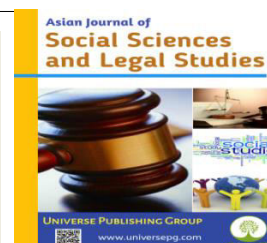




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Recycling of Plant Nutrients (Phosphorus) from Human Excreta

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Abstract

Human excreta contain substantial amounts of essential amounts of essential plant nutrients, Particularly Phosphorus (P), nitrogen (N), and potassium (K), which can be recovered and reused to support sustainable agriculture. This study aims to quantify phosphorus recovery from human excreta and evaluate its potential as an alternative to chemical fertilizers, along with assessing community awareness and practices regarding excreta management. A field based survey was conducted among 50 households in Patharghata Upazila, Barguna, Bangladesh using a structured questionnaire to assess sanitation practices, waste disposal behavior and perceptions toward resource recovery. Laboratory analysis was performed using the struvite precipitation method to recover phosphorus from wastewater. Results showed that phosphorus concentration significantly decreased from an initial high value of 21.48 to as low as 0.82 after treatment, indicating effective nutrient recovery. Survey findings revealed that 50% of respondents use improved (pacca) latrines, while 60% discharge waste directly into rivers, posing serious environmental risks. Additionally, 44% of households desludge septic tanks after more than one year, and 70% of respondents are unaware of the role of human excreta as a recyclable source and the majority expressed negative perceptions toward its use in agriculture. The study highlights that despite the high potential for nutrient recovery through struvite precipitation, limited awareness, inadequate sanitation practice remain significant barriers. Therefore, prompting public awareness, improving sanitation infrastructure and adopting safe nutrient recycling technologies are essential for sustainable water management, environmental protection and agricultural development.

Keywords: Phosphorus, Human excreta, Struvite precipitation, Recycling, Nutrients, Sanitation.

1. Introduction

Human beings acquire mineral nutrients from food for their growth and development (Welch, 2002). However, a significant portion of these nutrients remains unused and is excreted as waste, primarily through metabolic residues such as urine and feces (Harder *et al.*, 2019). Urine is a liquid by-product of metabolism in humans and many animals, excreted through the urethra (Marshall, 1926). Feces are the

solid or semi-solid residues of food that are not digested in the small intestine (MacFarlane, 2018). The physical and chemical characteristics of urine and feces largely depend on an individual's health status, as well as the quantity and type of food and liquid consumed (Lentner *et al.*, 1981; Feachem *et al.*, 1983; Kar *et al.*, 2021).

Human excreta are valuable sources of plant nutrients, particularly macronutrients such as nitro-

gen (N), phosphorus (P), and potassium (K). These nutrients can be recycled and used as alternatives to chemical fertilizers (Vinnerås *et al.*, 2008), which are largely produced from finite fossil resources and are not sustainable in the long term (Palmquist &

Jönsson, 2004). Nearly all nitrogen, phosphorus, and potassium present in urine and feces can be recycled in agriculture, with only minor nitrogen losses occurring in the form of ammonia (Jönsson, 2001).

Table 1: Presents the approximate amounts of nitrogen (N), phosphorus (P), and potassium (K) in human urine and feces (Jönsson, 1994).

Types of waste	Nitrogen	Phosphorus	Potassium
Urine	64	43	52
Feces	7	22	9

This recycling process conserves substantial energy by reducing dependence on synthetic fertilizers. Additionally, the organic matter in excreta enhances soil humus content, improves water-holding capacity, and helps prevent soil degradation (Esrey *et al.*, 2001; GTZ, 2002; Ahmed *et al.*, 2024).

The human kidney is the primary excretory organ (Jensen-Jarolim *et al.*, 2013). On average, an individual produces approximately 500 kg of urine and 50 kg of feces annually, with feces containing around 10 kg of dry matter. This corresponds to an annual production of approximately 5.7 kg of nitrogen, 0.6 kg of phosphorus, and 1.2 kg of potassium per person (Wolgast, 1993). Urine contributes the largest share of macronutrients, accounting for about 80% of nitrogen and 60% of phosphorus. Blackwater (a mixture of urine, feces, toilet paper, and flush water) contains approximately 90% of the nitrogen and phosphorus present in excreta (Jönsson *et al.*, 2005). The nitrogen in urine is mainly in the form of ammonium, with a plant availability of 85–100%, comparable to that of chemical fertilizers (Jönsson *et al.*, 2005).

A substantial portion (60–70%) of nutrients applied in agricultural fields eventually enters wastewater systems (Jönsson *et al.*, 1995). These nutrients are released through decomposition and transported to river systems via sewerage networks (Carey & Migliaccio, 2009). Consequently, excessive nutrient loading particularly nitrogen, phosphorus, and potassium in aquatic systems often exceeds the ecological carrying capacity, leading to environmental degradation and deterioration of water quality (Tiwari & Pal, 2022). Recycling nutrients from human excreta aligns with the principles of sustainable development. Instead of being lost in wastewater treatment systems, these nutrients can be

recovered and reused in agriculture, reducing dependence on non-renewable resources and minimizing environmental pollution. In particular, phosphorus is a finite and essential nutrient for plant growth, making its recovery and reuse critically important for long-term agricultural sustainability.

However, human excreta also contain pathogens and parasites that pose significant health risks, especially in developing countries (Prüss *et al.*, 2002). Most pathogens are present in feces (Feachem *et al.*, 1983), and improper handling can lead to contamination of water sources and the spread of infectious diseases (Esrey *et al.*, 1998). The risk can be minimized by proper sanitation practices, including the separation and safe treatment of fecal matter (Esrey *et al.*, 2001). Although urine generally contains fewer pathogens, contamination may occur due to fecal mixing; introducing potential health risks (Schönning *et al.*, 2002). In Bangladesh, nearly half of the 55 million urban populations lacks adequate sanitation infrastructure for proper waste management (Andersson *et al.*, 2016). As a result, large volumes of untreated waste are discharged into the environment, posing serious environmental and public health risks (Anetor, 2016; Lejars *et al.*, 2012). Therefore, there is an urgent need to develop safe, affordable, and sustainable methods for the collection, treatment, and reuse of human waste. Considering that human excreta are organic in nature (Sharma *et al.*, 2019), they represent a valuable resource that can be harnessed for nutrient recycling, particularly for phosphorus recovery in agriculture.

The objective of this study is to measure the amount of phosphorus in human excrement and investigate its possible application as a substitute fertilizer. Phosphorus recovery from human waste can pro-

mote sustainable agriculture and energy conservation. The study also looks at methods for recycling nutrients and evaluates people's attitudes, interests, and methods of handling human waste. It also emphasizes how crucial it is to increase awareness so that appropriate recycling and management can preserve resources and safeguard the environment. By encouraging poverty reduction, environmental sustainability, and better access to clean energy, water, and sustainable agricultural production, such practices may also help achieve the Millennium Development Goals.

Research questions

This research is conducted as an attempt to recycling nutrients of plants from human excreta and reusing them in agricultural production for saving agricultural energy. Based on the objective of the study, the following research questions will be answered in this paper:

- What are the plant nutrients exist in human excreta?
- What is the technology used in determination of plant nutrients (phosphorous)?
- What is the present status and knowledge gaps of community regarding to reusing and recycle human excreta?

2. Methodology

Study area of the research

Patharghata Upazila is located in the coastal region of Barguna district. Due to its coastal geographical setting and increasing salinity intrusion, access to safe water and sanitation facilities remains limited for many households (Shammi *et al.*, 2019). A large proportion of households still use non-sanitary latrines, while some families continue practicing open defecation because of inadequate sanitation infrastructure (Rakib *et al.*, 2019). A socio-economic survey in Patharghata reported that only about 44.15% of households have access to sanitary latrines, whereas around 50.97% use non-sanitary latrines and about 4.89% still use open spaces for defecation (UDD).

In addition, coastal communities in the area often suffer from poor water quality and sanitation-related health risks due to salinity intrusion and limited freshwater sources. Many residents depend on ponds or other alternative water sources because safe drinking water is scarce in the region (The Daily

Star, 2024). These conditions contribute to inadequate sanitation practices, poor hygiene behavior, and increased vulnerability to water-borne diseases in the community.

Research Design

A self-administered questionnaire was used to assess the community people perception, awareness, their knowledge about human excreta and their management way of waste and their interest to recycling waste. The questionnaire consisted 13 items distributed into different dimensions: Knowledge (2 items with 2 choices), Interest for crop production (3 items with 4 choices), Interest for biogas production (4 choices) and religious views about recycling human excreta, source of their drinking water (4 choices), suffering from water borne diseases (2 choices) etc.

Sample size

A sample of 50 households was chosen as it provided an adequate balance between statistical representation and practical feasibility because it adequately represented the different perceptions, awareness levels, and management practices related to human excreta among households in Patharghata Upazila, Barguna and at the same time was manageable within the study's time and funding constraints. Using the Cochran sample size formula to ensure statistical validity of the survey (Chao-kromthong & Sintao, 2021).

$$\text{Sample size, } n_0 = \frac{z^2 \times p \times q}{e^2} = \frac{(1.96)^2 \times 0.5 \times 0.5}{(0.14)^2} \approx 49$$

$$\text{Adjusted sample size, } n = \frac{n_0}{1 + \left[\frac{n_0 - 1}{N} \right]} = \frac{49}{1 + \left[\frac{49 - 1}{47166} \right]} \approx 48.95$$

Where, total targeted household, N= 47,166, Confidence level=95%, Margin of error, e= 10%

Laboratory Analysis

A nutrient recycling treatment known as 'Struvite Precipitation' was selected for this research. Struvite-type crystals are composed primarily of orthophosphate (PO_4^{3-}), magnesium (Mg^{2+}), and mono- or divalent cations such as ammonium (NH_4^+), potassium (K^+), sodium (Na^+), copper (Cu^{2+}), nickel (Ni^{2+}), lead (Pb^{2+}), and manganese (Mn^{2+}). These ions form structured crystalline compounds under suitable chemical conditions (Huang *et al.*, 2019, Perwitasari *et al.*, 2018). The

most common and stable form of struvite is magnesium ammonium phosphate hexahydrate ($\text{MgNH}_4\text{PO}_4 \cdot 6\text{H}_2\text{O}$), commonly abbreviated as MAP (Mpountas, Papadakis & Koutsoukos, 2017). MAP can exist in crystalline (orthorhombic) and non-crystalline forms. The crystalline structure typically appears as a white prismatic compound (John, 1992). Due to its high nutrient content and controlled solubility, struvite is widely recognized as an effective slow-release fertilizer and a valuable product in nutrient recovery systems, supplying essential nutrients to plants (Min *et al.*, 2019). Struvite precipitation occurs when magnesium,

ammonium, and phosphate concentrations exceed the solubility product, leading to supersaturation and crystal formation (Tansel, Lunn, & Monje 2018). Since wastewater often lacks sufficient magnesium, an external magnesium source is added to initiate the reaction (Semerjian & Ayoub, 2003). The precipitation process follows the chemical equation:

$$\text{Mg}^{2+} + \text{NH}_4^+ + \text{H}_n\text{PO}_4^{3-n} + 6\text{H}_2\text{O} \rightarrow \text{MgNH}_4\text{PO}_4 \cdot 6\text{H}_2\text{O} + n\text{H}^+$$

Where $n = 0, 1$, or 2 , depending on the phosphate species present (PO_4^{3-} , HPO_4^{2-} , or H_2PO_4^-) (Barbosa *et al.*, 2016).

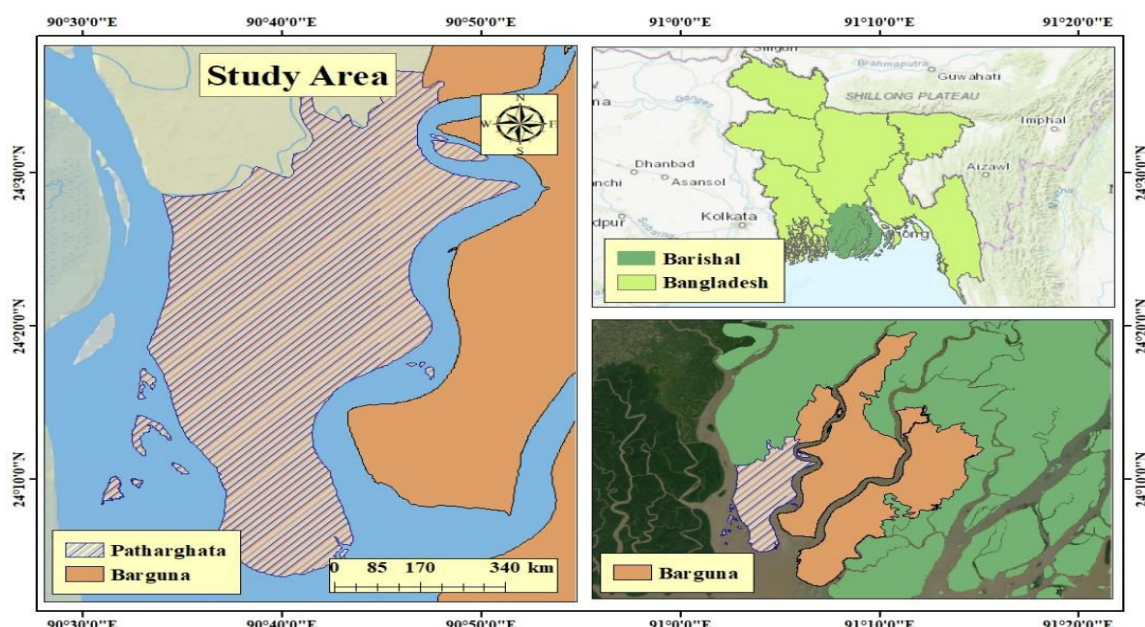


Fig. 1: Study Area Map.

Operational methods

First of all, MgCl_2 , NH_4Cl and sample waste water were taken in beaker. The volume was 30 ml. And the concentrations of MgCl_2 , NH_4Cl were the same 0.01M. After that stirred the 60 ml sample at the rate of 60 rpm, and add drop wise NaOH of the mol/L at the 0.10 ml/s flow to make the H reaction 10. After

that left the sample overnight to precipitate. Next day before started next step pH was measured of that 30ml sample .And until the pH reaction was stable 10 the sample was again left for precipitate overnight after adjusting drop wise NaOH solution. After stabled the pH, the solution was filtered.



Fig. 2: pH stabilizing, Filtration of solution, 0, 0.2, 0.5, 1 and 2 ppm P standard solution Solutions for P absorbance.

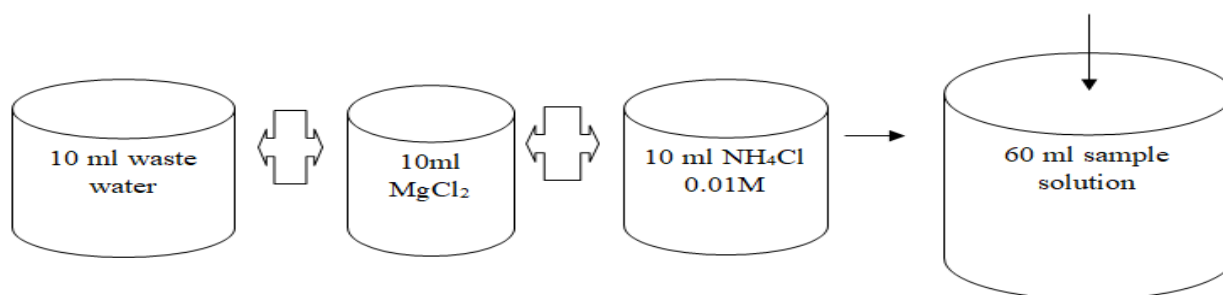


Fig. 3(a): Molar ratio and volume of waste water, MgCl_2 , NH_4Cl solution.

Extraction for P Analysis: Reagents

Stannous chloride dehydrate ($\text{SnCl}_2 \cdot 2\text{H}_2\text{O}$) stock solution:

By adding 2 g of $\text{SnCl}_2 \cdot 2\text{H}_2\text{O}$ in 5 ml of concentrated HCl was prepared. And Kept the solution in a black, glass-stoppered bottle, and the solution remains effective for every 6 weeks. After six weeks a fresh solution need to prepare.

Ammonium paramolybdate $[(\text{NH}_4)_6\text{Mo}_7\text{O}_{24} \cdot 4\text{H}_2\text{O}]$:

By dissolving 1.5 g of $[(\text{NH}_4)_6\text{Mo}_7\text{O}_{24} \cdot 4\text{H}_2\text{O}]$ in 35 mL of DI water and adding 35 mL of concentrated HCl to the flask slowly. Cool solution

to room temperature and added DI water to a volume of 100 mL. Stored in an opaque plastic bottle. A fresh solution need to be prepared every 2 months.

SnCl_2 dilute solution: By mixing 1mL of SnCl_2 stock solution in 333.34 mL of DI water dilute solution was prepared. Must have to make a fresh solution every 6 hours.

100 ppm P stock solution: By adding 0.5394 g of oven-dry Na_2HPO_2 in DI water, bring to 1 L 100 ppm stock solution was prepared.

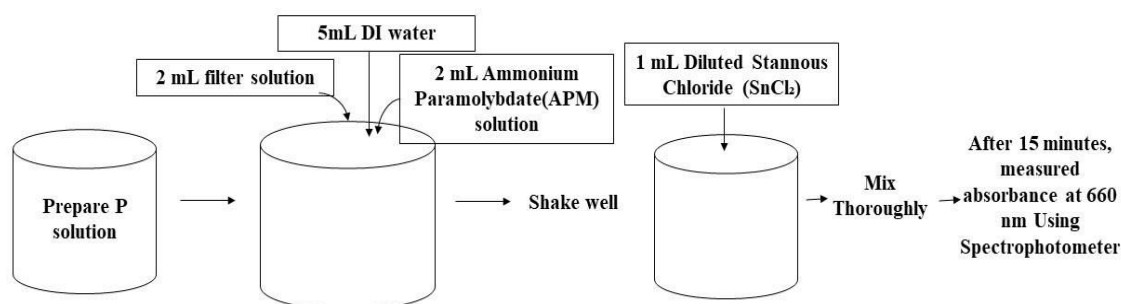


Fig. 3(b): Working Procedure.

Data analysis

A descriptive discussion has made for the better understanding of this study. Beside this some quantitative assessment has done through MS Excel software program and analysis to explain it more specific and finally the author could claim that the findings of the research would be representative and valid. Finally, results with summary and conclusion have been presented.

3. Results and Discussion

Phosphorous absorbance determination

Fig. 4(a) illustrates the variation in phosphorus (P) concentration following the application of the struvite precipitation treatment. Struvite precipitation is a nutrient recovery process that enables the removal and recovery of ammonium and phosphate

ions from wastewater through crystal formation (Lorick *et al.*, 2020, Wang *et al.*, 2019). The results exposed a noteworthy variation in P concentration. The highest recorded value was 21.48, while the lowest was 0.76. The initial phosphorus concentration in the wastewater was comparatively high. After the application of struvite precipitation, the phosphorus concentration was reduced to 0.82 and 4.93, indicating a considerable decrease. Prior to treatment, the P concentrations were significantly elevated (21.48 and 4.94), demonstrating the presence of high nutrient loads in the septic tank wastewater. High phosphorus removal efficiency through struvite crystallisation under ideal conditions has been reported in related research (Shalaby & El-Rafie, 2015). Septic tank wastewater can be a useful source of phosphorus recovery, as

demonstrated by the observed decrease in phosphorus levels. Phosphate ions can be resourcefully recovered and repurposed through struvite precipitation, supporting resource recycling and sustainable nutrient management (Starck, Fardet & Esculier, 2024).

Distribution of Toilet Facilities among Respondents

A large and growing proportion of the overall population depends on improved sanitation facilities. In Bangladesh, the proportion of households with access to improved sanitation increased steadily from 25.4% to 45.4% between 2007 and 2014, but slightly decreased to 44.0% in 2017-18 (Ahmed *et al.*, 2023). The graph indicates that 50%

of the respondents use *pacca* latrines, which are considered improved sanitation facilities. However, 10% of respondents use *kacha* latrines, which are classified as unimproved and unhygienic sanitation systems and may contribute to the spread of diseases and infections. Additionally, 16% of respondents use semi-*kacha* latrines, which are also considered insufficient in terms of hygiene standards. Around 24% of respondents use semi-*pacca* latrines. The whole distribution of toilet types suggests that sanitation facilities in Patharghata, Barguna are not sufficiently developed and still require substantial improvement to ensure better public health and environmental conditions (Hoque *et al.*, 2022).

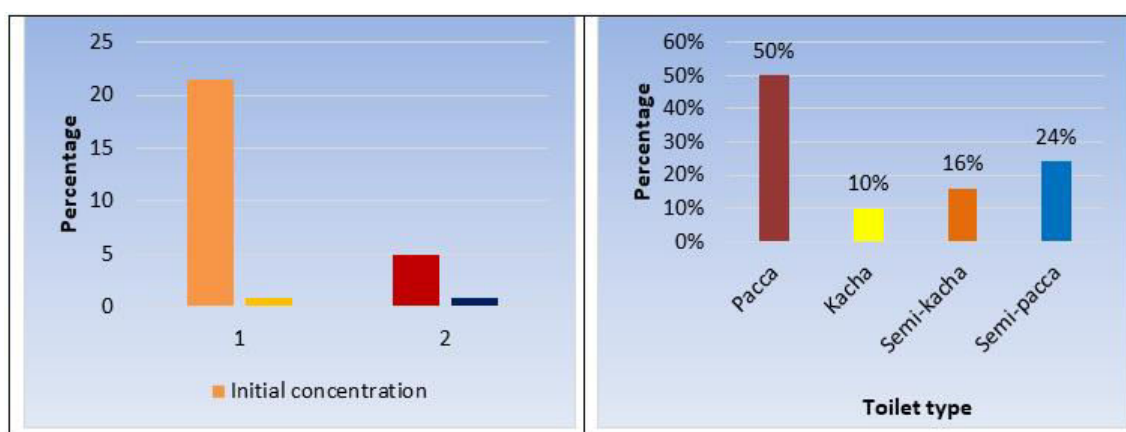


Fig. 4(a): The variation of Phosphorous concentration; b) Patterns of Toilet Usage among Respondents.

Frequency of Septic Tank Desludging

Fig. 5(a) illustrates the desludging practices of the respondents. The graph shows that only 12% of respondents desludge their waste every three months, while 20% do so after six months. Additionally, 24% of respondents reported desludging once a year, and 44% stated that they desludge their septic tanks after more than one year.

These findings indicate that regular desludging practices are not appropriately maintained. Such infrequent waste management is not considered hygienic and does not follow recommended sanitation guidelines. Ideally, septic tanks should be desludged at appropriate intervals to ensure proper operation and maintain public health standards (Strande & Brdjanovic, 2014, Peal *et al.*, 2014). In the same way, Tilley *et al.* (2014) indicated that in order to prevent over-flow, system failure, and contamination risks, septic tanks should be desludged at suitable intervals.

Waste Disposal Practices of Respondents

Fig. 5(b) presents the waste disposal practices of the respondents. The results show that 16% of respondents dispose of their waste by digging a hole in the land. This method can be considered relatively safer compared to open dumping, and over time, it may contribute to fertility of soil. However, 14% of respondents have drainage systems connected to ponds, resulting in direct waste discharge into water bodies that leads to environmental contamination.

Moreover, 10% of respondents discharge their waste into lakes, negatively affecting aquatic life, including plants and fish, and further degrading the environment. Since the study area is a coastal region, a significant proportion (60%) of respondents has drainage systems connected to rivers. This practice poses serious environmental risks, as it contributes to river pollution and creates substantial ecological and public health hazards.

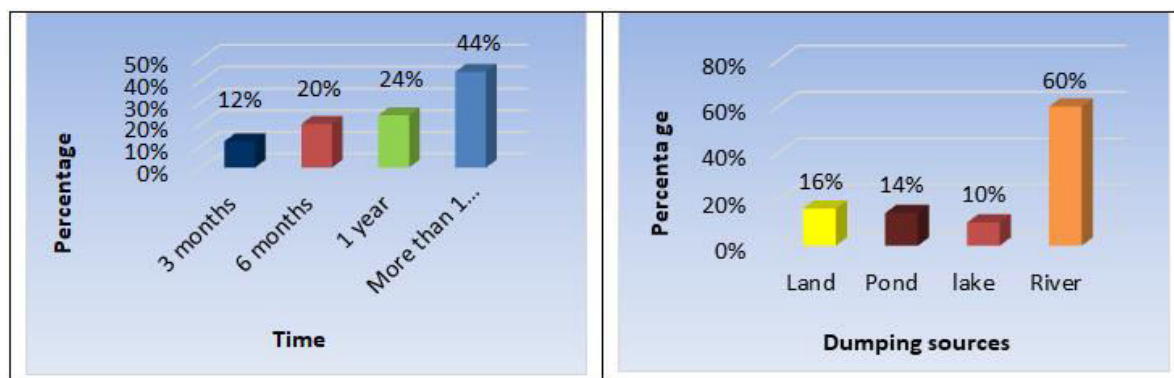


Fig. 5(a): Desludging Practices of Respondents; b) Dumping Sites of Household Waste.

The current results are consistent with earlier research (Wilson *et al.*, 2015; WHO, 2018; Islam & Tanaka, 2004) that found improper waste disposal, especially direct discharge into water bodies, contributes to environmental pollution, ecosystem degradation, and public health risks.

Human excreta responsible for environmental contamination

As the study area is a coastal region, many respondents have limited awareness regarding the environmental impacts of improper human excreta management. **Fig. 6(a)** clearly illustrates the level of awareness among the respondents. The results show that 40% of respondents are aware that improper management of human excreta contributes to environmental contamination. On the other hand, 60% of respondents reported that they are not conscious to the consequences of environment which associated with human excreta mismanagement. Similar findings have been documented in earlier research, showing that poor sanitation practices and environmental contamination are largely caused by a lack of knowledge and awareness (WHO, 2018; UNEP, 2015). Furthermore, research has shown that increasing environmental education and raising community

awareness are crucial for improving sanitation practices and depressing risks to environmental health (Rosenthal *et al.*, 2020).

Sources of drinking water

From the **Fig. 6(b)**, it is evident that 40% of respondents collect their drinking water from tube wells, while 30% obtain water from taps. In contrast, 20% of respondents depend on river water, and 10% collect water from ponds. The use of river and pond water for drinking purposes is measured unsafe and unhygienic, as these water sources are often exposed to various forms of waste contamination. In the study area, some respondents discharge human waste into rivers and canals, which further raises the risk of water contamination. According to the World Health Organization, drinking contaminated water greatly increases the risk of contracting waterborne illnesses (WHO, 2017; WHO, 2018). Furthermore, research has shown that poor sanitation practices, such as the release of human waste into bodies of water, increase the risks to public health and water contamination (Prě-Ustün *et al.*, 2019). Such practices may contribute to the spread of waterborne diseases and pose significant health threats to the community.

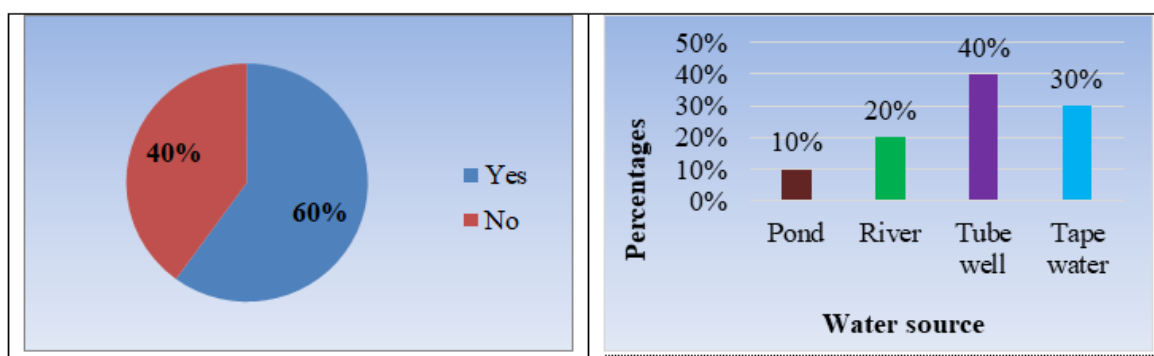


Fig. 6(a): Human excreta are related to environmental pollution, b) Sources of drinking water.

Water borne diseases faced by respondents

Due to the use of unsafe water for domestic and household purposes, many respondents in the community suffer from water borne diseases such as diarrhea, cholera, and dysentery. **Fig. 7(a)** illustrates the prevalence of waterborne diseases among the respondents. The results show that 40% of respondents reported suffering from water-related illnesses, while 60% stated that they do not suffer any such diseases. As indicated earlier, the majority of respondents use tube wells for drinking purposes,

which may contribute to the comparatively lower incidence of waterborne diseases. The prevalence of water borne diseases in the study area is in line with the global evidence that water, sanitation, and hygiene (WASH) conditions are a major contributor to the burden of diarrheal and water-related diseases (Prüss-Ustün *et al.*, 2019; Wolf *et al.*, 2014). Research has also shown that unsafe drinking water and poor sanitation practices are major contributors to water-related problems in developing countries (Fewtrell *et al.*, 2005; WHO, 2023).

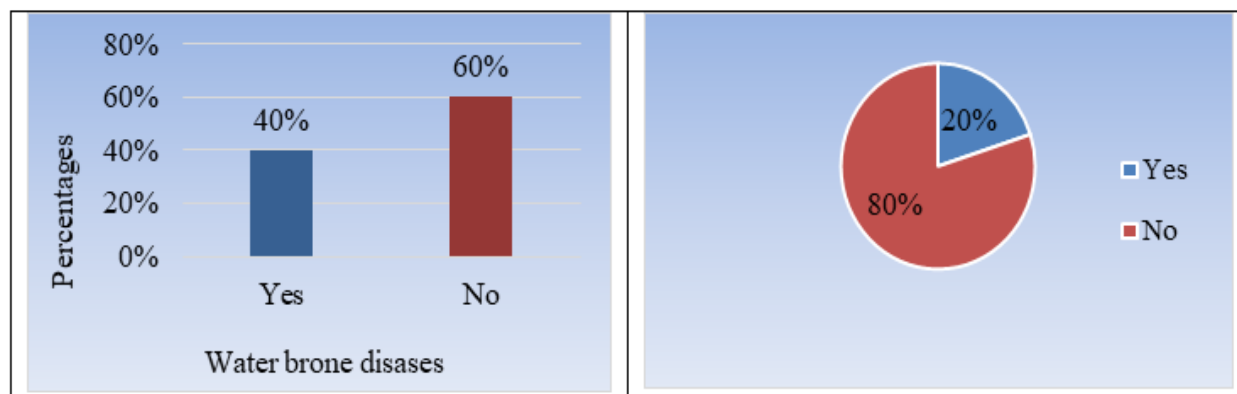


Fig. 7(a): Water borne diseases faced by respondents; b) Attitudes toward Integrated Sanitation-Aquaculture Systems.

Perception of Sustainable and Hygienic Fish Farming Practices in the Study Area

During the survey, respondents were asked whether they were aware of fish farming ponds where toilets are constructed or hung above the water. They were also asked about their perception of fish farming practice types. The findings reveal that 80% of respondents have a negative perception of this practice, while 20% stated a positive perception **Fig. 7(b)**. The majority's negative response indicates concerns regarding hygiene, environmental safety,

and public health implications associated with this cultivation method. The results obtained in this study verify previous studies that emphasize that the lack of incorporation between the sanitation system and aquatic environments can create potential environmental and health risks (WHO, 2018; Moe & Rheingans, 2006). The importance of adopting a hygienic and sustainable method in the management of aquatic cultures has also been emphasized in some studies (Subasinghe, 2017; Islam & Tanaka, 2004).

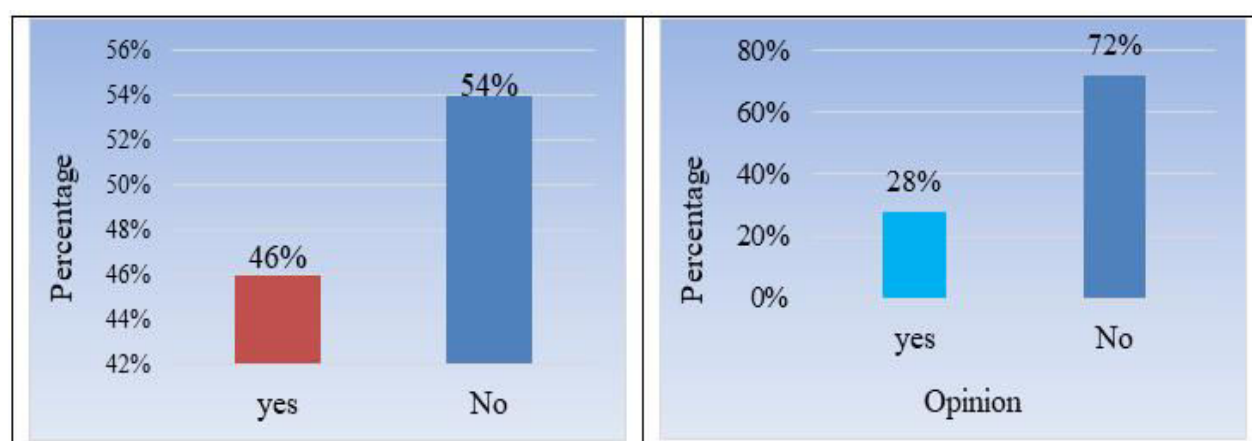


Fig. 8 (a): Knowledge about the uses of human excreta; b) Perception of Human Excreta as a Recyclable Resource.

Community Awareness Regarding the Utilization and Management of Human Excreta

As the study area is a coastal and relatively underdeveloped region, many people have limited knowledge regarding the proper use and management of human excreta. The survey results show that 46% of respondents are aware of the potential uses of human waste; however, they do not practice or apply this knowledge actually. On the other hand, 54% of respondents reported that they have no knowledge about the usage or benefits of human waste **Fig. 8(a)**. Earlier studies have highlighted that for sustainable human excreta management, there is a need for ample community awareness, knowledge, and implementation strategies (WHO, 2018; Strande & Brdjanovic, 2014; Tilley *et al.*, 2014). These findings indicate a significant gap in awareness and highlight the need for education and training programs to help sustainable waste management practices in the community.

Perception of Human Excreta as a Recyclable Resource

Many respondents lack awareness that human waste can be recycled and employed for agricultural purposes, biogas production, and other sustainable applications. The **Fig. 8(b)** indicates that 72% of respondents do not know whether human waste is recyclable or not. In contrast, only 28% of respondents are aware of its potential for reuse. These findings highlight a considerable knowledge gap within the community regarding resource recovery and sustainable waste management. Previous studies have emphasized that human excreta can be recycled securely for agricultural purposes, biogas generation, and nutrient recovery

with the provision of adequate treatment facilities and awareness among the people (WHO, 2018; Strande & Brdjanovic, 2014; Andersson, Dickin & Rosemarin, 2016). Therefore, increasing awareness and providing proper education on recycling human waste could contribute to environmental protection and resource sustainability.

Perception of Respondents toward Human Excreta Recycling

Fig. 9 shows respondents' attitudes toward the use of human excreta in crop production. The results specify that 56% of respondents strongly disagreed with the use of human excreta for crop production, while 30% disagreed. Only 10% of respondents agreed with this practice. Regarding the recycling of nutrients from human excreta, 46% of respondents disagreed and 36% strongly disagreed with the concept. In contrast, only 8% of respondents agreed and 10% strongly agreed with nutrient recycling from human excreta. When asked whether recycling human excreta could reduce the use of chemical fertilizers, only 20% of respondents agreed and 14% strongly agreed with the statement. On the other hand, 42% of respondents strongly disagreed. The findings highlight that the majority of respondents have negative perceptions and limited acceptance concerning the recycling and use of human excreta. The results are consistent with previous studies that emphasized the significance of nutrient recovery from human excreta for sustainable agriculture, decreasing the need for chemical fertilizers while addressing the issue of public acceptance as a major challenge (Cordell *et al.*, 2009; Sengupta, Nawaz, & Beaudry, 2015; Smol, 2017).

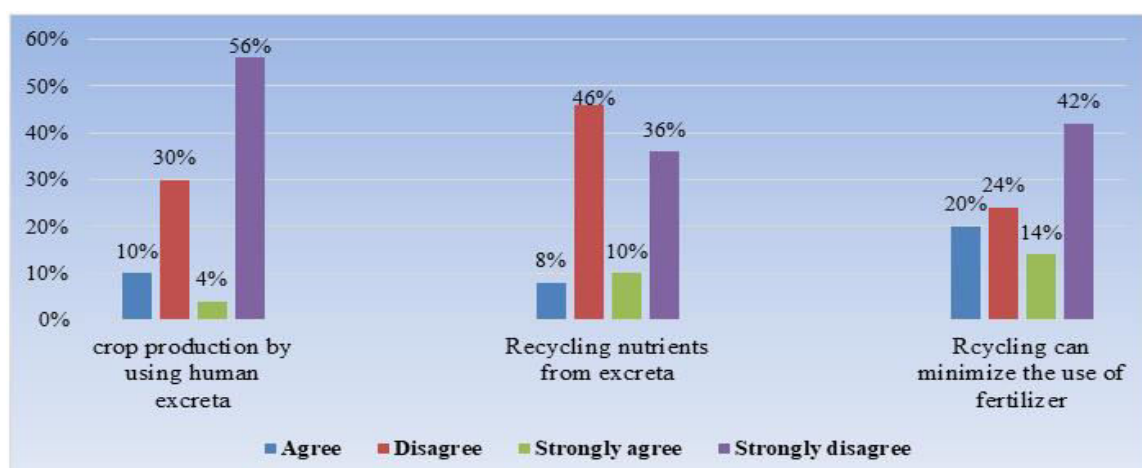


Fig. 9: Perception of Respondents toward Human Excreta Recycling.

Biogas production

Fig. 10 illustrates the respondents' opinions regarding biogas production using human excreta. The results indicate that 30% of respondents agreed with the production of biogas from human excreta. In contrast, 20% of respondents disagreed, while 34% strongly disagreed with this statement. These findings indicate that although some respondents are supportive of this sustainable practice, a considerable proportion still hold negative perceptions toward the use of human excreta for biogas production. Previous studies have highlighted the importance of producing biogas from organic waste materials, including human excreta, for generating renewable energy, reducing dependency on fossil fuels, and improving waste management systems (Atelge *et al.*, 2020; Bond & Templeton, 2011). Biogas technology has been widely renowned as an effective approach for converting organic waste into useful energy while simultaneously addressing sanitation challenges (Kothari *et al.*, 2024). However, several studies have also reported that socio-economic constraints, lack of awareness, and cultural perceptions often hamper the adoption of biogas technologies in rural communities (Mwirigi *et al.*, 2014). Moreover, anaerobic digestion of organic waste is considered a technically feasible and environmentally sustainable process for energy recovery and waste stabilization (Huang *et al.*, 2019).

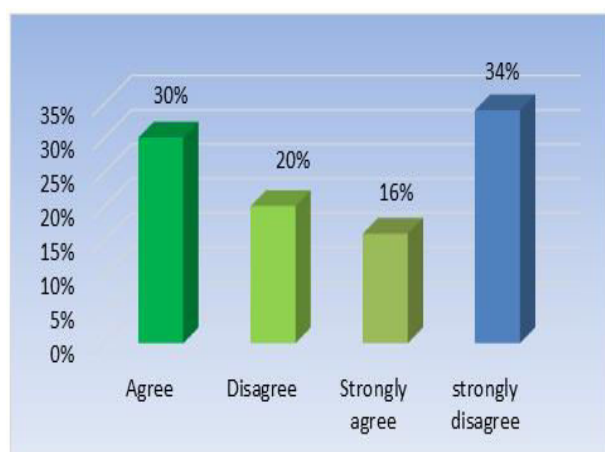


Fig. 10: Biogas production using human excreta.

Awareness of Water Contamination Caused by Human Excreta

Human excreta can significantly contribute to water contamination if not properly managed. However, many people are not aware of this environmental impact. **Fig. 11(a)** clearly shows that 70% of

respondents do not know that human excreta can cause water pollution. In contrast, only 30% of respondents are aware of the role of human excreta in contributing to water pollution. This result indicates a significant lack of knowledge in the community about the connection between water quality and sanitation practices. Similar findings have been documented in earlier research, which emphasises how environmental pollution and the spread of waterborne illnesses are caused by a lack of knowledge and awareness about sanitation practices (Prë-Ustün *et al.*, 2019; Mara *et al.*, 2010). The World Health Organization also highlights that one of the main causes of water contamination in many developing countries is inappropriate handling of human waste (WHO, 2018). As a result, the results of this study are in line with previous research, showing that low public awareness continues to be a significant obstacle to effective environmental protection and sanitation management.

Awareness of Environmental Protection through Reuse of Human Excreta

Reusing human excreta can play an important role in protecting the environment. Reusing and properly treating human waste can minimize the spread of dangerous pathogens that could contaminate soil and water bodies, prevent uncontrolled disposal, and lessen environmental contamination. Reusing human waste can help reduce environmental pollution, but many people are still unaware of this. Only 36% of respondents are aware of this idea, and 64% are unaware of it, according to **Fig. 11(b)**. These results show that the community is largely unaware of the advantages resource recovery from human waste has for the environment. According to related studies (WHO, 2018; Strande *et al.*, 2014; Andersson *et al.*, 2016), treated human waste can be safely repurposed as a valuable resource for agriculture and energy production, thereby supporting sustainable sanitation and environmental protection.

Religious Views on Waste Recycling in Different Religions

Muslims: The Islamic teachings on environmental health and waste management could be observed from various teachings of Islam. First, with regards to the hygienic lifestyle, to show the importance of being clean and hygienic, as reported by Imam al-Bukhari in his authentic collection, the Prophet (s. a.

w.) mentioned that: “cleanliness/purification of half of faith. Second, in another narration, to prevent health complications that might arise from consuming or using contaminated water, and perhaps to maintain environmental health, the Prophet (s. a. w.)

prohibited the urination on standing or static water. So from the second statement production of crops by recycling human excreta can be acceptable by Muslims.

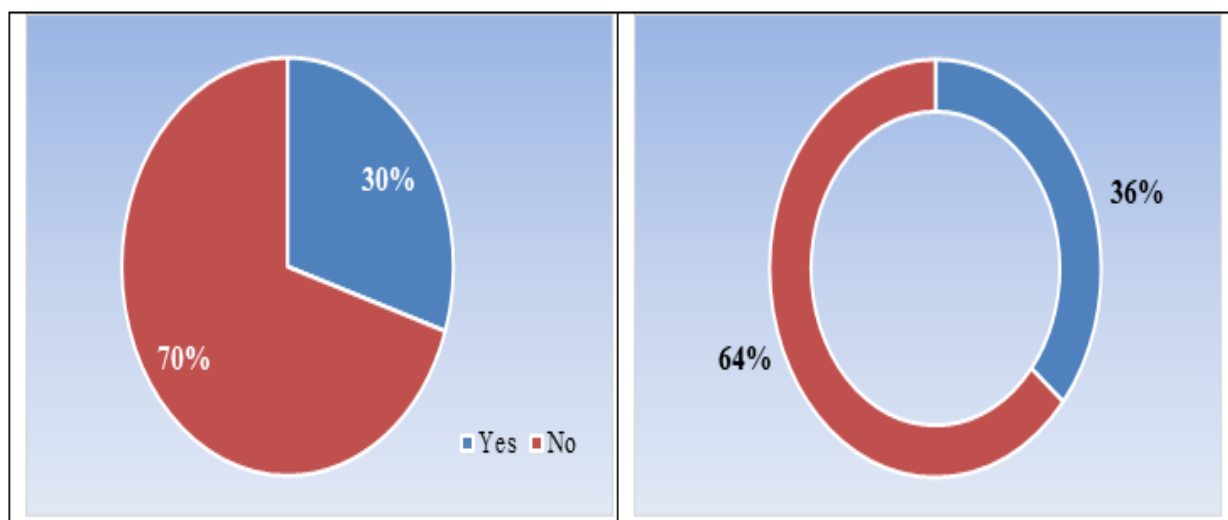


Fig. 11(a): Human excreta responsible for the water pollution; b) Controlling environmental pollution by reusing human excreta.

Hinduism: The Batu Caves temple (also known as the Sri Subramaniam Swamy Temple) is located on a limestone hill dedicated to Lord Muruga. It is one of the Hindu religion’s major sacred areas in Malaysia. As it is located in a natural limestone cave, the temple has a very close relationship with its environment. Recycling activities at the temple started about 11 years ago, as a response to the launching of the national recycling day. The temple recycles bottles, cans, tins, paper, and cardboard. The temple has worked closely with other partners to organize, during the festival, a recycling campaign, called “Kempen Sampah Masyarakat” (community waste campaign), involving young volunteers from all walks of life. As the holy place Batu Caves temple appreciates the process of recycling waste so recycling human excreta and using in human welfare can also be appreciated if we can properly convince the people of Hindu religion.

Christianity: Beautiful Gates Centre the Beautiful Gates Centre was established in 1993 and is one of the establishments under the Malaysian Chinese Methodist Church. The main objective of the center is to provide support for people with disabilities. The Beautiful Gates recycling program has also obtained permission from the Petaling Jaya municipality to place recycling bins at apartments

and also churches. Once collection is done, the recyclables are then sorted according to different categories at a recycling centre. Main categories of recyclables include paper, glass, plastic, clothes, furniture and electronic devices.

In fact every religion appreciates recycling waste and save environment from hazardous event. So by telling the activities of the every religion according to the respective religion of people we can invite and convince the people for recycling human excreta and using it different purposes.

4. Conclusion

The present study demonstrates that human excreta are a valuable source of essential plant nutrients, particularly phosphorus, which can be effectively recovered through struvite precipitation. The significant reduction in in phosphorus concentration after treatment confirms the efficiency of this method for nutrient recovery and highlights its potential as a sustainable alternative to conventional chemical fertilizers. Recycling nutrients from human excreta can contribute to resource conservation, reduce environmental pollution, and support sustainable agricultural practices. However, the findings also reveal limited community awareness and predominantly negative perceptions regarding the reuse of human waste, which remain key barriers

to its adaptation. Therefore enhancing public awareness, improving sanitation infrastructure and prompting safe, culturally acceptable recycling technologies are crucial for the successful implementation of sustainable waste management systems and long-term environmental and public health protection.

5. Author Contributions

P.H.: Conceptualization, Questionnaire formulation, Data Analysis, Writing, Editing; J.N.: Conceptualization, Questionnaire formulation, Data Collection, Laboratory Analysis, Draft Writing; M.S.: Draft Writing, Analysis;

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7. Conflicts of Interest

The authors declare no conflict of interest.

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