016). Chen et al. (2016) compared the antibiotics removal performance of three different CW configurations namely SF and SSF (VF and HSF CW) wetland facilities, and SSF systems (89.1–98.9%) show higher performance for the removal of antibiotics (e.g., erythromycin) than the SF system (76%). Moreover, among the HSF and VF configurations, HSF (98.9%) had higher capability for the removal of pollutants compared to the VF unit (89.1%). Xu et al. (2016) also observed differences in the reduction of pollutants in pilot-scale HSF-based and VF-based CW systems. The former type showed high performance for the removal of COD (74%) and ammonia (79%), while the latter one was effective mainly for the total nitrogen removal (64%) (Xu et al., 2016).

Hydraulic loading rate (HLR) could affect the performance of CW systems, and in most of the cases, the pollutant removal efficiency decreased with an increase of HLR (Trang et al., 2010). In HSF-based CW systems treating a mixture of wastewater and stormwater, it was observed that the removal efficiency of TN and TP constantly decreased with a gradual increase of HLR (31, 62, 104 and 146 mm/day). Also, the TN and the TP removal efficiency decreased from 84 to 16% and from 99 to 72%, respectively with the rise of HLR from 31 to 146 mm/day (Trang et al., 2010). In a pilot-scale HSF CW system, the removal efficiency of COD, TN and TP was 95, 95 and 95%, respectively at a HLR of 0.025 m/day, but the removal efficiency decreased to 91, 87 and 89% when the HLR was doubled (0.05 m/day) (Angassa et al., 2019).

Hydraulic retention time (HRT) is one of the important operational parameters which impacts the effectiveness of CW systems. Sultana et al. (2016) investigated the COD removal from cheese whey wastewater in pilot-scale unplanted and planted (reed: *Phragmites australis*) HSF-based CW systems at four different HRTs (1, 2, 4 and 8 days). In both CW systems, the percentage of COD removal was reduced with a decrease of HRT, i.e., in an unplanted CW system; the percentage of COD removal decreased from 100 to 76% when HRT was reduced from 8 days to 1 day. However, in the vegetated cell, a similar decrease of performance was also noticed (a reduction from 100 to 76% with a reduction of HRT from 8 days to 1 day). In VF-based CW systems, Sarmiento et al. (2013) evaluated the influence of four distinct HRTs (1, 2, 3 and 4 days) on the decontamination of various pollutants from swine wastewater. It was observed that the pollutant removal efficiency was enhanced with the rise of HRT up to 3 days, and then decreased. In a recent pilot-scale study on the treatment of synthetic wastewater using a vertical subsurface flow CW vegetated with two plants namely *Typhalatifolia* and *Phragmites australis*, the pollutant (e.g., COD) removal efficiency constantly increased with the rise of HRT from 2 days (69.4%), 4 days (77.6%), 6 days (86.3%), 8 days (86.4%) and 10 days (88.8%) (Shruthi and Shivashankara, 2021b).

Plants are one of the important components in CW systems and could influence the decontamination performance of wetlands. Sarmiento et al. (2013) compared the performance of three plant species namely *Cyperus* sp. (grass), *Heliconiarostrata* (shrub) and *Hedychium coronarium* (herbaceous) for the removal of various pollutants from swine wastewater in VF-based CW systems. In addition to plant species diversity, plant root characteristics (length, biomass, architecture, etc.) could also impact the rate of uptake of

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pollutants since among the three types of plants namely *Canna* (flowering plant), *Phragmites australis* (reed) and *Cyperus papyrus* (flowering seed plant) vegetated in VF-based CW systems investigated for the decontamination of municipal wastewater, the uptake of nitrogen and phosphorus as well as the removal faecal indicator bacteria was higher in *Canna* than the other two vegetations (Abou-Elela and Hellal, 2012). *Canna* showed better performance since the roots were spread broadly and uniformly in the CW filter bed. Diversity of vegetation species in CW influenced the removal of nitrogen more compared to that of phosphorus (Liang et al., 2017).

Microbial degradation is one of the important pathways for removal of pollutants from wastewater/stormwater in CW systems. Thus, in addition to CW operational parameters and surrounding climatic conditions, the abundance and diversity of various functional microbial communities (nitrifiers, denitrifiers, organic carbon degraders, etc.) could influence the treatment performance of CW systems (Zhang et al., 2018 and Zhou et al., 2020).

#### **4.5 Recommendations for Enhanced Efficiency of Horizontal Flow Constructed Wetland**

(i) Horizontal subsurface flow (HSSF) systems require coarse media (10–25 mm) to enhance flow and minimize clogging. Hybrid systems benefit from a mix of finer (4–10 mm) and coarse substrates (10–40 mm) for improved nitrification.

(ii) A longer hydraulic retention time (HRT) improves nutrient removal; hybrids are effective at four days, whereas HSSF requires at least three days.

(iii) Loading frequency and distribution: Intermittent loading (four to six times daily) increases oxygenation in hybrids, and even an influent distribution helps prevent clogging in horizontal systems.

(iv) Vegetation Management: Regular harvesting of plants like *P. Australis* enhances pollutant uptake and decreases organic build-up.

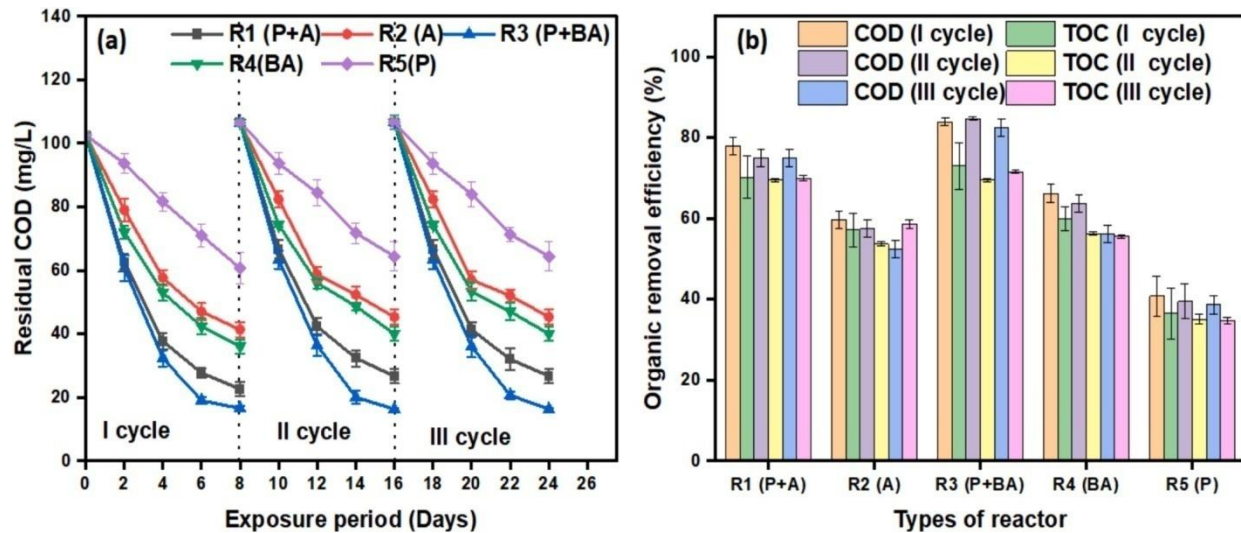
(v) Operational Considerations: Effective influent control is vital for preventing clogging; future designs should prioritize balanced flow inlets.

#### **4.6 Review of Research Studies on Biochar and Evaluation of Outcomes**

##### **4.6.1 Removal of Organics**

Studies have shown that, CFWs with different configurations operated under identical conditions showed significant differences in their performances ( $p < 0.05$ ) in removing COD. With a COD concentration of 100 mg/L in the influent, the COD levels in the effluent of each CFW were below 25 mg/L for reactors R1(P + A) and R3(P + BA), with removal rates exceeding 75%, indicating substantial organic COD removal by CFWs containing biochar and plants. As shown in Figure 9(a)–(b), the COD concentrations in the effluent from the biochar and bioactive biochar were consistently low across all reactors for different cycles, demonstrating the effectiveness of modified corncob biochar in removing organic COD. The clear effect of plants along with biochar was noted ( $p < 0.05$ ) in reducing COD in R1(P+A) and R3(P+BA) compared to R2(A) and R4(BA), indicating the synergistic roles of plants, microbes, and biochar in removing organics. Furthermore, significant COD removal was observed in R2(A) and R4 (BA) compared to R5(P), likely due to the roles of biochar through sorption and biodegradation via microorganisms (Bano et al., 2023; Qiet al., 2024). The reactor setup, R3(BA), exhibited

the best performance, with the lowest COD concentration in effluents ( $16.27\text{--}18.67\text{mg/L}$ )  $< 20\text{mg/L}$  for all three runs, as shown in Figure 9. This better removal effect was attributed to the bioactive biochar, which aided the microbial community. Similar findings were reported by Qi et al. (2024) in modified biochar and Zhang et al. (Zhang et al., 2023) in microbe-assisted CWs. Similar trends were observed for TOC reduction in all systems.



**Figure 9: (a) Residual COD and (b) COD removal efficiency in reactors R1 to R5 during cycles I, II, and III. (Adapted from Karki, B. K., & Philip, L., 2026).**

At the end of the experiment, the microbial biomass (total protein content) attached to the biochar in different setups was determined to be  $6.50 \pm 0.50\text{mg/g}$ ,  $5.34 \pm 0.76\text{mg/g}$ ,  $11.50 \pm 0.51\text{mg/g}$ , and  $10.30 \pm 0.91\text{mg/g}$  for Reactor R1(P+A), R2(A), R3(P+BA), and R4(BA), respectively. The significantly higher biomass protein content (about twice,  $P$  value  $< 0.05$ ) in reactors R3 (P + BA) and R4 (BA) compared to R1(P+A) and R2(A) is likely due to the use of pre-acclimatized biomass prior to the experiments.

As a result, CFW setups incorporating bioactive or biochar-supported systems with plants showed higher overall organic removal than other reactors. This suggests that adding biochar/bioactive biochar significantly enhances treatment performance, likely due to improved sorption and favorable conditions for biodegradation (Zhuang et al., 2022b).

However, overall pollutant removal was influenced by two key factors: first, the low net coverage by plants and biochar columns ( $< 20\%$ ) meant the remaining area functioned as an open pond, which also contributed to pollutant removal through natural processes (Pavlineri et al., 2017). Second, the absence of mechanical agitation, designed to mimic natural systems, slowed the contact between pollutants and treatment media, while in plant-only systems (such as A or BA), about 50% of openings remained exposed, allowing photo degradation to aid removal (Shen et al., 2022b). Despite these limitations, incorporating biochar improved treatment efficiency by 30–40%, exceeding the  $< 10\%$  improvement reported by Chand et al. (2022) for biochar-amended constructed wet lands. Similarly, Shen et al. (2022b) observed comparable phosphorus removal efficiencies in

both plant-based systems and CFWs enhanced with AAC blocks. These results align with findings from Bano et al. (2023), demonstrating that biochar and bacterial intensification in floating treatment wetlands can substantially improve pollutant reductions, offering a low-cost, eco-friendly solution for treating polluted waters.

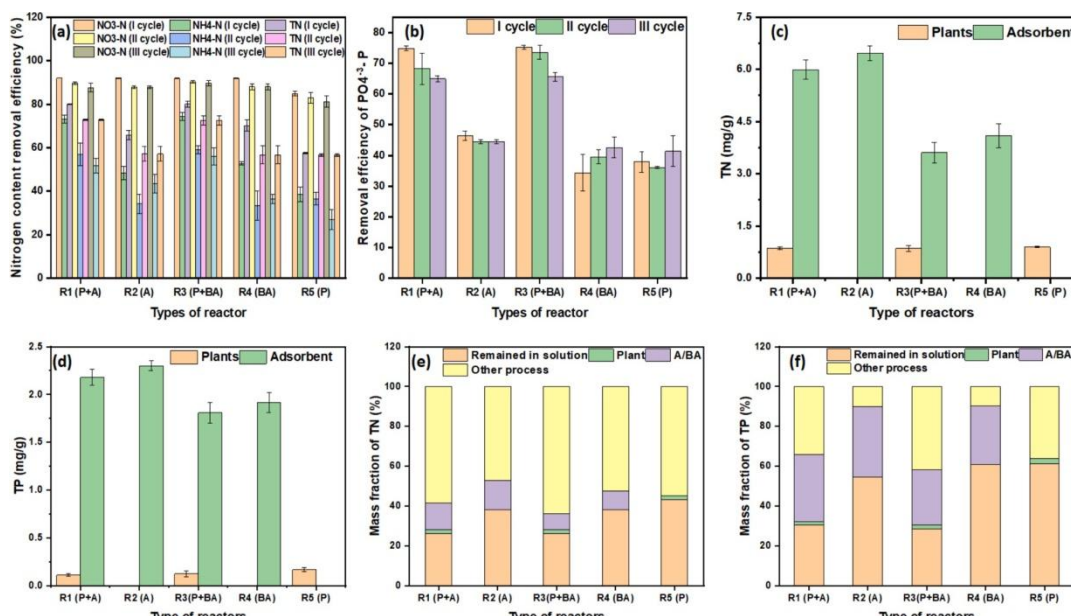
#### 4.6.2 Removal of Nutrients

In CFWs, suspended roots remove nutrients through biosynthesis and rhizo-filtration (Pavlineri et al., 2017). In this study, the removal of nutrients such as different nitrogen species (TN,  $\text{NO}_3\text{-N}$ ,  $\text{NH}_4\text{-N}$ ), and  $\text{PO}_4\text{-P}$  were also examined across different configurations of CFWs (Figure 10). Nitrate removal ranged from 80% to 92% in various setups, with over 90% reduction observed in the R3 (P +BA) reactor. Similar removal trends were observed for TN and  $\text{NH}_4\text{-N}$  in the R3(P +BA) reactor. Various studies have mentioned a significant reduction of nitrogen from CFWs. The high reductions of TN removal (above 98%) were reported for *Iris pseudacorus* plants supported FTW by Keizer-Vleket al. (2014). *Pontederia cordata* and *Juncus effuses* assisted CFWs were reported to remove 84.3%-88.9% and 35.5%-66.3% of TN from polluted water, respectively (Spangler et al., 2019 a, 2019 b). Moreover, the TN reduction improved by 1.39 to 1.40 times in the R1(P+A) and the R3(P +BA) compared to the R5(P) reactor. These improvements indicate that amended corn cob modified biochar can promote nitrification and denitrification activities (Qiet al., 2024). Similar increments in TN reduction up to 1.78 times were reported by Bano et al. (2023) due to the amended biochar in CFWs.

The significant TN reduction ( $P$  value < 0.05) in R1(P+A) and R3(P+BA) compared to R5(P) is attributed to the synergistic effects of micro organisms, plant uptake, and sorption capacity of biochar (El Barkaoui et al., 2023). Other studies have also reported a noteworthy reduction of nitrogen in the CFW system (Bano et al., 2023; Shahid et al., 2019). It has been further reported that ammonium removal in CFW ranges from 24% to 100%, depending on plant species, influent load, input system (batch/ continuous), and other environmental factors (Sharma et al., 2021). Similarly, in CFWs, phosphate removal primarily occurs through plant uptake, microbial activity, sorption, and precipitation (Sharma et al., 2021). Plants in CFWs absorb phosphorus from the water column through their roots, while microorganisms immobilize phosphorus through microbial assimilation. Similar to TN, reactors R1(P+A) and R3(P+BA) showed a significant reduction ( $P$  value < 0.05) of phosphorus compared to other reactors, demonstrating the removal enhancement due to addition of biochar.

TN and TP accumulation in biochar and plants were also evaluated at the end of experiments after 24 days, as shown in (Figure 10(c) and (d)). TN accumulation in biochar was observed to range from 5.99 to 6.46 mg/g dry weight (DW) of biochar in the biochar-amended system. In contrast, a reduction in accumulation was noted in the bioactive biochar-amended CFW system, where TN levels ranged from 3.61 to 4.09 mg/g DW of biochar. Similarly, in plants, TN accumulation was between 0.87 and 0.90 mg/g of DW of plants compared to those in plants on the initial day. Similar results were observed for TP accumulation with 1.81–2.30 mg/g of DW in biochar and 0.11 to 0.17 mg/g of DW in plants. Moreover, mass balance analysis (Figure 10(e) and (f)) revealed that direct plant uptake of TN was limited to 2%, while TN accumulated in

biochar ranged from 8.23 to 14.71%. In case of TP, slightly more accumulation of phosphorous was observed upto 27.88–35.46% in biochar. The substantial reduction of TN (52 to 63%) and TP (10 to 36%) was attributed to other processes, including microbial processes and other activities within the CFW systems. Narayanasamydamodaran et al.(2024) reported TN and TP accumulation of 48.10mg/g of DW and 2.82 mg/g of DW of Vetiver plants in bioretention cells, respectively. The lower TN and TP accumulation observed in bioactive biochar column compared to biochar column may be due to enhanced microbial activity on the bioactive biochar surfaces. Microbes colonizing biochar can actively transform nitrogen and phosphorous compounds through biological processes, inhibiting static accumulation (Chand et al., 2022; Shen et al., 2022a).

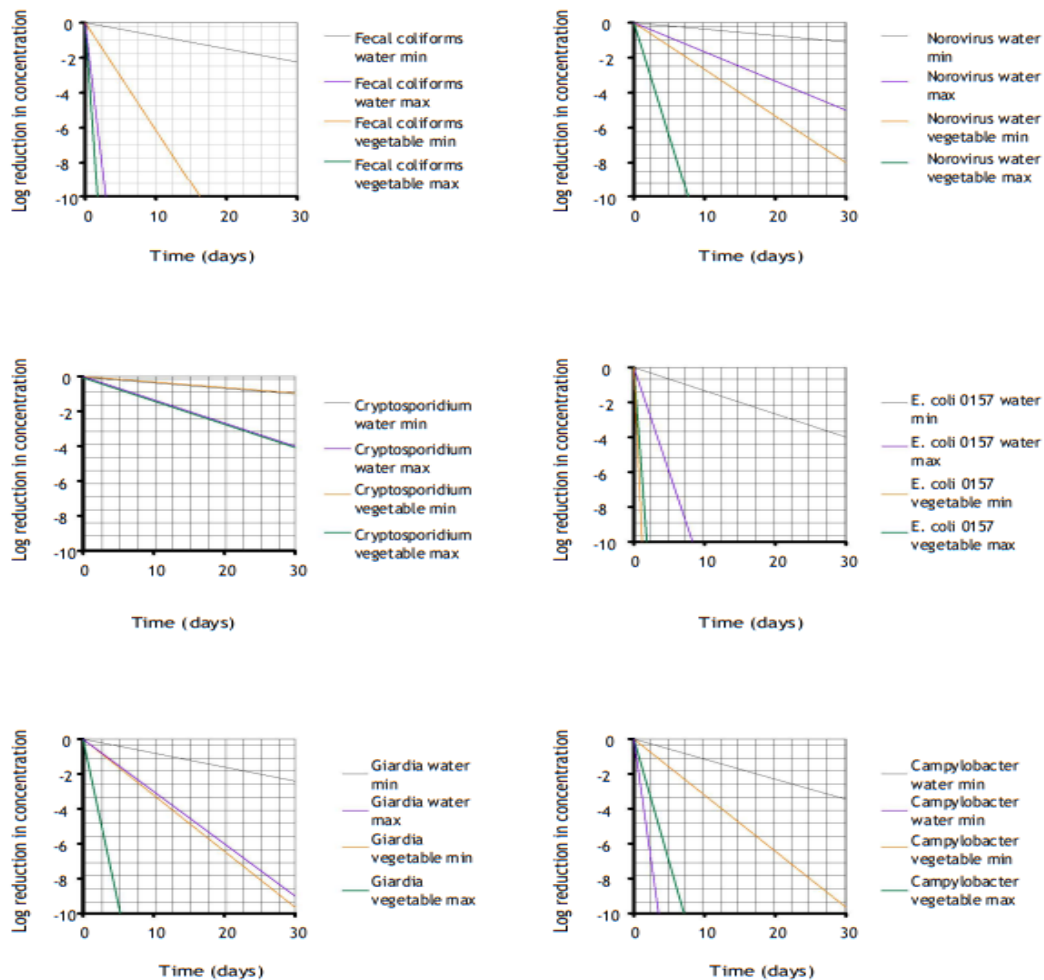


**Figure 10: Removal of (a) nitrogen species (TN, NH<sub>4</sub>-N, NO<sub>3</sub>-N), (b) phosphorous, during I cycle, II cycle, and III cycle runs in different CFWs configurations (R1 to R5), (c) accumulation of TN in plants and biochar, (d) accumulation of total phosphorous content in plants and biochar, (e) fate of TN and (f) Fate of TP.(Adapted from Karki, B. K., & Philip, L., 2026).**

#### 4.7 Crop Quality (Lettuce and Kale)

To assess the quality of lettuce and kale, physicochemical and microbiological characteristics will be compared with selected standards and macronutrients and micronutrients against optimum ranges and phytotoxic thresholds found in related literature (Hartz et al., 2007; Marschner, 2012). Water content in lettuce and kale among the six treatments should fall in the 93.0%–94.9% range; thus, not presenting significant differences. To prevent inaccuracies, irrigation with different waters will be evenly maintained throughout the experiment for the drip irrigation system, according to their technical specifications. However, all treatments should comply with the commercial minimum weight of 100 g for lettuce and kale (classes I and II) grown under protection (OECD, 2002; UNECE, 2012). Total N concentrations presented significant differences in regard to the irrigation waters, and all of them are slightly over the optimum range (33–48 g/kg) for this type of crop (Hartz et al., 2007).

The pollution parameters evaluated were faecal coliforms and helminth eggs. Water quality was monitored for two months, and their concentration levels ranged from 3 to 4 log units of faecal coliforms per 100 mL and from 6 to 15 eggs of helminth per L. Regarding the evaluated product of consumption (lettuce), the concentration of faecal coliforms ranged from  $7 \times 10^2$  to  $1.8 \times 10^3$  per 10 g, and the concentration of helminth eggs ranged from 6 to 9 per 100 g. The annual risk of infection was 10–2 for *Ascaris* and 10–1 for *E. coli*. This study is relevant for the development of risk assessments for possible infections caused by helminths and *E. coli* (see Figure 8).



**Figure 8. Modelled Survival Rates in Water and on Vegetables**

(Adapted from Pond, K. et al. (2007), B17005 Review of the Use of Water in UK Agriculture)

## 5. DISCUSSIONS

### 5.1 Environmental Benefits

The use of treated wastewater promotes environmental sustainability by connecting rural and urban areas, reducing pollutant discharge, and minimizing groundwater contamination while effectively utilizing nutrients from wastewater. A management plan for the Caroni River Basin

(CRB) aims to protect ecological integrity and conserve biodiversity through sustainable resource use, emphasizing a participatory approach rather than top-down legislation. Implementing vertical-flow constructed wetlands will help manage stormwater runoff, and educating farmers on system management will address health and environmental risks.

Reusing agricultural wastewater can save costs associated with groundwater extraction, as pumping groundwater can account for up to 65% of irrigation expenses. Additionally, the nutrients in wastewater can lower fertilizer costs, creating a closed nutrient cycle and preventing excess nitrogen and phosphorus from re-entering water bodies. This practice has been shown to improve crop yields and reduce the need for fertilizers, ultimately decreasing water body eutrophication and farmers' agrochemical expenses.

### **5.2 Social/Community Benefits**

Regulatory and institutional improvements, alongside awareness campaigns, will empower the population regarding drought management and enhance their involvement in related decision-making processes. Infrastructure enhancements, such as treated wastewater supply and solar-powered drip irrigation systems, will improve the quality of life for farmers by ensuring a reliable water source and promoting health by reducing pesticide use and pollution. These measures are expected to conserve water, improve public health, and reduce the spread of waterborne diseases, ultimately benefiting farmers through better marketability of their produce and providing consumers with healthier food options. Based on regulatory aspects, agricultural wastewater reuse can contribute to the justification of suitable investment policies and financing mechanisms for pollution control and prevention.

### **5.3 Economic Benefits**

Treated wastewater can create a financial advantage and increase revenue for farmers by avoiding development costs, increasing land and property values, boosting tourism activities in dry regions, generating additional revenue from recycled water sales, creating secondary revenue for customers and industries, reducing or eliminating the need for commercial fertilizers, and lowering water treatment costs for downstream users.

An implicit economic benefit of agricultural wastewater reuse is the valuation of treated water discharged for human consumption, as this use is considered to be of the highest priority. In some countries, wastewater reuse contributes to reducing the municipal cost of sourcing water, which can be achieved through more expensive means.

### **5.4 Legal Benefits**

The findings of this study will provide valuable insights to support the safe and sustainable reuse of treated wastewater in agriculture, promoting resource conservation and enhancing agricultural practices. This pilot study seeks to catalyze the development of programmes for the national-scale adoption of wastewater reuse schemes and improved policies and procedures, such as

1. Policy and Administrative Measures
2. Policy Development Driving Forces
3. Legislation: Water Pollution Regulation, Miscellaneous Water-Related Laws,

Occupational Safety and Health Act, Role and Function of the Pesticides and Toxic Chemicals Control Board, Obligations under International Instruments

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1. Development of Safe and Effective Wastewater Reuse and Irrigation Water Management
2. Development of a GIS-Based Water and Wastewater Management Assessment Model

Treated wastewater initiatives will lead to improvements through increased policy awareness, alignment with international treatment regulations, and the development of guidelines for wastewater reuse.

### **5.5 Case Studies in the Caribbean**

Scope of Projects:

- Construction and rehabilitation of wastewater treatment plants.
- Installation of new sewage collection systems to reduce untreated wastewater discharge.
- Capacity building and training for local communities and stakeholders on sustainable wastewater management practices.
- Public awareness campaigns to educate the public on the importance of proper wastewater management.

The Projects achieved several positive Outcomes:

- Improved wastewater treatment capacity and efficiency, leading to better water quality in affected areas.
- Reduction in pollution and environmental impact from untreated wastewater.
- Increased community engagement and awareness about wastewater management issues.
- Enhanced resilience to climate change impacts through improved water resource management.

Lessons Learnt from Case Studies

- Community Involvement is crucial for the success of IWWM projects.
- Sustainable Practices and Infrastructure Upgrades are essential for long-term success.
- Capacity building and Public Awareness campaigns are vital for changing behaviours and ensuring project sustainability.

This case studies of the Caribbean countries listed, highlight the importance of integrated approaches to wastewater management and the positive impact such projects can have on both the environment and local communities.

#### **5.5.1 Jamaica: Wastewater Reuse in Crop Production**

Jamaica has implemented several initiatives that utilize treated wastewater for irrigation in crop production, particularly in the cultivation of vegetables such as tomatoes and lettuce. The National Irrigation Commission developed a pilot project that utilized aerobic treatment systems to enhance water quality before municipal irrigation. This case study illustrated that reclaimed water significantly contributed to water supply sustainability, especially during dry seasons.

#### **5.5.2 Dominican Republic: Constructed Wetlands for Rice Cultivation**

In the Dominican Republic, a project implemented constructed wetlands to treat municipal wastewater before it was used for irrigation in rice fields. The system effectively removed

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contaminants, demonstrated successful pollutant reduction, and improved water quality for agricultural use. The study highlighted how the wetlands provided additional benefits, such as supporting local biodiversity.

### **5.5.3 Trinidad and Tobago: Pilot Study on Horizontal Flow Constructed Wetlands**

A pilot project at the Guanapo Landfill in Trinidad and Tobago focused on using a Horizontal Flow Constructed Wetland System (HFCWS) to treat leachate, with preliminary findings showing improved water quality that exceeded WHO standards. The treated water was then tested for suitability in agricultural applications, demonstrating the potential of HFCWS as a cost-effective and viable technology for safe water reclamation in rural areas.

### **5.5.4 Cuba: Integrated Ecological Agriculture and Wastewater Treatment**

In Cuba, ecological agriculture practices have been integrated with wastewater treatment systems, utilizing biogas digesters and biofilters to treat waste effectively. The treated effluent is used for irrigation in urban and peri-urban farming. This approach not only improves crop yield but also enhances food security while addressing both sanitation and water scarcity issues.

### **5.5.5 Bahamas: Water Reclamation for Sustainable Farming**

A project in the Bahamas focused on water reclamation technologies involving anaerobic digestion and constructed wetlands to treat wastewater from agricultural runoff as well as municipal sources. The reclaimed water was reused for irrigation in agricultural fields. The outcomes of this initiative showcased improved crop productivity and soil health, contributing to sustainable agricultural practices.

### **5.5.6 Barbados: Wastewater Irrigation in Vegetable Production**

In Barbados, a project aimed at reusing treated wastewater for irrigation in the production of vegetables demonstrated significant increases in yield and quality compared to traditional irrigation methods. The project involved educating farmers on the safe use of treated wastewater, which ultimately led to enhanced community acceptance and willingness to adopt such practices.

### **5.5.7 Saint Lucia: Aquaponics and Wastewater Recycling**

An innovative approach in Saint Lucia involved integrating aquaponics systems that utilized wastewater from fish farming. The nutrient-rich water was circulated to vegetable crops, effectively treating the wastewater while creating a sustainable food production system. This project emphasized the dual benefit of enhancing agricultural outputs and promoting efficient water use.

### **5.5.8 Belize**

#### **Case Study titled Los Porticos Villas Wastewater Treatment Project**

Los Porticos Villas in Placencia, Belize faced significant wastewater management challenges, including untreated wastewater discharge and environmental pollution. The project aimed to address these issues by implementing a sustainable and cost-effective wastewater treatment solution.

Objectives:

The project had several key objectives:

1. Reduce untreated wastewater discharge to protect the environment.
2. Improve water quality in the area.
3. Implement a cost-effective and sustainable wastewater treatment system.

Implementation:

Designing a unique wastewater treatment system that combined a septic/balancing tank, biological active filters, humus sludge handling, a polishing filter (artificial wetland), and disinfection.

Constructing a gravity sewer system to feed the treatment plant, minimising visual impact and odours.

Awarding the contract to a local contractor to ensure community involvement and support.

### **5.5.9 Cuba, Dominica, Guadeloupe, Martinique, and Saint Lucia**

The CARIBSAN project is an inter-Caribbean cooperation initiative aimed at promoting the use of constructed wetlands for wastewater treatment in the Caribbean region. The project is co-financed by the European Union through the INTERREG Caribbean program and involves partners from several Caribbean countries, including Cuba, Dominica, Guadeloupe, Martinique, and Saint Lucia.

Objectives

- Promote nature-based solutions for wastewater treatment using constructed wetlands.
- Improve wastewater treatment in fragile coastal ecosystems and sensitive areas, such as swimming areas.
- Enhance resilience to natural hazards, such as cyclones, by using locally adapted plants and substrates.

Implementation

- Constructed wetlands using local plants like Heliconia (birds-of-paradise) combined with substrates to filter and treat wastewater.
- Training and capacity building for sanitation professionals in the Caribbean on the use of constructed wetlands.
- Preliminary studies and pilot projects to demonstrate the effectiveness of constructed wetlands in different Caribbean countries.

Outcomes

- Successful implementation of constructed wetlands in Martinique and Guadeloupe, demonstrating their effectiveness and cost-efficiency.
- Increased awareness and adoption of nature-based solutions for wastewater treatment in the Caribbean.
- Enhanced collaboration among Caribbean countries and international partners in promoting sustainable wastewater management.

The CARIBSAN project highlights the potential of nature-based solutions to address wastewater treatment challenges in the Caribbean, offering a sustainable and resilient approach to protecting the environment and public health.

## 6. CONCLUSION

The WWR prototype reclamation system investigated in this study is expected to effectively examine the primary environmental, agricultural, and public health issues associated with reclaimed water, particularly salinity and pathogenicity. Empirical studies of the WWR prototype will evaluate the capture of contaminants within the structure's layers and the long-term efficacy of the geotextile membrane in accumulating pollutants. Analysis of water quality suggests that the infiltration technologies employed in the gravel structure successfully remove typical pollutants found in treated wastewater effluents. Findings related to crop water quality, agronomic factors, and microbiological aspects indicate that the WWR prototype, combined with vertical flow constructed wetlands and solar-powered automated drip irrigation systems, represents advanced technologies suitable for safe water reclamation in agricultural production. Although the WWR prototype shows promise in producing high-quality reclaimed water for vegetable crop cultivation, it is crucial to strive for optimal, fit-for-purpose treatment performance. Defining acceptable ranges for irrigation water quality based on crop type, agronomic standards, and microbiological guidelines will enable the refinement of the prototype reclamation system to meet specific requirements. This strategy will ensure the efficient utilization of valuable plant nutrients while maintaining environmental compliance and mitigating risks in agricultural production. Tolerance ranges in the quality of irrigation waters regarding the type of crop, as well as in the agronomic and microbiological standards and guidelines, will fine-tune the prototype reclamation system according to specific needs, thereby retaining the most valuable plant nutrients while ensuring environmental compliance and a less risky agricultural production. This research will seek to catalyse the development of programs for the national-scale adoption of wastewater reclamation schemes for agricultural irrigation and enhance related policies and procedures.

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## TECHNIQUES OF CULTIVATION AND METHODS ON BUILDING BASED INTEGRATED FARMING IN URBAN AGRICULTURE

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The original research work entitled ‘Techniques of cultivation and methods on building based integrated farming in urban agriculture’ carried out in Bhubaneswar a smart city of India. The study relevant to the plants cultivation on building integrated farming be used group of plants grown as per the use, most categories of containers and the methods of planting in places, planted materials Bio-fertilizer or compost and media, kinds of external soil use in containers and constructed place for cultivation, which help to maintained nutritive value of food as the food security, cultivated propagates like as the seed, seedling and plan parts, eventually the study reflected on the equipment use for water supply (irrigation) methods to the plants. I express my deep sense of gratitude to all the city dwellers, urban farmers, respondents, experts, researchers, for support in every respect throughout the research work. I would like to thanks organizations/institution such as City farmer association/Kitchen garden association/City farmer groups extending help in data collection and immense encourage and support for this study.

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### ABSTRACT

*In recent scenario the urban agriculture in terms of building based integrated farming in cities grow rapidly. Various types of plants has been grown in urban area, now the basically hub of the cultivation in buildings in cities. The building based cultivation carried out in the varieties of methods in terms of perform cultivated place withi8n the buildings, such are known as rooftop farming, rooftop garden, balcony garden, terrace garden and the vertical garden, hanging gardens etc. There is diversity of plants grown in the building as per the used by the cities farmers. Such as the vegetables, Fruits, Spice as food, Flowers as ornamental, medicinal etc. are grown in building based integrated farming in the system. In this study implication of use of containers in this cultivation which has fixed and movable commodity used in the same farming, Combine used as Grow bags, Concrete pots, Polythene bag, Plastic drums, Earthen pots, cement carry bags use in groups as per their dominancy. The containers have been choice according to the characteristic and cultivation methods of the plant species. The present study containers has been fixed on the roofs this type of cultivation in Belayed, Lawns, Beds, Vertical garden settled in a groups in the buildings. The study express planting materials has used on put off in containers, beds or lawns in different farms. Further the soil used in a building based farming. Most of the soil being used Garden soil and crop field soil, again the planted material for cultivation belong to propagates like seeds, seedlings, plants part and Bio-fertilizers and*

*manures used in the processes. The methods of water supply and tools combinations has been adopted, most of the combination has traditional by mug, Jug, Plastic pipe and in spray form. The combinational study all the materials, technique and the methods used in the building based mixed farming.*

**KEYWORDS:** *Agriculture, Building, Cultivation, Farming, Integrated, Urban, Technique.*

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## 1. INTRODUCTION

Urban agriculture contain of building based farming in cities has been rapidly growing in urban area reported by Choguill, C. L. (1995). Estee, L.Y., Kishnani, N. T. (2010) has been study building-integrated agriculture utilizing rooftops for sustainable food crop cultivation in Singapore The mixed farming means the more no of plant species cultivated in same area and same time with in the building, carried out the integrated farming in cities, Jha, R. K. et al., (2019). This farming grown fresh and organic product surrounding and within the building .The vegetables ,fruits, spices and flowers (ornamental) plants grown on the rooftop, balcony, terrace and vertical places studded by Gajbe, P. U. (2021). The cultivation technique has something different from the field crops. The recent study the urban agriculture provide nutritive organic food in own building, explained by Specht, K., et al., (2021). The technique of cultivation meet to the propagates, planted material, container, organic manure or compost, soil, water management and the structure of building pre-preparation and construction use of materials tools for the calculation proposed by Sanye-Mengual, E., et al., (2015). The data has collected on the basis of dominant materials of following combination has been recorded.

## 2. REVIEW OF LITERATURE

The study large numbers of reprints are available in the various sources. The rationales of the study have very specific. Rapidly growth of population in urbanities meet to the production of own food in urban agriculture by Torreggiani, D. et al., (2012). Now the urban agriculture plays an important role in food security and urban sustainability. Planning of food production is the main propose of urban agriculture, Feininger, U. B., et al., (2015), urban agriculture in terms of building based farming is most important because of the organic farming to grow fresh nutritive and tasty food near the door steps, Abu, G. A., & Soom, A. (2016). Review of literature this study context of types of plant cultivation on the Rooftop farming, Rooftop gardens, balcony gardens and terrace gardens on the buildings of urban area, Ackerman, et al., (2014). Container used in the garden has control the space, soil, arrangements and water scarcity for cultivation. Variables of containers groups adopted in cultivation methods. Planted materials for urban farming has very unique for cultivation which bio-compost, media, manure etc, that increase of fertility of the soil and the nutritive value of the veggies and fruits. Alaima, K, et al., (2008), Astee, L. & Kishnani, N. (2010). The external soil also use for the process. Further the planted materials like seeds seedlings and the plant parts for propagules were use for cultivation. Equipments of water supply have been studied on the farming systems.

## 3. RESEARCH VARIABLES

The study presents the variables with methods of cultivation on buildings in various aspects.160 numbers of buildings poses farming included in group and categorize of materials, process and methods has analyzed. The study belong plants, containers, planted materials, methods of farming and the water supply and management.

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#### 4. RESEARCH METHODOLOGY

The method of study by open survey with the respondents, data has been collected through structured interview by the questioner methods with the respondents to door to door visit and field study. The considered sampling of data have collected from 160 respondents which have the standard integrated farming on own buildings in a mart city Bhubaneswar of India. The primary data has gathered in tabulated form for analysis. The data for analyzed by the used of software ANOVA, SPSS and calculated the value frequency, percent, valid percent and cumulative percentage and interpret in each combination of the process of cultivation in building based integrated urban farming in cities.

#### 5. RESULT AND DISCUSSION

The result of the current study of integrated farming of building carried out data collection, documentation and analysis to different variables in terms of the plant cultivated in the farming system. The study epic the dominant group of cultivar and materials data have been reported and documented in tabulated and interrelated .the research study explore the plants cultivated, container used, bed, lawn, barricade, vertical methods of cultivation been studied in the building. Further study exposed the used of planted materials accompanied Bio-fertilizers and compost also soil in the cultivated system. The study explores the combination of propagules, seeds, seedlings, and plant parts used for cultivation and better production of the crops. The method water and growth materials has supplied to the growing plants. All the data collected for sampling of 160 represented with building integrated farming. The data has analyzed and interpreted in tabulated and the graphic form as follows.

##### 5.1 Study of common category of plants species cultivation in buildings on the basis of uses.

**Table 5.1 Majority category of plants cultivation on the basis of uses.**

Types of plants cultivation.

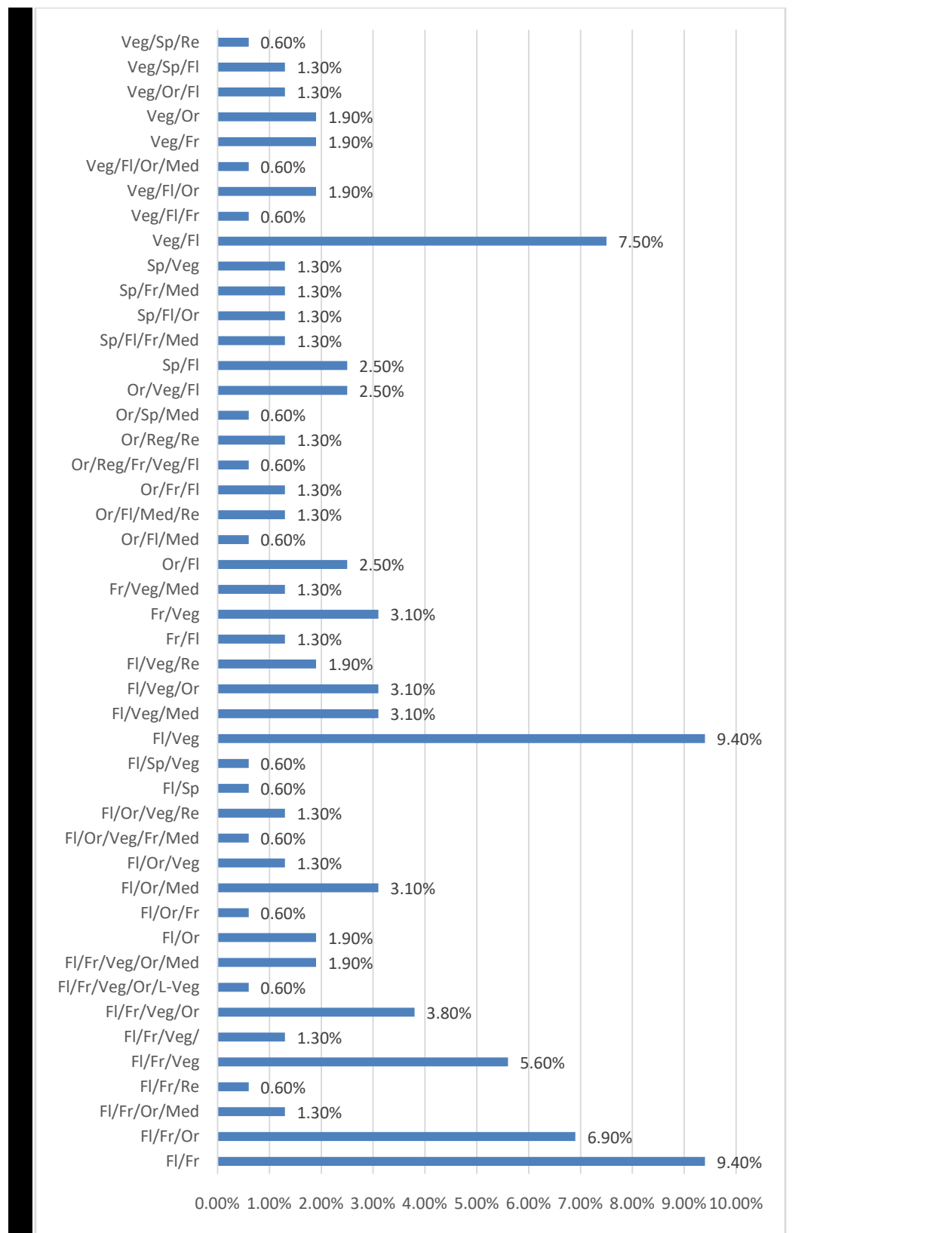
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid Plants	Fl/Fr	15	9.4	9.4	9.4
	Fl/Fr/Or	11	6.9	6.9	16.3
	Fl/Fr/Or/Med	2	1.3	1.3	17.5
	Fl/Fr/Re	1	.6	.6	18.1
	Fl/Fr/Veg	9	5.6	5.6	23.8
	Fl/Fr/Veg/	2	1.3	1.3	25.0
	Fl/Fr/Veg/Or	6	3.8	3.8	28.7
	Fl/Fr/Veg/Or/L-Veg	1	.6	.6	29.4
	Fl/Fr/Veg/Or/Med	3	1.9	1.9	31.3
	Fl/Or	3	1.9	1.9	33.1
	Fl/Or/Fr	1	.6	.6	33.8
	Fl/Or/Med	5	3.1	3.1	36.9
	Fl/Or/Veg	2	1.3	1.3	38.1
	Fl/Or/Veg/Fr/Med	1	.6	.6	38.8
	Fl/Or/Veg/Re	2	1.3	1.3	40.0
	Fl/Sp	1	.6	.6	40.6
	Fl/Sp/Veg	1	.6	.6	41.3

Fl/Veg	15	9.4	9.4	50.6
Fl/Veg/Med	5	3.1	3.1	53.8
Fl/Veg/Or	5	3.1	3.1	56.9
Fl/Veg/Re	3	1.9	1.9	58.8
Fr/Fl	2	1.3	1.3	60.0
Fr/Veg	5	3.1	3.1	63.1
Fr/Veg/Med	2	1.3	1.3	64.4
Or/Fl	4	2.5	2.5	66.9
Or/Fl/Med	1	.6	.6	67.5
Or/Fl/Med/Re	2	1.3	1.3	68.8
Or/Fr/Fl	2	1.3	1.3	70.0
Or/Reg/Fr/Veg/Fl	1	.6	.6	70.6
Or/Reg/Re	2	1.3	1.3	71.9
Or/Sp/Med	1	.6	.6	72.5
Or/Veg/Fl	4	2.5	2.5	75.0
Sp/Fl	4	2.5	2.5	77.5
Sp/Fl/Fr/Med	2	1.3	1.3	78.8
Sp/Fl/Or	2	1.3	1.3	80.0
Sp/Fr/Med	2	1.3	1.3	81.3
Sp/Veg	2	1.3	1.3	82.5
Veg/Fl	12	7.5	7.5	90.0
Veg/Fl/Fr	1	.6	.6	90.6
Veg/Fl/Or	3	1.9	1.9	92.5
Veg/Fl/Or/Med	1	.6	.6	93.1
Veg/Fr	3	1.9	1.9	95.0
Veg/Or	3	1.9	1.9	96.9
Veg/Or/Fl	2	1.3	1.3	98.1
Veg/Sp/Fl	2	1.3	1.3	99.4
Veg/Sp/Re	1	.6	.6	100.0
Total	160	100.0	100.0	

The table 5.1 represents the frequency and percentage distribution of various combinations of plant types cultivated by respondents. Each combination is abbreviated, with "Fl" representing flowers, "Fr" representing fruits, "Or" representing ornamental plants, "Med" representing medicinal plants, "Re" representing religious plants, "Veg" representing vegetables, and "Sp" representing spices (Fig.5.1). The most common cultivation types are "Fl/Fr" and "Fl/Veg," each with 15 instances, comprising 9.4% of the total responses. Less frequent combinations include "Fl/Fr/Re," "Fl/Or/Fr," and "Veg/Fl/Fr," among others, each with only 1 instance (0.6%) (Fig. 5.3). The cumulative percentage column shows the running total percentage, indicating the proportion of respondents accounted for as each new combination is added. The total number of responses is 160, making up 100% of the sample (Fig.5.2).



**Fig. 5.1** Vegetables grown on the basis of use in Bhubaneswar. (Source from Author).



**Fig. 5. 2 Majority combination groups integrated of plants cultivation.**



**Fig. 5. 3 Flowers grown in building based integrated farming in Bhubaneswar. (Source from Author).**

**5.2 Combination groups of containers in building integrated farming.**

**Table 5.2 Combination groups of containers.**

Containers used.

	Frequency	Percent	Valid Percent	Cumulative Percent
C-pot	3	1.9	1.9	1.9
C-pot/GB	4	2.5	2.5	4.4
C-pot/Pl-drum	2	1.3	1.3	5.6
C-pot/pl-pot	1	.6	.6	6.3
C-pot/Pl-pot	5	3.1	3.1	9.4
CB/C-pot	2	1.3	1.3	10.6
CB/E-pot	2	1.3	1.3	11.9
CB/GB/JR	2	1.3	1.3	13.1
CB/JR	3	1.9	1.9	15.0
CB/Pl-drum	1	.6	.6	15.6
CB/Pl-pot	6	3.8	3.8	19.4
CB/Ply-B	3	1.9	1.9	21.3
E-pot	2	1.3	1.3	22.5
E-pot/C-pot	1	.6	.6	23.1
E-pot/CB	16	10.0	10.0	33.1
E-pot/GB	6	3.8	3.8	36.9
E-pot/Ply-B	4	2.5	2.5	39.4
GB/C-pot	1	.6	.6	40.0
GB/CB	14	8.8	8.8	48.8
GB/CB/C-pot	1	.6	.6	49.4
GB/CB/E-pot	1	.6	.6	50.0
GB/CB/JR	1	.6	.6	50.6
GB/CB/Ply-B	1	.6	.6	51.2
GB/E-pot	4	2.5	2.5	53.8
GB/E-pot/Ply-B	2	1.3	1.3	55.0
GB/JR/CB	2	1.3	1.3	56.3
GB/Ply-B	14	8.8	8.8	65.0
GB/Ply-B/E-pot/	4	2.5	2.5	67.5
GB/Ply-B/E-pot/CB	9	5.6	5.6	73.1

Valid Containers

GB/Ply-B/P-pot	1	.6	.6	73.8
JR/GB	2	1.3	1.3	75.0
JR/GB/CB	3	1.9	1.9	76.9
Pl-drum	2	1.3	1.3	78.1
Pl-drum/GB	4	2.5	2.5	80.6
Pl-drum/JR	5	3.1	3.1	83.8
Pl-pot/CB	6	3.8	3.8	87.5
Pl-pot/GB	2	1.3	1.3	88.8
Pl-tray	5	3.1	3.1	91.9
Pl-tray/E-pot	1	.6	.6	92.5
Ply-B/CB	2	1.3	1.3	93.8
Ply-B/GB	9	5.6	5.6	99.4
Ply-B/GB/E-pot	1	.6	.6	100.0
Total	160	100.0	100.0	

Abbreviation used in the table 5.2: C-Pot=Concrete pot/GB=Grow bag/Pl-drum=Plastic drum/Pl-pot=Plastic pot/CB=Cement carry bag/JR=Jar (plastic Jar)/E-Pot=Earthen pot/Ply-B=Plythene bag.

The table 5. 2 show the frequency and percentage distribution of various container combinations used in a study, with a total of 160 responses. Each container combination is listed under the "Valid" category, with specific combinations such as "C-pot," "CB/C-pot," and "GB/CB/E-pot." (Fig. 5.4). The "Frequency" column indicates the number of times each combination was used, while the "Percent" column shows the percentage of the total 160 responses. The "Valid Percent" column repeats these percentages, as all responses are valid. The "Cumulative Percent" column adds these percentages sequentially to indicate the running total. The most frequently used container combination is "E-pot/CB," accounting for 10% of the responses, followed by "GB/CB" and "GB/Ply-B," each with 8.8%. Less common combinations, such as "C-pot/Pl-pot" and "GB/CB/C-pot," appear at the lower end of the frequency distribution, each representing 0.6% of the total. The cumulative percentages help understand the incremental addition of each combination's frequency to the overall distribution, culminating in 100%.



**Fig. 5. 4 Plants grown by the use of containers on building based integrated farming by urban farmers in Bhubaneswar. (Source from Author).**

**5.3 Combination categories of dominant methods used in cultivation.****Table 3.3 Distribution of different combination categories of dominant methods used in cultivation.**

Types of dominant methods of cultivation

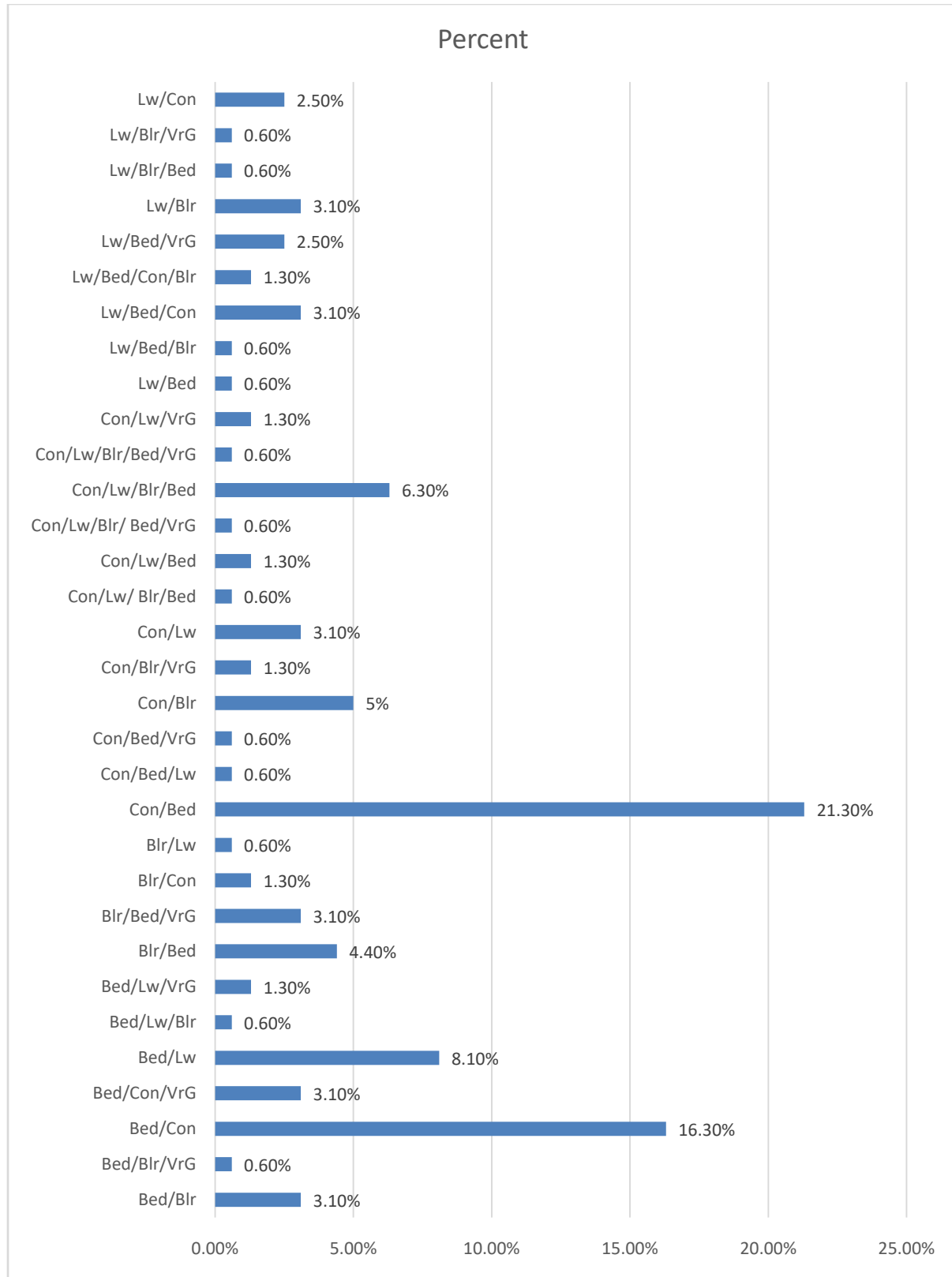
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid Gardens	Bed/Blr	5	3.1	3.1	3.1
	Bed/Blr/VrG	1	.6	.6	3.8
	Bed/Con	26	16.3	16.3	20.0
	Bed/Con/VrG	5	3.1	3.1	23.1
	Bed/Lw	13	8.1	8.1	31.3
	Bed/Lw/Blr	1	.6	.6	31.9
	Bed/Lw/VrG	2	1.3	1.3	33.1
	Blr/Bed	7	4.4	4.4	37.5
	Blr/Bed/VrG	5	3.1	3.1	40.6
	Blr/Con	2	1.3	1.3	41.9
	Blr/Lw	1	.6	.6	42.5
	Con/Bed	34	21.3	21.3	63.7
	Con/Bed/Lw	1	.6	.6	64.4
	Con/Bed/VrG	1	.6	.6	65.0
	Con/Blr	8	5.0	5.0	70.0
	Con/Blr/VrG	2	1.3	1.3	71.3
	Con/Lw	5	3.1	3.1	74.4
	Con/Lw/ Blr/Bed	1	.6	.6	75.0
	Con/Lw/Bed	2	1.3	1.3	76.3
	Con/Lw/Blr/ Bed/VrG	1	.6	.6	76.9
	Con/Lw/Blr/Bed	10	6.3	6.3	83.1
	Con/Lw/Blr/Bed/VrG	1	.6	.6	83.8
	Con/Lw/VrG	2	1.3	1.3	85.0
	Lw/Bed	1	.6	.6	85.6
	Lw/Bed/Blr	1	.6	.6	86.3
	Lw/Bed/Con	5	3.1	3.1	89.4
	Lw/Bed/Con/Blr	2	1.3	1.3	90.6
	Lw/Bed/VrG	4	2.5	2.5	93.1
	Lw/Blr	5	3.1	3.1	96.3
	Lw/Blr/Bed	1	.6	.6	96.9
Lw/Blr/VrG	1	.6	.6	97.5	
Lw/Con	4	2.5	2.5	100.0	
Total	160	100.0	100.0		

The table 5.3 reflected the distribution of different types of dominant cultivation methods among a sample of 160 respondents. Each method is identified by a combination of abbreviations: Bed (Bedding plants), Blr (Bleyer plants), (Fig.5.7) VrG (Vertical Gardening), Con (Containers), and Lw (Lawns) (Fig.5.5). The most common method is "Con/Bed" (Container and Bedding plants), used by 34 respondents, representing 21.3% of the total sample. Other notable combinations include "Bed/Con" (Bedding plants and Containers) and "Bed/Lw" (Bedding plants and Lawns),

each accounting for 16.3% and 8.1% respectively. Less common methods such as "Lw/Blr" (Lawns and Bleyer plants) and "Blr/Lw" (Bleyer plants and Lawns) are each used by 5 respondents (3.1%). The table shows that some combinations, like "Con/Lw/Blr/Bed" and "Con/Lw/Blr/Bed/VrG", are extremely rare, each occurring only once (0.6%) (Fig. 3.2). Overall, the data indicates a diverse range of cultivation methods with varying levels of adoption among the respondents, with cumulative percentages illustrating the incremental addition of each method's frequency to the total process present in graph (Fig.5.6).



**Fig. 5. 5 Plants grown in lawn farming of rooftop farming in Bhubaneswar. (Source from Author).**



**Fig. 5.6 Distribution of different types of dominant cultivation.**



**Fig. 5. 7 Vegetable grown by the help of belayed on rooftop farming in Bhubaneswar. (Source from Author).**

**5.4 Preparation and use of planted material.**

**Table 5.4 Preparation and use of planted material in building based integrated farming.**

Preparation and use of planted material.

	Frequency	Percent	Valid Percent	Cumulative Percent
Amrut arka	1	.6	.6	.6
Amrut sanjebani	1	.6	.6	1.3
Bin-Compost	24	15.0	15.0	16.3
Bin-Compost/Kitchen compost	1	.6	.6	16.9
Bin-Compost/Liquid media	1	.6	.6	17.5
Bin-compost/Mulch	1	.6	.6	18.1
Cocopeat/Liquid media	2	1.3	1.3	19.4
Compost	8	5.0	5.0	24.4
Compost media	2	1.3	1.3	25.6
Compost/Amrit Jal	2	1.3	1.3	26.9
Compost/Cocopeat	4	2.5	2.5	29.4
Compost/Liquid enzyme	2	1.3	1.3	30.6
Compost/Liquid fertilizer	1	.6	.6	31.3
Compost/Mulch	2	1.3	1.3	32.5
Enzyme Compost	1	.6	.6	33.1
Forest Com/Mulch	1	.6	.6	33.8
Forest Compost	1	.6	.6	34.4
Forest Compost/Kitchen compost	3	1.9	1.9	36.3
Forest Compost/Liquid media	2	1.3	1.3	37.5
Kitchen Compost	7	4.4	4.4	41.9
Kitchen compost/Cocopeat	2	1.3	1.3	43.1
Kitchen-Compost	6	3.8	3.8	46.9
Leaf Compost	4	2.5	2.5	49.4
Liquid Compost	8	5.0	5.0	54.4
Liquid fertilizer	2	1.3	1.3	55.6
Liquid media	3	1.9	1.9	57.5
Liquid media/Cocopeat	1	.6	.6	58.1

Valid Materials

Micro-bacterial	1	.6	.6	58.8
Open Compost	53	33.1	33.1	91.9
Open Compost/Amrut jal	1	.6	.6	92.5
Open Compost/Cocopeat	3	1.9	1.9	94.4
Open Compost/Enzyme	2	1.3	1.3	95.6
Open Compost/liquid arka	1	.6	.6	96.3
Open Compost/Liquid arka	1	.6	.6	96.9
Potted Compost/Mulch	2	1.3	1.3	98.1
Potted Compost/Cocopeat	2	1.3	1.3	99.4
Potted-Compost/Liquid arka	1	.6	.6	100.0
Total	160	100.0	100.0	

The table 5.4 explores the frequency and percentages of different types of planted material preparations and their usage. Among the 160 total responses, "Open Compost" is the most commonly used method, accounting for 33.1% of the total, followed by "Bin-Compost" and "Liquid Compost," each representing 15.0% and 5.0% respectively. Other combinations such as "Kitchen Compost," "Compost," and various mixed methods, including combinations with cocopeat, liquid media, and mulch, show lower frequencies, mostly around 0.6% to 4.4%. The cumulative percentage column shows the running total of the valid percentages, culminating at 100%. This indicates a diverse range of materials and combinations used in preparation, with a notable preference for open composting methods among respondents.

**5.5 Used of soil in farming.**

**Table 5. 5 Different types of soils use.**

Soil use

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid Soil	Alluvial Soil	24	15.0	15.0	15.0
	Crop Field Soil	41	25.6	25.6	40.6
	Field Soil	3	1.9	1.9	42.5
	Garden Soil	53	33.1	33.1	75.6
	Loam Soil	37	23.1	23.1	98.8
	Sandy Soil	2	1.3	1.3	100.0
	Total	160	100.0	100.0	

The table 5.5 presents data on the frequency and distribution of different types of soil used. The soil types and their respective frequencies are as follows. Alluvial soil (24 occurrences, 15.0%), crop field soil (41 occurrences, 25.6%), Field Soil (3 occurrences, 1.9%), Garden Soil (53 occurrences, 33.1%), loam soil (37 occurrences, 23.1%), and sandy soil (2 occurrences, 1.3%). Each type's valid percent is equal to its frequency percent, indicating no missing data. The cumulative percent shows a running total of the percentages, reaching 100% with sandy soil. Garden soil is the most commonly used type at 33.1%, followed by crop field soil and loam Soil and while field soil and sandy soil are the least used (Fig.5.8). The total number of cases is 160, ensuring that all soil use categories sum up to 100% of the sample.

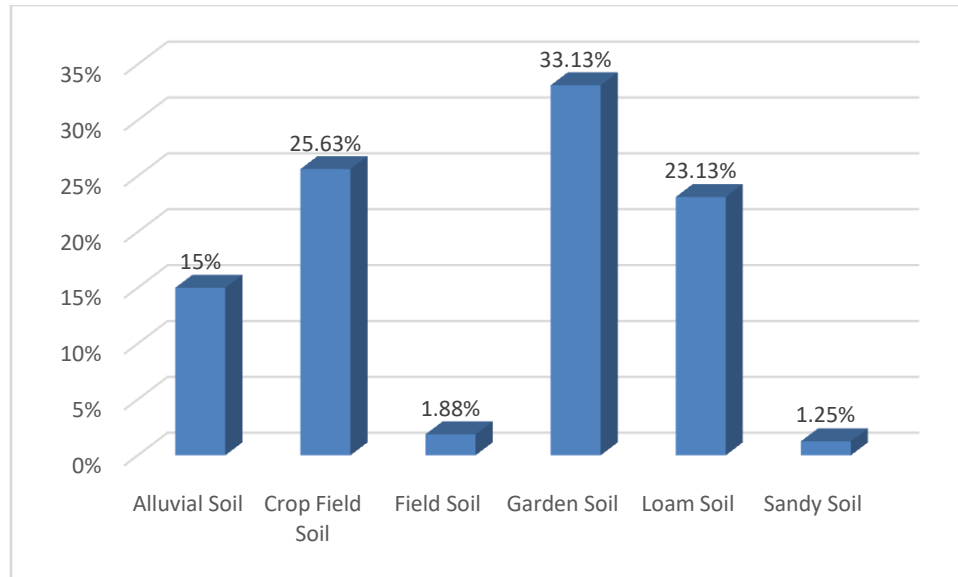


Fig.5.8 Different types of soils use.

**5.6 Combinations of seeds, seedlings, and plants Parts (Propagules) used for building based integrated cultivation.**

**Table 5.6 Different combinations of seeds, seedlings, and plants cultivation.**

Seed / Seedling/ Plants Cultivation

	Frequency	Percent	Valid Percent	Cumulative Percent
Rh/Sd	1	.6	.6	.6
Rh/Sdl	5	3.1	3.1	3.8
Rh/Tr	2	1.3	1.3	5.0
Rh/Tr/Sd	5	3.1	3.1	8.1
Rh/Tr/Sd/Sdl	3	1.9	1.9	10.0
Rh/Tr/Sdl/Sd	2	1.3	1.3	11.3
Sd/Rh	1	.6	.6	11.9
Sd/Rh/Tr	2	1.3	1.3	13.1
Sd/Rh/Tr/Sdl	1	.6	.6	13.8
Sd/Sdl	45	28.1	28.1	41.9
Sd/Sdl/Rh	4	2.5	2.5	44.4
Sd/Sdl/Rh/Tr	1	.6	.6	45.0
Sd/Sdl/St-cut	3	1.9	1.9	46.9
Sd/Sdl/Tr	2	1.3	1.3	48.1
Sd/St-cut	15	9.4	9.4	57.5
Sd/St-cut/Sdl/Rh	2	1.3	1.3	58.8
Sd/Tr	2	1.3	1.3	60.0
Sd/Tr/Rh	1	.6	.6	60.6
Sdl/Rh	3	1.9	1.9	62.5
Sdl/Sd	18	11.3	11.3	73.8
Sdl/Sd/Rh	2	1.3	1.3	75.0
Sdl/Sd/St-cut	1	.6	.6	75.6
Sdl/St-cut	5	3.1	3.1	78.8

Valid Propagule

Sdl/Tr	1	.6	.6	79.4
St-cut/Rh	2	1.3	1.3	80.6
St-cut/Rh/Tr	2	1.3	1.3	81.9
St-cut/Sd	15	9.4	9.4	91.3
St-cut/Sdl	5	3.1	3.1	94.4
St-cut/Sdl/Sd	1	.6	.6	95.0
Tr/Sd	2	1.3	1.3	96.3
Tr/Sd/Sdl	2	1.3	1.3	97.5
Tr/Sdl	1	.6	.6	98.1
Tr/St-cut	3	1.9	1.9	100.0
Total	160	100.0	100.0	

Abbreviation used in the table 5.6: Rh=Rhizome/Sd=Seed/Sdl-Seedling/Tr=Tuber/St-cut=Stem cutting (stomp).

The table 5.6 presents a detailed breakdown of different combinations of seed, seedling, and plant types used in cultivation, along with their frequencies and percentages. The total number of observations is 160. Each combination is listed with the frequency of occurrences, percentage of total responses, valid percentage, and cumulative percentage. For example, the combination "Sd/Sdl" appears most frequently, accounting for 28.1% of the responses. Other notable entries include "Sdl/Sd" (11.3%) and "Sd/St-cut" (9.4%). Combinations with lower frequencies, such as "Rh/Sdl" (3.1%) and "Tr/Sdl" (0.6%), are also included, showing the variety in cultivation

Practices. The cumulative percentage column indicates the cumulative total of each combination up to that point, providing an overall view of the distribution of cultivation practices across the dataset.

**5.7 Water managements in building based integrated farming.**

**Table 5.7 Equipments and method of water supply.**

Method of water supply.

	Frequency	Percent	Valid Percent	Cumulative Percent
Btl/Spy	2	1.3	1.3	1.3
Btl/M/J	3	1.9	1.9	3.1
Btl/PP	15	9.4	9.4	12.5
Btl/Spy	15	9.4	9.4	21.9
M/J/Bol	1	.6	.6	22.5
M/J/Btl	12	7.5	7.5	30.0
M/J/Btl/Spy/PP	2	1.3	1.3	31.3
M/J/PP	18	11.3	11.3	42.5
M/J/PP/Spy/Bol	1	.6	.6	43.1
M/J/PP/Spy/Btl	7	4.4	4.4	47.5
M/J/Spy	15	9.4	9.4	56.9
Mug/Jar/Btl	2	1.3	1.3	58.1
Mug/Jar/PP/Spy	1	.6	.6	58.8
Mug/Jar/PP/Spy/Btl	4	2.5	2.5	61.3
Mug/PP	2	1.3	1.3	62.5
Mug/Spy	1	.6	.6	63.1

PP/Btl	10	6.3	6.3	69.4
PP/M/J	6	3.8	3.8	73.1
PP/Spy	10	6.3	6.3	79.4
Spy/Btl	12	7.5	7.5	86.9
Spy/M/J	8	5.0	5.0	91.9
Spy/PP	13	8.1	8.1	100.0
Total	160	100.0	100.0	

Abbreviation used in the table 5.7: Btl=Balty/Spy= spey/M=Electric motor by pipe/J=Jar /Bot=Bottle /PP=Plasic pipe/Mug=Mug(plstic).

The table 5.7 present data on various methods of water supply among 160 respondents. The different combinations of water supply methods are listed in the first column, with their corresponding frequencies and percentages provided in subsequent columns. The most common methods include "M/J/PP" (11.3%), "Spy/PP" (8.1%), and "PP/Btl" (6.3%). Less common methods, with only 0.6% each, include "M/J/Bol," "M/J/PP/Spy/Bol," "Mug/Jar/PP/Spy," and "Mug/Spy." The "Valid Percent" column mirrors the "Percent" column, as there are no missing values. The "Cumulative Percent" column indicates the running total percentage, showing the accumulation of each method's percentage as we move down the list. The cumulative percent reaches 100% at the end, indicating that all methods of water supply have been accounted for.

## CONCLUSION

A method of urban agriculture that is both practical and forward-thinking to the issue of urban food security is the growth of crops on urban agriculture, which has emerged as a potential opportunity. This method, which involves the growing of food and flowers (ornamental) plants on building rooftops, offers a myriad of benefits, including improved air quality, enhanced building insulation, and the availability of fresh, locally grown veggies. In addition to making the most efficient use of vacant urban spaces, this practice also offers a multitude of other advantages. Techniques like as hydroponics, aquaponics, soil-based systems, and vertical gardens are examples of methods that can be utilized to the fullest extent possible in order to maximize the utilization of space and resources. Effective waste management solutions, such as composting and recycling, contribute to the further enhancement of sustainability by reducing the environmental imprint and enhancing resource efficiency. This is accomplished through the reduction of their environmental impact. The practice of urban agriculture is associated with containers gardens, use of manure, water supply and the production of local fresh organic food on buildings of the cities.

## CONFLICT OF INTEREST

The research carried out in own interest of author and it has partial work of the Ph D. thesis of the Author. Further the own funding has been spent in research work by author. No, any funding from other sources spend towards the research, the research work have not any conflict of interest as per my faith and believe.

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