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Economic Efficiency and Circular Economy of *Corchorus olitorius* L. and *Garcinia mangostana* as Natural Coagulants in Domestic Wastewater Treatment

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Abstract

Attempts were made in this study to examine the economic efficiency and circular economy of *Corchorus olitorius* L. and *Garcinia mangostana* as natural coagulants in the treatment of domestic wastewater along with synthetic coagulant Alum. To evaluate the economic efficiency, incremental cost-effectiveness ratio (ICER) was the method used in finding the most efficient treatment design, considering the cost and the effect of treatment which is the removal efficiency of the contaminant. Additionally, to assess the circular economy related to the two natural coagulants (C100 and M100), the results of measured values of the parameters under study were compared with the DENR standard (DAO-2016-08) to see if the values are within the specified standards. Based on the findings of the study, treatment combination with saluyot as a coagulant attained cost per unit gram per liter at PHP1.32 ($A_{50}C_{50}$), 1.08 pesos ($A_{75}C_{25}$) & PHP 1.56 ($A_{25}C_{75}$). It has turbidity removal efficiency of 84.15%, 83.47% & 80.27%, respectively. Moreover, with mangosteen as the coagulant, results obtained for cost per unit gram per liter of wastewater were PHP0.43 with a removal efficiency of 91.40% ($A_{50}M_{50}$), PHP 0.64 with a removal efficiency of 90.22% ($A_{75}M_{25}$), and PHP 0.22 with a removal efficiency of 88.87% ($A_{25}M_{75}$). Using mangosteen as a coagulant proved economically efficient compared to saluyot. Further, the circular economy assessment showed that pure natural coagulant has the potential to remove water pollutants with effluents acceptable to DENR standards.

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Introduction

Building on the principle of "Leaving no one behind", sustainable development goals were adopted to achieve a better and more sustainable future for all. According to the sustainable development goal (SDG #6), there should be clean water and sanitation for all people. Water is vital to life and this resource has become scarce due to anthropogenic activities, which resulted in the contamination of water bodies. Wastewater treatment industries played a significant role in addressing the problem of water pollution. In wastewater treatment, various methods were used to remove or reduce pollutants to an acceptable level. Coagulation and flocculation processes are widely used in water and wastewater treatment for the removal of contaminants like suspended colloidal particles, which are responsible for the degradation of water quality (Choy *et al.,* 2014). In the actual wastewater treatment process, coagulation-flocculation happens during the secondary treatment and the procedure usually takes place in a chemical reactor in which the influent water or wastewater enters the basin and is mixed with a coagulant agent with a mechanical mixer, followed by sedimentation to remove particle through gravity settling (Hammer *et al.,* 2004). There are several types of coagulants being used in water and wastewater treatment industries and the use of chemical coagulants like aluminum sulfate and ferric salts are discouraged due to their downsides like a high volume of sludge production and chemical residuals that may be present after the treatment. Chemical coagulant residuals are harmful because it is known to cause Alzheimer's disease when consumed (Garde *et al.,* 2017). Moreover, with the use of a chemical coagulant, a high dosage is needed for effective results, while with a natural coagulant, only a small dosage is needed but with greater removal (Radin Mohamed *et al.,* 2014). Presently, the use of a natural coagulant has become a good alternative because it is safe to use and environmentally friendly. Likewise, a bio-coagulant is much cheaper than a chemical coagulant because it can be extracted from various plant wastes, which greatly reduces the cost of treatment (Debora *et al.*, 2013). In this study, *Corchorus olitorius* L. (Saluyot) and *Garcinia mangostana* (Mangosteen) were investigated for their economic efficiency when used as coagulant/ coagulant aid in the treatment of domestic sullage. These two plant species were found abundant locally and can be produced commercially if demand for wastewater treatment is established. Moreover, this paper also evaluates the circular economy with the use of pure bio-coagulant.

The circular economy is an economic system that aims to eliminate waste and the continual use of resources. This is a closed-loop system wherein wastes are recovered and become a resource to produce another product.

Specifically, the study: a.) determines the cost per unit gram of natural coagulants: *Corchorus olitorius* L. and *Garcinia mangostana* based on the preparation of the powder; b.) compare the cost per cubic meter of wastewater being treated with different treatment design; c.) determine the circular economy in the use of pure natural coagulants.

Materials and methods

Research setting

Fig. 1 shows the study area. The wastewater sample is collected at the sump pit of the University of Science and Technology of Southern Philippines, Cagayan de Oro Campus, and brought to the laboratory for coagulation treatment.

Collection of water sample

A wastewater sample is collected from the sump pit of the University of Science and Technology of Southern Philippines, Cagayan de Oro Campus.

It is characterized as grey water, which is generated from the buildings of the school campus. The sample water is taken and brought to the school laboratory for its analysis using the coagulation process.

Preparation of natural coagulants

The preparation of the natural coagulant involved an experimental set-up where heating and treatment with propanol were done to derive the saluyot mucilage, and heating with a water bath was utilized to produce the mangosteen powder. A jar test was then conducted and treatment of wastewater was done using the treatment design as shown in Table 1.

Cost-effective analysis

The economic efficiency of natural coagulants *Corchorus olitorius* L. and *Garcinia mangostana* is evaluated using cost-effective analysis. To conduct a cost-effect analysis of the study, determining the cost of the natural coagulant yielded from an identified amount of raw material is necessary.

The cost of the saluyot yield was calculated using the formula below:

$$C = (C_{RawMaterial}) + (EC_{HotPlate} \times N) + (V_{2\text{-}propanol} \times MC) + (EC_{DryOven} \times N) \quad 1$$

Where C is the cost of producing saluyot powder, CRawMaterial is the cost of raw material, $EC_{HotPlate}$ is the energy cost of a hot plate, N is the number of hours used, $V_{2\text{-}propanol}$ is the volume of 2-propanol used, MC is the market cost of 2-propanol per milliliter) and $EC_{DryOven}$ is the energy cost of a dry oven.

The cost of the mangosteen yield was calculated using the formula below:

$$C = (C_{RawMaterial}) + (EC_{HotPlate} \times N) + (EC_{DryOven} \times N) + G \quad 2$$

where C is the cost of producing mangosteen powder, $C_{RawMaterial}$ is the raw material cost, $EC_{HotPlate}$ is the energy cost of a hot plate, N is the number of hours used, $EC_{DryOven}$ is the energy cost of a dry oven and G is the market price of grinding per gram.

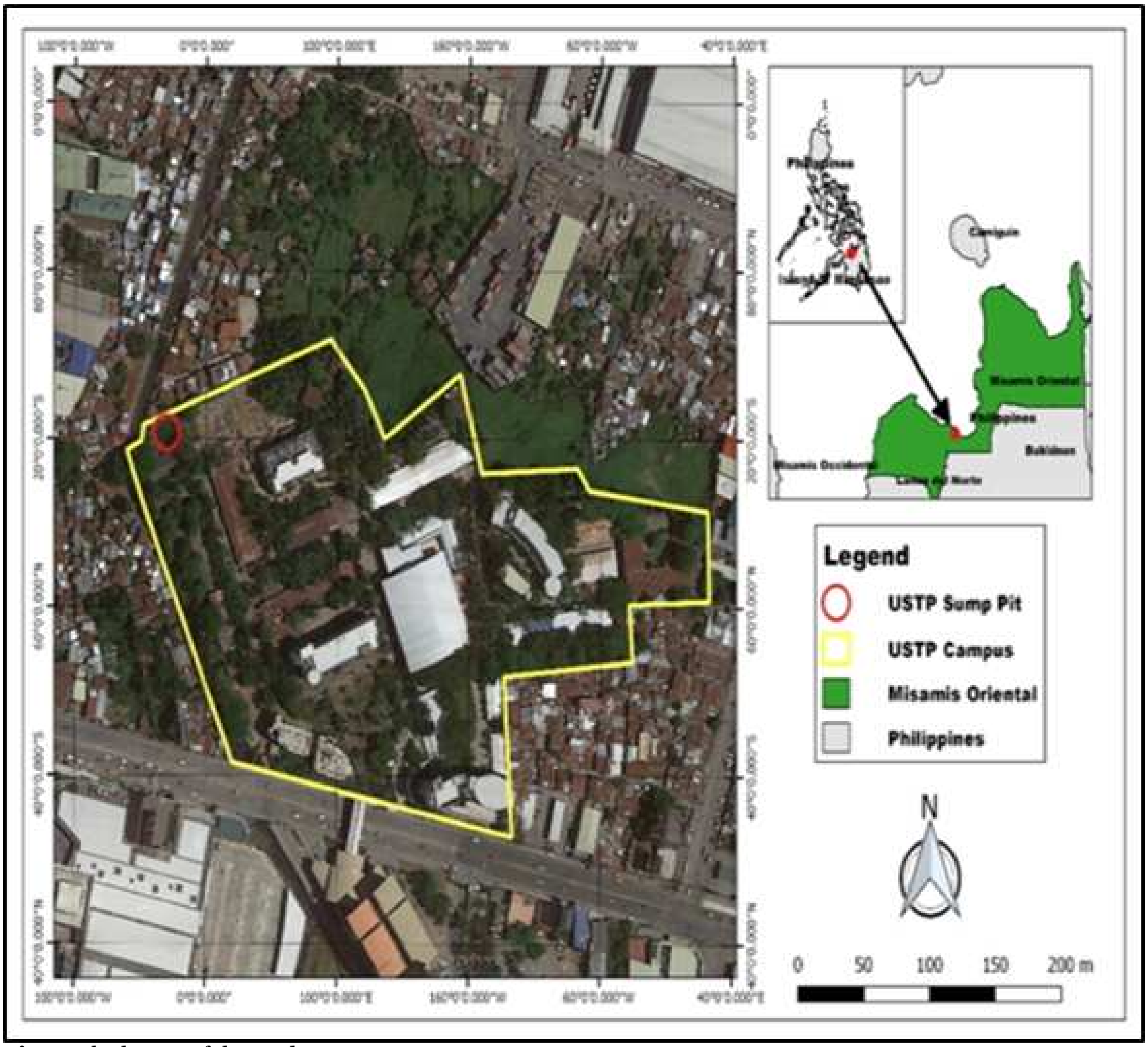

Fig. 1. The layout of the study area.

Operating cost is one of the most important parameters in the EC process because it affects the application of any method of wastewater treatment. The operating cost includes material costs and electrical energy costs. Thus, in this study, the operating cost was calculated with the cost of producing both saluyot and mangosteen powder and electrical energy costs. So, both energy and material production costs were considered major cost items. The calculation of operating cost is expressed as (Adapted from Ozyonar and Karagozoglu, 2011):

$$\text{Operating Cost} = E\ \text{Energy}_{consumption} + C\ \text{Material}_{production} \quad 3$$

where E $\text{Energy}_{consumption}$ and C $\text{Material}_{production}$ are consumption quantities per cubic meter of treated wastewater. In order to evaluate the economic efficiency, we used the ICER statistical formula (Eq. 4). In this formula, the cost differences between the two interventions are divided by the differences in their effects (Birch and Gafni 2006; Gaziano *et al.* 2006).

$$(C_1 - C_0)\ \text{Incremental Cost-Effectiveness Ratio (ICER)} = \text{-------------}(E_1 - E_0) \quad 4$$

where C_1 and C_0 are the cost and E_1 and E_0 are the effects in the intervention and control groups, respectively.

Circular economy on the use of natural coagulants

The concept of the circular economy being applied in wastewater treatment using natural coagulants *Corchorus olitorius* L. and *Garcinia mangostana* produced zero waste. During the treatment with the coagulation-flocculation process, effluent is produced along with sludge. Sludge produced with natural coagulant is minimum and safe to be recycled as a resource to produce other products like soil conditioners as compared to chemical coagulants. The effluent, on the other hand, is tested for its water quality parameters like biochemical oxygen demand (BOD), total suspended solids (TSS), turbidity, total nitrogen (TN), and total phosphorus (TP) to evaluate if the values are within the DENR standards. In this study, measured values of the parameters in the effluent after treatment are compared with DENR Administrative Order (DAO)-2016-08; thus, if the measured values of the parameters are acceptable with DENR standards, then the use of these bio-coagulants would prove to have the potential for economic sustainability.

Results and discussion

Percentage yield

Percentage yield is the amount of product derived from a certain formulation or production. It is computed based on actual yield and theoretical yield.

Saluyot: The percent mucilage of saluyot obtained was about 3.5% from the aqueous fresh saluyot leaves. Out of 186 grams of fresh saluyot, it produced 6.5 grams of dried saluyot mucilage powder. The color of the powder is grayish-white, odorless, and with a fibrous texture.

Table 1. Field Layout of various coagulant optimum doses.

Treatment #	Description	% Coagulant added
1	Control	0
2	M100	100% Mangostana
3	C100	100% Corchorus
3	A100	100% Alum
4	$M_{75}A_{25}$	75% Mangostana & 25% Alum
5	$M_{50}A_{50}$	50% Mangostana & 50% Alum
6	$M_{25}A_{75}$	25% Mangostana & 75% Alum
7	C75A25	75% Corchorus & 25% Alum
8	C50A50	50% Corchorus & 50% Alum
9	C25A75	25% Corchorus & 75% Alum

The estimated percentage yield of corchorus powder

% Yield Saluyot Mucilage = (6.5 grams)/ 186 grams = 3.5%

Mangosteen: The percentage yield of mangosteen extract powder after preparation is 58.1% (93 grams out of 160 grams of fresh mangosteen peel); it has a brownish color and odorless and fine gummy texture.

The estimated percentage yield of mangosteen powder

% Yield of Mangosteen Extract = 93g/ 160 g = 58.1%

Economic efficiency of natural coagulants

Natural coagulants have become popular in recent years over chemical coagulants because it is known to be safe and environmentally friendly (Pongvinyoo *et al.,* 2015). It is more affordable because it is locally accessible. In this study, mangosteen and saluyot were investigated for their economic efficiency when used as a natural coagulant in wastewater treatment. Mangosteen is a locally prized tropical fruit in the Philippines and one of the important economic crops in the country today. Mangosteen has been utilized for various purposes ranging from usage in industrially important products to applications to advance technology (Aizat *et al.,* 2019). Luzon and Mindanao are considered the two highest important mangosteen-producing islands in the Philippines (Berame *et al.,* 2020). This crop can produce 2,000 - 3,000 fruits per tree when properly fertilized, pruned, and irrigated (Ramage *et al.,* 2004).

Table 2. Estimated cost for treating domestic sullage for turbidity removal using natural coagulants: *Corchorus olitorius* L. and *Garcinia mangostana* as coagulant aid at pH7.

Treatment Design	Removal Efficiency of Turbidity (%)	COST diff. in pesos / 1000 mL WWtreated (C1-Co)	ICER(C1- Co)/(E1-Eo)
C50A50	84.15	-0.4725	-0.005615
C25A75	83.47	0.1888	0.002262
C75A25	80.27	-1.1325	-0.01411
M50A50	91.4	0.4186	0.004579
M25A75	90.22	0.6343	0.007031
M75A25	88.87	0.203	0.002284

Mangosteen is an economically important species. The demand for fruit in the domestic and export markets is tremendous. Thus, the fruit fetches a good price (Upaganlawar and adole, 2013). In the local market today, mangosteen fruit has a remarkable price due to its excellent taste. It can be observed that the pulp or mangosteen peel is thrown everywhere after the fruit is eaten. For every 10 kg of mangosteen harvested, 6 kg of mangosteen peel is generated (Chen *et al.,* 2015). The increasing consumption of mangosteen fruit has a corresponding increase in abandoned mangosteen peel residue. This peel residue can be explored as a new potential for medicinal or natural coagulants for wastewater treatment to derive more economic value (Devi *et al.,* 2009; Chen *et al.,* 2015).

Additionally, Saluyot in the Philippines is dubbed as the poor man's vegetable because it is abundantly growing everywhere with little or no care and grows in all types of soil conditions. Presently the sole use of this plant species is for food; however, recent research has proven the medicinal use of this plant. Due to its medicinal value saluyot has become in demand in the market and many farmers opt to plant and care for this crop. Many people prefer saluyot because of its nutritional value, which is rich in antioxidants, minerals, vitamins, and fibers (Aliteg 2015). The potential of saluyot as an effective coagulant aid in wastewater treatment will have an economic benefit to the Filipino people.

Results (Table 2) of the economic evaluation achieved by incremental cost-effectiveness ratio (ICER) showed that among the treatment with *Corchorus olitorius* L. as the coagulant, $A_{75}C_{25}$ design obtained ICER values of 0.002262 as compared to $A_{50}C_{50}$ (-0.005615), and $A_{25}C_{75}$ (-0.014110). Using *Garcinia* *mangostana* as the coagulant showed an ICER value of 0.004579, 0.007031, and 0.002284 for treatment design of $A_{50}M_{50}$, $A_{75}M_{25}$, and $A_{25}M_{75}$, respectively. The cost of producing saluyot mucilage powder is 35.95 pesos per gram, while the production cost of mangosteen is 0.253 pesos per gram. Based on the results, mangosteen powder, when used as a coagulant, proved to be economical as compared to saluyot mucilage powder. Removal efficiency is also much higher with the use of mangosteen as a coagulant which attained the highest turbidity removal efficiency at 91.40% ($A_{50}M_{50}$), followed by 90.22% ($A_{75}M_{25}$) and 88.87% ($A_{25}M_{75}$).

Fig. 2 showed the cost per treatment design using the natural coagulant saluyot and mangosteen. According to the results, treatment with pure *Garcinia mangostana* (mangosteen) showed the lowest cost at 0.01 cents per liter and treatment with pure *Corchorus olitorius* L. (saluyot) showed the highest cost at 1.79 pesos. In the results with treatment combination using coagulant aids, a combination with 75% mangosteen and 25% alum ($A_{25}M_{75}$) had the lowest cost; however, considering the removal efficiency, a treatment combination containing 50% mangosteen ($A_{50}M_{50}$) proved to be the most economical, with the highest turbidity removal of 91.40%, it reduced the cost of treatment by 50.74% as compared to when using pure alum. The study of Haydar and Aziz 2009b reported that the cost of treatment for one cubic meter of wastewater was reduced by 50% when alum was combined with cationic polymer as compared to pure alum alone. In this study, it appeared that the treatment combination containing 50% mangosteen and 50% alum ($A_{50}M_{50}$) proved to be efficient.

Table 3. Measured values of parameters as compared to DENR standard For Class C Water Body.

Parameter	pH5		pH7		pH8		DAO-2016-08 (Class C)
	C100	M100	C100	M100	C100	M100	
Turbidity (NTU)	17.5	14.8	19.2	12.3	22.4	11	*
TSS (mg/L)	118	98	121	90	129	78	100
Nitrogen (mg/L)	3	3.2	3.2	2.7	3.8	2.9	14
Phosphorus (mg/L)	4	3.9	4.2	3.7	6.2	3.2	1
BOD (mg/L)	19.2	16	20.2	14.4	21.5	13.9	50

* No standard.

Circular economy on the use of natural coagulants

A circular economy (CE) is a system of resource utilization where the education, reuse & recycling of elements prevails to create a closed-loop system. It promotes the use of as many biodegradable materials as possible in the manufacture of products so they can get back to nature without causing environmental damage. Companies that have implemented CE systems are proving that reusing resources is much more cost-effective than creating them from scratch (UNEP, 2016; Suarez *et al.,* 2019). CE practices are relevant for the implementation of sustainable development goals (SDGs). The results of the literature review determine the relationship between CE practices and SDG targets. It shows that CE practices potentially contribute directly to achieving a significant number of SDG targets, among them achieving SDG 6, Clean Water and Sanitation (Schroeder *et al.,* 2019). Water has always been a key resource to industry linked to the development of a set of services to use it that currently are conceived as a closed cycle, such as withdrawal, purification, distribution, sanitation, treatment, and reuse, imitating nature, which we should not stray from for continuous development and growth. This is the concept of circular economy which, in this study, the use of natural coagulants in wastewater treatment would lead to zero waste.

In the wastewater treatment process, two products are produced after treatment with the coagulation-flocculation process and these are the effluents or the clear liquid after treatment and the sludge, which settled at the bottom of the coagulation tank.

Normally, the typical wastewater treatment uses chemical coagulants like alum; however, some problems are associated with possible health risks due to the presence of chemical residuals in the effluent or in the sludge. Moreover, with the use of chemical coagulants, there is a high volume of sludge that is produced. Using the natural coagulants *Corchorus olitorius* L. and *Garcinia mangostana* in wastewater treatment would reduce the problem in sludge disposal and these coagulants are more effective in treating sullage as they do not alter the pH that much and produce low sludge volume, which can be used as eco-products by possible conversion of sludge into fertilizer or soil conditioner. Thus, there is no waste after the treatment, which will reduce production costs associated with sludge disposal and the industry can benefit from this zero-waste strategy. Bio- coagulants are economical and eco-friendly.

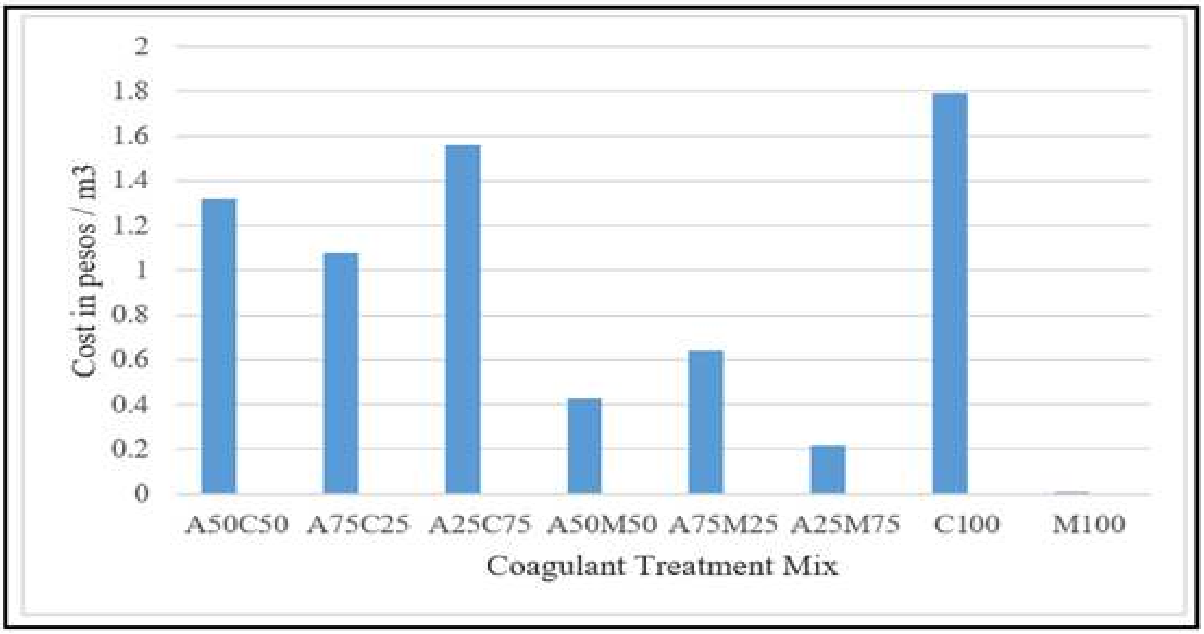

Fig. 2. Cost per treatment design of one liter of wastewater.

Table 3 shows the measured values of the parameters in this study at different pH conditions in comparison with the DENR standard (DAO-2016-08) when pure natural coagulants (C100 and M100) are used. As presented in the results, when pure *Corchorus olitorius* L. (C100) was used as a pure coagulant, measured values were: turbidity (17.5 NTU), TSS (118 mg/L), nitrogen as nitrate (3.0 mg/L), phosphorus (4 mg/L), and BOD (19.2 mg/L). Furthermore, results with pure *Garcinia mangostana* (M100) revealed the following: turbidity (14.8 NTU), TSS (98 mg/L), nitrogen as nitrate (3.2 mg/L), phosphorus (3.9 mg/L), and BOD (16.0 mg/L).

Comparing the measured values of TSS, nitrogen, phosphorus, and biochemical oxygen demand (BOD) to the standard values of DAO-2016-08 for class C-water body showed that using a pure natural coagulant (M100) produces effluents that have total suspended solids (TSS), nitrogen & BOD within the limits and acceptable to DENR standard. Whilst the use of pure natural coagulant (C100) produces an effluent with a BOD also within limits stipulated in the DENR standard. It signifies that with the use of pure natural coagulant in the wastewater treatment process, DENR standard is attained at the same time, and the problem associated with health risks and sludge disposal is minimized.

Conclusion

Based on the findings of the study revealed that treatment combinations containing *Garcinia mangostana* as a natural coagulant proved to be efficient in treating wastewater with a cost per unit gram per liter of PHP 0.43, which obtained the highest turbidity removal efficiency of 91.40%

($A_{50}M_{50}$), followed by 90.22% at PHP 0.64 per unit gram per liter ($A_{75}M_{25}$) & 88.87% removal at the cost of PHP 0.22 pesos ($A_{25}M_{75}$). Natural coagulant proves efficient in the removal of contaminants; however, natural polymers have a shorter shelf life because their active components will biodegrade with time and thus needs to be suitably controlled.

Additionally, the concept of circular economy can be used in this study to eliminate wastes as a result of the coagulation-flocculation technique in wastewater treatment. As stated in the comparison of results of some measured water quality parameters of the study, pure natural coagulants can remove pollutants in wastewater.

With the zero-waste concept in this process, wastewater treatment companies would reduce costs related to sludge disposal and possibly increase their revenues. The use of these natural coagulants would ensure sustainable use of coagulants in the domestic wastewater treatment industry and sustainable development goals, SDG #6 would surely be addressed.

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