



CLUSTER THREE

ENVIRONMENTAL SCIENCE

The greenness of the plant symbolizes growth and progress towards exploring agricultural wastes for environmental science. Trapped inside are the contaminants and pathogens present in our water sources portrayed by the droplet shape, thus providing great capacity for new sorbent materials. Repurposing agricultural wastes offers a sustainable solution to both waste management and oil spill remediation, productively addressing two major environmental issues. Overall, this symbol is a testament to the scientific investigation of the unlimited potential roles of agricultural wastes and the importance of environmental preservation for the community.

Cluster 3 encapsulates the essence of environmental science research, particularly in repurposing sugarcane bagasse, rice residues, and pineapple leaf fibers in diesel oil recovery. Oil sorption studies involve the submersion of sorbents in the oil sorbate to test their ability to absorb or adsorb the molecules into their matrix. Alongside water quality analyses, these studies attempt to address the long-term detrimental impact of pollution in the environment, consequently affecting ecosystems. These studies are dedicated to future research that will uncover the potential of agricultural wastes for the preservation of the environment.

Diesel oil sorption potential of sugarcane bagasse incorporated with human hair

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Abstract

Sorbents remove pollutants by absorption, adsorption, or both. Sugarcane Bagasse (SCB) has excellent sorption ability, but it can acquire water in its pores, limiting its field application in oil spills. Due to the high oleophilic and hydrophobic properties of human hair (HH), the study aimed to determine the sorption percentages of SCB incorporated with HH of varying ratios in diesel oil. Three treatments with the ratios (1:1), (1:3), and (3:1), and three controls were subjected to 60-minute sorption tests by placing sorbent samples on oil-seawater mixtures. Kruskal-Wallis H Test and the Mann-Whitney U test revealed significant differences among groups. An equal ratio of SCB and HH had significantly the highest percent sorption, likely due to the lignocellulosic content in SCB and the lipid layer in HH. Cellulose in SCB is suspected to promote water absorptivity and consequently, percent water sorption, while the hydrophobicity of HH possibly caused low percent water sorption. The synthetic sorbent pad exhibited the highest percent oil sorption, which can be attributed to its hydrophobicity, oleophilicity, and large surface area. The incorporation of HH in SCB shows favorable results in diesel oil removal, specifically in an equal ratio. With this, the study can be a basis for the establishment of sorbents incorporating SCB and HH.

Introduction. - The Philippines, being an archipelago, relies heavily on maritime transport for movement, including motorized “pump” boats or *bangkas* powered by diesel-powered outriggers, where spillage usually occurs during refueling and bilge discharge [1]. Vessels caused more than half (55.15%) of the oil spills in the country between 1975 and 2019, and more than three-fourths of which were Tier 1 oil spills (between 1 to 10,000 liters) [2].

Various methods and technologies such as chemical treatment, bioremediation, and physical remediation like skimmers, booms, and sorbents have been applied in the recovery and remediation of oil spills [3,4]. Sorbents are materials used to remove or recover pollutants by absorption, adsorption, or both [5]. Absorption involves the oil penetrating the pore spaces of the material, while adsorption only entails physical accumulation on the surface of the adsorbent [6,7,8].

Effective sorbents should have high hydrophobicity, oleophilicity, uptake capacity, and appropriate efficiency in oil recovery, retention, reusability, and biodegradability [9, 10]. Based on these criteria, synthetic sorbents are the most widely applied materials but they are not advantageous economically and environmentally, hence there is a rising trend in publications on oil spill cleanup and alternatives [11]. Specifically, there is a growing interest in natural sorbents [11,12,13] due to their accessibility, low costs [11,14]; biodegradability, and non-toxicity [3]. However, a disadvantage for most

natural materials is low hydrophobicity which reduces potential oil uptake due to competition between seawater and oil molecules [3,11].

Studies [15,16,17] have investigated the sorption ability of various natural materials such as raw sugarcane bagasse (SCB), specifically for oil. It is a fibrous agricultural by-product obtained after sugarcane is crushed for juice extraction [16,18].

SCB and its derivatives have been studied as potential adsorbents in both their raw and modified forms [19]. Ali et al. [15] found that SCB exhibits excellent sorption capacity, exceeding 10 g/g, however, its oil-to-water sorbency ratios were considerably low. SCB can still acquire water in its pores despite having a strong high affinity for oil, which hinders its field application. Ifelebuegu and Momoh [18] reported that the high oleophilicity and hydrophobicity of human hair (HH) resulted in increased oil adsorption and decreased water adsorption once integrated with coconut coir. In order to increase usability of SCB, the current study used SCB with added HH, which are agricultural and human waste, respectively. SCB may be more effective in oil spills with reduced water sorption ability [17] and increased oil sorption capacity by incorporating HH in 1:3, 1:1, and 3:1 ratios [18].



In addition to the multiple studies on SCB [6,16,22] and HH [20,21,23] for oil sorption, this research may offer additional insight into oil spill removal, sorbent materials, and the potential of agricultural waste. The abundance and low-cost of raw lignocellulosic materials and HH are favorable for practical applications and clean-up efforts, specifically in oil-water separation [11,24,25].

The study aimed to determine the sorption percentages of SCB incorporated with HH in varying ratios (1:1, 1:3, 3:1) in diesel oil using 60-minute sorption tests. Specifically, it aimed to:

- (i) measure and compute the mean percent sorption (PS) (%), mean percent oil sorption (POS) (%), and mean percent water sorption (PWS) (%) of each treatment and control group;
- (ii) compare the mean PS, mean POS, and mean PWS of groups using the Kruskal-Wallis H test; and
- (iii) determine which pairs of means are statistically different using the Mann-Whitney U test.

Methods. - The methodology is divided into five (5) parts: preparation, sorption, separation of oil and seawater, computation of parameters, and statistical analysis. The estimated duration of the experiment was four weeks, which included periods for procurement, data gathering, and data analysis.

Preparation. SCB and HH were washed and soaked in distilled water, respectively, and dried under sunlight. SCB was sieved to a particle size of 0.25 mm and randomized using the coning and quartering method. A total of 4 g for each sorbent group (excluding sorbent pads) were wrapped in polypropylene fabric for easy retrieval after sorption. A 3-D sphere was used to shape and pack sorbent bags with consistency and minimal disparity.

The oil-seawater mixtures composed of 200 mL of seawater and 20 mL of diesel oil were prepared in 600 mL beakers and measured with a calibrated toploading balance (Sartorius QUINTIX1102-1S).

Sorption. The sorption test was performed by subjecting the wrapped SCB + HH (1:1) sorbent to the surface of the oil-seawater mixture and allowing it to float freely, following the American Society for Testing and Materials (ASTM) F726-99 - Standard Method for Testing Oil Spill Sorbents [5.] After 60 minutes, the sorbent was removed and drained in a basket for 2 minutes. Finally, the resulting sorbent was weighed using a calibrated analytical balance (KERN ABJ 320-4NM). The same procedures were done for the remaining treatment (1:3 and 3:1) and control groups (SCB only, HH only, and sorbent pads). Six samples were tested for each group. To control the substance sorbed by the polypropylene fabric used to wrap the treatments, six samples of empty polypropylene bags of the same dimensions as those used in wrapping the sorbents were subjected to the same procedures and same

experimental conditions. The average weight of the substance sorbed by the empty bag was subtracted from the weights of the sorbent samples.

Separation of Oil and Seawater using Decantation. To obtain POS and PWS values, the remaining oil-seawater mixture was transferred to a separatory funnel, where the mixture was left to rest. The seawater layer was first collected, followed by the oil layer. The separated remaining oil and seawater were individually weighed using a toploading balance.

Computation of Parameters. All variables were measured in grams. PS is the ratio of the substance sorbed by the sorbent to the initial substance in the oil-seawater mixture, disregarding the effect of the polypropylene fabric. It was computed with the formula [20]:

$$PS = \frac{W_a - W_b - W_s}{O_t + W_t} \times 100\%$$

where:

W_a is the weight of the sorbent after sorption,
 W_b is the weight of the sorbent before sorption,
 W_s is the weight of the substance sorbed by the polypropylene fabric,
 O_t is the initial weight of the oil in the oil-seawater mixture, and
 W_t is the initial weight of the seawater in the oil-seawater mixture

The POS is a ratio of oil sorbed to the initial oil in the oil-seawater mixture, disregarding the effect of the polypropylene fabric. It was computed with the formula:

$$POS = \frac{O_t - O_r - O_s}{O_t} \times 100\%$$

where:

O_t is the initial weight of the oil in the oil-seawater mixture,
 O_r is the weight of the oil remaining in the beaker after sorption, and
 O_s is the average weight of oil sorbed by the empty polypropylene bags.

The PWS is the ratio of seawater sorbed to the initial seawater in the oil-seawater mixture, disregarding the effect of the polypropylene fabric. It was computed with the formula:

$$PWS = \frac{W_t - W_r - W_w}{W_t} \times 100\%$$

where:

W_t is the initial weight of the seawater in the oil-seawater mixture
 W_r is the weight of the seawater remaining in the beaker after sorption; and
 W_w is the average weight of seawater sorbed by the empty polypropylene bags.



For the group sorbent pads, the same formulae were used, but O_s and W_w had no values.

Statistical Analysis. The computed mean values of each group for each parameter were analyzed using the Kruskal-Wallis H test. The Mann-Whitney U test was made to identify which pairs of means were statistically different. All tests were performed using Statistical Package for the Social Sciences (SPSS) (Version 28.0.0.0, IBM SPSS Statistics).

Safety Procedure. Precautionary measures for transport, storage, handling, first aid, personal protective equipment, and disposal were observed and implemented. Diesel oil was placed away from items that can create possible hazards. Safety glasses with side shields, aprons, boots, air-purifying respirators for organic vapors (Elastomeric Half Facepiece Respirators), and gloves were worn throughout the data gathering. Lastly, liquid substances and sorbent waste were handed over to Caltex Station Tabuc Suba and PSHS WVC's Research Assistants, respectively, for proper disposal.

Results and Discussion. - The treatment with an equal ratio of SCB and HH had significantly the highest mean PS and PWS, while the control group sorbent pad had significantly the highest mean POS.

Percent Sorption. The mean PS between the treatment and control groups was significantly different using the Kruskal Wallis H test ($H(5) = 26.8393$, $p = <0.001$). The Mann-Whitney U test revealed that the pairs of means that showed statistical differences were T1 and T2, T1 and C2, T1 and C3, T2 and C1, T2 and C2, T3 and C1, T3 and C2, T3 and C3, C1 and C2, and C1 and C3.

Table 1. The Mean Percent Sorption of Treatment and Control Groups.

Group	Mean Percent Sorption (%)
T1 (1 SCB: 1 HH)	16.5783 ± 4.97
T2 (1 SCB : 3 HH)	9.2233 ± 3.78
T3 (3 SCB: 1 HH)	12.9033 ± 1.73
C1 (SCB only)	16.1600 ± 1.08
C2 (HH only)	1.7700 ± 1.90
C3 (Sorbent Pad)	3.9117 ± 0.28

The mean PS of T1 (1 SCB: 1 HH) is significantly higher compared to the PS of T2 (1 SCB : 3 HH), C2 (HH only), and C3 (Sorbent Pad), while it is comparable to the PS of T3 (3 SCB: 1 HH) and C1 (SCB only). This may be attributed to the higher SCB content comprising T1 (1 SCB: 1 HH), T3 (3 SCB: 1 HH), and C1 (SCB only). SCB contains a carbon percentage greater than 50%, providing an initial indication of high lignocellulosic content [18]. SCB is a combination of 40-45% cellulose, 20-30% lignin, and 30-35% hemicellulose [26,27]. Since the groups contain 50% or more SCB, it is supported by its main constituents and polymeric structures, which have a strong influence on the adsorption capacity [28].

The PS of T1 (1 SCB: 1 HH) can also be attributed

to the presence of keratin and cuticles covered by a layer of lipid (18-methyleicosanoic acid), which contributes to the hydrophobic and oleophilic characteristics of HH, hence, the ability to sorb large quantities of oil from aqueous solution [29,30,31]. However, despite its porous structure [32], rough texture, large surface area, and the presence of amine (NH-), hydroxyl (OH), sulfide group, S-S, carboxyl group, C-O, and carbonyl (C=O) groups on its surface [21,30,31], which are factors for high sorption affinity of HH, C2 (HH only) shows the lower than expected sorption affinity for HH (Table 1) in contrast to the recommendation of Ifelebuegu and Momoh [18]. Another mechanism may have been involved in T1 leading to improved distribution because SCB particles and/or HH fibers might be optimally more separated in the 50% mixture.

C1 (SCB only) had a significantly higher mean PS compared to T2 (1 SCB : 3 HH). Surface morphology of the sorbent material is a factor that affects oil adsorption [9]. The rough exterior of SCB [15] provides more active sites for oil adsorption which is desirable and linked to high sorption capacity. Moreover, the oil adsorptivity of a natural sorbent is directly dependent on its active surface area [34,35]. Given that the SCB content was reduced when comparing C1 and T2 as well as SCB having better sorption than HH when comparing C1 and C2, it can be implied that reducing the SCB content also diminishes the sorption potential.

C1 (SCB only) had a significantly higher mean PS compared to T3. It can be speculated that this was contributed by SCB's high water absorptivity [18]. It was observed during the experiment that most samples of T3 (3 SCB: 1 HH) and C1 (SCB only) sank to the bottom of the beaker. This phenomenon is in accordance with the study of Ali et al. [15] and supported by Chau et al. [36], where it was stated that when enough water is absorbed, natural cellulose-based absorbents would sink.

Moreover, T3 (3 SCB: 1 HH) was significantly higher than C2 (HH only), an indication that the incorporation of HH to SCB is better compared to HH alone. T3 (3 SCB: 1 HH) is also significantly higher than C3 (Sorbent Pad), suggesting the potential of the sorbent when compared to commercially manufactured sorbent pads. Additionally, C1 (SCB only) is significantly higher than C2 (HH only) and C3 (Sorbent Pad), which means that SCB exhibits better PS compared to the sorbent material HH or sorbent pads. Similar to the previous discussion, these may be attributed to the higher SCB content comprising T3 (3 SCB: 1 HH) and C1 (SCB only) [16].

The treatment and control groups (excluding C3 (Sorbent Pad) which were laid in sheets) were wrapped with a polypropylene fabric using a 3-D printed sphere to maintain consistent bulk density among samples. Bulk density is also a key factor in determining sorbent porosity and sorption capacity. It indicates how much weight of material could be packed per unit volume and is used to determine how much material can fit in the container [37].



Paulauskienė et al. [38] found that sorbents with high sorption capacity exhibit low bulk density values, since in theory, lower bulk density defines higher porosity. To achieve similar packing space and bulk density across samples, a 3D-printed sphere was used to determine the tightness and amount of space the sorbent bags of the treatment and control groups (excluding C3 (Sorbent Pad)) would have.

Percent Oil Sorption. Kruskal-Wallis H test showed a statistically significant difference between the treatment and control groups ($H(4) = 15.413$, $p = 0.004$). Using the Mann-Whitney U test, C3 (Sorbent Pad) was statistically different from all treatment and control groups as it had significantly the highest POS (excluding T1 (1 SCB: 1 HH)) from the parameter.

Table 2. The Mean Percent Oil Sorption of Treatment and Control Groups, excluding T1*.

Group	Mean Percent Oil Sorption (%)
T2 (1 SCB : 3 HH)	2.45 ± 1.28
T3 (3 SCB: 1 HH)	1.07 ± 0.78
C1 (SCB only)	1.94 ± 1.03
C2 (HH only)	5.63 ± 5.91
C3 (Sorbent Pad)	59.70 ± 7.47

*T1 was excluded from the POS data analysis due to insufficient number of samples.

It was also found that C3 (Sorbent Pad) had the significantly highest mean POS, which may be due to synthetic sorbents having good hydrophobic and oleophilic properties [24] and high sorption capacity [4]. Sorbent pads are made from engineered polymers with a high surface area, a factor that promotes sorption [39]. Additionally, C2 (HH only) had a large standard deviation (Table 2) which may be due to the small sample size of the study.

Percent Water Sorption. Kruskal-Wallis H test showed a statistically significant difference between the treatment and control groups ($H(4) = 14.601$, $p = 0.004$). The Mann-Whitney U test showed that the mean PWS of C2 was significantly lower than those of other treatments – T1 (1 SCB: 1 HH), T2 (1 SCB : 3 HH), T3 (3 SCB: 1 HH), and C1 (SCB only). Furthermore, T1 (1 SCB: 1 HH) had significantly higher PWS compared to T2 (1 SCB : 3 HH) (Table 3).

Table 3. The Mean Percent Water Sorption of Treatment and Control Groups, excluding C3**.

Group	Mean Percent Water Sorption (%)
T1 (1 SCB: 1 HH)	36.65 ± 7.34
T2 (1 SCB : 3 HH)	15.97 ± 13.30
T3 (3 SCB: 1 HH)	30.71 ± 6.65
C1 (SCB only)	29.76 ± 4.35
C2 (HH only)	2.09 ± 1.64

**C3 was excluded from PWS data analysis due to significant outliers.

C2 (HH only), sorbents containing only HH, had significantly lower mean PWS than the other groups. The low sorption of water can be attributed to the hydrophobic property of HH, which is contributed by the layer of lipid that shelters keratin and the cuticle [6] and its affinity for oil [40,41]. In

comparison to T1 (1 SCB: 1 HH), T2 (1 SCB : 3 HH), T3 (3 SCB: 1 HH), and C1 (SCB only), the absence of SCB in the C2 (HH only) group entails a lack of potential water absorptivity, whereas SCB is highly capable of 400% to 700% water absorptivity [17].

It was also found that T1 (1 SCB: 1 HH) had a significantly higher mean PWS than T2 (1 SCB : 3 HH). The difference could be explained by the high water sorption capacity of SCB [7, 17] combined with the hydrophobicity of HH [6]. Comparing the two groups, T1 (1 SCB: 1 HH) has one more gram of SCB and one less gram of HH than T2 (1 SCB : 3 HH). It follows that T1 (1 SCB: 1 HH) is able to absorb more seawater. It can be noticed that groups containing 50% or more SCB are comparable and have a mean of 29% PWS or more. This may be due to the SCB's natural sorption capabilities.

Limitations. Considering that this study was conducted at the height of the pandemic, the organic materials were sun-dried instead of oven-dried due to feasibility concerns, specifically, limited access to equipment. Variations in room temperature may have occurred due to ventilation at the data collection site.

Conclusion. - The PS, POS, and PWS of SCB incorporated with HH in varying ratios in diesel oil were investigated to determine its applicability as an oil spill sorbent.

SCB when incorporated with HH resulted in the highest PS and PWS, which can be attributed to the combination of the water absorptivity of SCB and the oleophilicity of HH. In regards to POS, sorbent pads exceeded all other treatment and control groups consisting of organic materials possibly due to its high surface area and synthetic nature.

This study can serve as a basis for the formulation of SCB with HH as viable oil sorbents in diesel oil removal, and when comparing the treatments of the study, an optimal sorbent ratio would be an equal amount of SCB and HH.

Recommendations. - Experiments can be conducted within a day to avoid possible influence in the following days or all control groups can be tested per day for a more accurate comparison with the treatments. The polypropylene fabric in the study may have had an effect on the treatments and results, hence efficient methods to disregard its effect can be implemented, along with more replicates. Excess substance caused by weak capillary forces can be excluded from the sorbed substance of the sample.

The weighing of glassware can be done repeatedly and with minimal movement in the surroundings to reduce the chances of error in the resulting measurement. Further research can be done at a microscopic level to establish the synergistic effect of SCB and HH provided that both absorption and adsorption are present. Additionally, adsorption isotherm modeling and kinetic modeling are suggested to determine maximum sorbent uptake and reaction rate. Future studies can also test



variations in oil types and the packing of the materials into the bag. For bulk density, different geometrical shapes can be considered to determine a standard measurement in packing and significant differences with respect to their sorption abilities.

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Comparison of raw rice husk and raw rice straw (*Oryza sativa* L.) for diesel oil removal

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Article Info	Abstract
Submitted: Jul 07, 2023 Approved: Dec 26, 2023 Published: Dec 31, 2023 Keywords: rice husk rice straw sorption diesel oil oil spill	Oil spillages result in detrimental environmental hazards, posing mutagenic and carcinogenic effects. Targeting oil removal and repurposing of agricultural wastes, this study aims to assess and compare the percent sorption of raw rice husk (RRH) and raw rice straw (RRS) for pure diesel oil. A tetrahedral framework in the packing of the sorbents was incorporated to control their bulk density. Results showed that RRH, RRS, and sorbent pad have mean percent sorption of 2.97%, 4.71%, and 7.25%, respectively. The significantly higher mean percent sorption of RRS than RRH can be linked to their porosity, surface roughness, and presence of functional groups and lignocellulosic components. Thus, RRS can better sorb diesel oil than RRH. Although it is not comparable with the commercially-used sorbent pad, the use of RRS is still recommended as an alternative sorbent for oil spill clean-up.

Introduction. - Oil spills may contribute environmental damage to lands and seas that could necessitate years or decades of recovery due to the release of toxic hydrocarbon compounds known as polycyclic aromatic hydrocarbons [1,2]. Among reported spill incidents, diesel constitutes 20% of the encountered oil type that originates from major sources such as power plants and power barges [3]. Consequently, diesel oil, with a density of 0.81-0.84 g/cm³, has been recognized as one of the relevant oils that require oil spill response in the Philippines [3]. Thus, diesel, exhibiting better diffusion and higher penetration in sorbents, has been utilized for evaluating the adsorptive characteristics of sorbents [4,5]. Specifically, the diesel used in this study contains a mixture of paraffins, cycloparaffins, aromatic and olefinic hydrocarbons, and has a density of 0.84 g/cm³ [6].

Various technologies for the removal of organic pollutants have been explored by previous studies, such as oxidation, reverse osmosis, ion exchange, electrodialysis, electrolysis, and adsorption [7]. Among these, sorption, constituting both absorption and adsorption processes, was widely used due to its wide availability, low cost, and ease of operation [7, 8]. It refers to the mechanism dependent on sorbent porosity by which a sorbate is incorporated into the porous structures of a material [9]. Other processes involve splitting the compounds into their basic elements and utilizing pressure or electric energy for oil removal.

With the increased amount of non-edible biomass, organic sorbents have been targeted in oil spill treatments, owing to their low cost, high availability, good biodegradability, and other

eco-friendly properties [9,10,11,12]. Sorption capabilities of rice husk and rice straw have been investigated in various sorbates such as dyes, light crude oil, and crude, spent, and engine oil [13,14,15]. Modifications of sorbents have been employed including alkali treatment, thermal modifications, acetylation, and carbonization [1,5,17,18,19,20]. However, these pre-treatment processes were contradicted as time-consuming and costly [18]. Therefore, researchers utilized the raw states of the sorbents. On the other hand, the sorbent pads obtained for this study meet the standards set by the industry for managing spills.

The properties of the sorbents promote their sorption capabilities. The void spaces in the matrices contribute to their porosity, while the composition such as cellulose, hemicellulose, and lignin account for their hydrophobic-oleophilic properties [10,19]. These properties allow the attachment and entrapment of oil within their structures [21]. However, grinding causes damage to the pores, which hinders oil attachment on its surfaces [15]. Thus, the use of raw unground materials appears to be more desirable in emergency oil spill circumstances.

Bulk density, the mass of a bulk solid occupying a unit volume including interparticle voids, influences oil sorption [1,22]. Specifically, low bulk density favors the formation of capillaries between particles, increasing the available contact area between particles [23]. Although previous studies employed various packing methods such as sphere-shaped mesh bags and tetrahedral oil bags, uniformity of bulk density was not specified which could affect oil sorption [16,24]. Thus, the tetrahedral-shaped mesh from Ismail et al. [16] with



fixed volume was adapted to ensure a rigid structure and uniform volume, thereby maintaining a constant bulk density throughout sorption while still allowing oil to penetrate into the sorbents [25].

Porosity was found to be higher in rice straw than in rice husk [26]. Studies have also shown that porosity influences sorption more than phase composition since sorption capacity increases along with increasing porosities [14,27]. Thus, rice straw is hypothesized to yield a higher diesel percent sorption than rice husk.

This study aimed to determine and compare the percent sorption of raw rice husk (RRH), raw rice straw (RRS), and sorbent pad for diesel oil. It specifically aims to:

- (i) determine the pre-submersion and post-submersion weights (in grams) of the treatment groups (RRH and RRS sorbents) and control group (sorbent pads);
- (ii) evaluate the percent sorption (%) of the three sorbents; and
- (iii) compare the differences in the mean percent sorption of the treatment groups and control group using one-way ANOVA at $p \leq 0.05$.

Methods. - The rice husks and rice straws were washed, oven-dried, cut, sifted, randomized, and then packed inside a tetrahedral frame wrapped in mesh net (TFMN). After which, the samples were weighed and submerged in pure diesel oil. The control samples, or the sorbent pads, were also subjected to the same packing and submersion procedures. All the sorbents were allowed to drip before getting their post-submersion weights. The percent sorption values were then calculated, compared, and analyzed using One-Way Analysis of Variance (ANOVA) at $p \leq 0.05$. A total of 30 samples, 10 for each type of sorbent, were administered.

Procurement of materials. The RRH and RRS were collected from a rice farm in Guimaras Island (10°43'46.88"N latitude and 122°40'59.594"S longitude) and were verified as *Oryza sativa* L., Rc 418 variety by the Office of Municipal Agriculturist in Buenavista, Guimaras. Meanwhile, the commercial-grade sorbent pads were purchased from YMC Philippines based in Metro Manila. The diesel oil was obtained from a gasoline station in Iloilo City. The tetrahedral frames and mesh net were acquired from local stores in Iloilo City.

Preparation. The RRH and RRS were washed with distilled water and oven-dried at 60°C for 24 hours. The RRS was cut into 9mm similar to that of the RRH, while the RRH remained at its original length. Both of these were hand-sieved through fine mesh sieves of 3 mm and 5 mm to attain the desired particle size range of 3 to 5 mm.

Randomization. To minimize the biases in this study, the sorbents were subjected to the coning and quartering method by gradually reducing the aggregate to randomly obtain each sample. The oil sorbates were subjected to the "lottery method" to assign them to their respective sample treatment groups with equal chances of being selected.

Packing of Sorbents. All sorbents were packed inside the TFMN as storage for oil retrieval. This was prepared by wrapping a 15x15cm mesh net around the frame, then filled with 3.00 grams of the specific sorbent, and sealed using a plastic heat sealer. The excess fabric was then cut. There were 10 samples for each type of sorbent: RRH, RRS, and sorbent pads, resulting in a total of 30 samples.

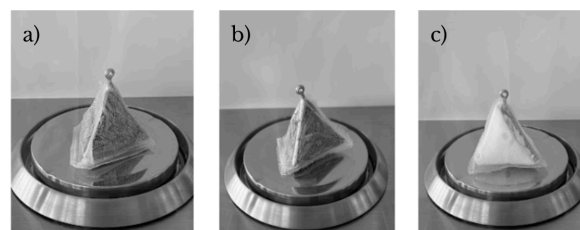


Figure 1. TFMN with a) RRH sample, b) RRS sample, and c) sorbent pad.

Bulk Density. To ensure the uniformity of packing across the sorbents, a constant edge length was set among all TFMN such that the bulk density, when computed, would uniformly equate to 0.28 g/cm³.

Sorption Test. The packed sorbents were simultaneously submerged in 300 mL of pure diesel oil for 15 minutes and were then allowed to drip for another 15 minutes. To minimize the possible effects of any trapped oil in the TFMN, five (5) replicates of empty TFMN were subjected to the same sorption procedures. After which, each packed sorbent was weighed, followed by subtracting the average weight of the empty TFMNs to obtain the final post-submersion weight of the sorbents only.

Data Analysis. The percent sorption values across the sorbents were computed with the formula derived from Razavi et al. (2014):

$$\% \text{ Sorption} = \left(\frac{S_t - S_0}{\text{initial oil}} \right) \times 100$$

Where:

S_t = post-submersion weight (in grams) of the sorbent containing the sorbed oil

S_0 = pre-submersion weight (in grams) of the sorbent
initial oil = weight (in grams) of the diesel oil before sorption

Statistical Analysis. There are three independent means to analyze; therefore, one-way ANOVA, along with its applicable inferential non-parametric, parametric, and post-hoc tests, is an applicable statistical test for this study [28]. The computed percent sorption data of each sorbent was inputted in the Jamovi Software (ver. 2.3.17.0) and was subjected



to the inferential non-parametric Shapiro-Wilk test to determine the normality of the data. To assess the homogeneity of variances across the normally distributed percent sorption of the sorbents, the parametric Levene's test was utilized.

One-way ANOVA was used to determine the presence of a significant statistical difference across the three mean percent sorption values. The significance level was set at 0.05. Lastly, to make pairwise comparisons between the three means, the Tukey post-hoc test was used to further reveal the specific differences.

Safety Procedure. Health and safety protocols were observed during the conduct of the whole experiment, including the wearing of personal protective equipment such as gloves, goggles, masks, and polypropylene laboratory gowns. High-density polyethylene containers were used for the storage and handling of hazardous chemicals or the diesel oil in accordance with the MSDS. For disposal, excess and contaminated diesel oil and used sorbents were handed to the health and safety officer of Philippine Science High School - Western Visayas Campus.

Results and Discussion. - RRS yielded a mean percent sorption of 4.71 which is significantly higher than RRH of 2.97. Sorbent pads, on the other hand, exhibited the highest mean percent sorption of 7.31. (Table 1)

Table 1. Mean weights of RRH, RRS, and sorbent pads before and after sorption (in grams), and their corresponding mean percent sorption values (%).

Sorbent Type	Before Sorption (g)	After Sorption (g)	Percent Sorption (%)
RRH	3.00±0.0006	10.33±0.38	2.97±0.15
RRS	3.00±0.0002	14.66±0.82	4.71±0.38
Sorbent Pads	3.00±0.0003	21.01±0.66	7.25±0.42

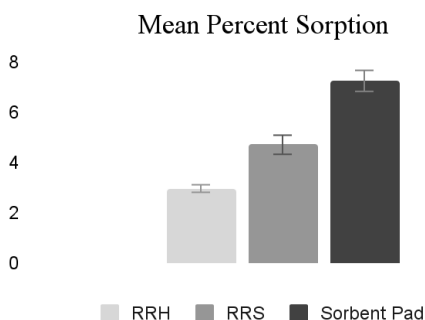


Figure 2. Mean percent sorption of RRH, RRS, and sorbent pad in diesel oil.

The Shapiro-Wilk test revealed a normal distribution among the calculated percent sorption values. The homogeneity of variances in the data was confirmed through the Levene's test. Following the satisfied assumptions, one-way ANOVA indicated a statistically significant difference among the three types of sorbents ($p < 0.00001$). The Tukey post-hoc test further showed that sorbent pad has the highest

mean percent sorption (7.25%) while RRS (4.71%) exhibited significantly higher sorption than RRH (2.97%).

The oil sorption performances of sorbents can be associated with the hydrophobic-oleophilic properties of the material, which were dependent on, porosity, chemical constituents of the sorbent (i.e. lignocellulosic components), and surface roughness [29]. In addition, bulk density is recognized as a critical factor in the oil uptake of sorbents [5].

Relating to previous studies, porosity can be accounted for the higher percent sorption of RRS. A study on the physical properties revealed that rice straw has porosity values ranging from 71.21% to 85.28% while rice husk, on the other hand, has values ranging from 63.64% to 73.23% [26]. Porosity is defined as the measure of the volume space occupied by the pores per volume space occupied by the total sample [30]. It enables the incorporation of oil spillages into their matrix in which as porosities of different sorbents increase, the sorption capacities also increase [27,31].

For the filling of pores to occur, the following must be present: (1) the porous structure and (2) the mechanism that will transport the oil into the porous structure, such as the oil adhesion to its surface, thereby promoting capillary movement [32]. RRH and RRS are made up of cellulose, hemicellulose, and lignin with values of 45.8%, 16.9%, 17.2% for RRH, and 42.2%, 23.7%, 13.1% for RRS, respectively [33]. Cellulose and hemicellulose contain hydroxyl (OH) and acid groups that contribute to the samples' hydrophilicity thus limiting their usage for oil cleanup [29,34]. Lignin, on the other hand, is the hydrophobic component of organic materials. Petroleum components bind to the hydrophobic functional groups of the sorbent for sorption to occur [13]. A previous report has found a higher lignin content of rice husk than rice straw which is in contradiction with the trend observed from the results in this study [33]. Nevertheless, porosity was established to have a stronger influence on sorption performance than phase composition [14]. This may explain the higher sorption of RRS despite having less lignin content than RRH. The high percent sorption of the commercial sorbent pads can be attributed to their high oil recovery ratio once used to their full capacity [20].

A material can be characterized as a sorbent if it allows the sorbate to penetrate into its void through capillary forces or attach to its external surfaces [7]. Focusing on the surface roughness of the samples, this property was suggested to be a part of the adhesion process between the oil and the sorbent's surface [35,36]. A previous report has proven the rough surface of raw rice husk and rice straw [37]. Thus, the oil sorption performance of these sorbents could have also been affected by the factor above. In light of these, RRH and RRS can be considered as sorbents such that diesel oil was able to attach to their structures, thereby acquiring mean percent sorption values of 2.97% and 4.71% respectively.



During the sorption procedures, similar contact times and dripping times that were previously employed in the investigation involving adsorption and absorption procedures were taken into consideration [38,39]. The 15-minute contact time was adopted in line with the observation that 5 grams of RRH and RRS sorbents yielded the highest sorption values when submerged within the given timeframe [38]. This duration is important in allowing sufficient oil-sorbent contact to ensure that saturation has been reached. Similarly, a 15-minute dripping time was also employed in consideration for real-world applications and also to account for more oil uptake by the sorbent [40].

Varying values of bulk density may influence oil sorption performance, i.e. lower bulk density facilitates the formation of capillaries between particles [23]. This increases the contact area between the particles or porosity, increasing the flow of oil inside the material and also resulting in higher sorption of oil molecules [1]. Taking this into consideration, all the sorbent containers were set with a fixed bulk density of 0.28 g/cm³. This value was only set to accommodate the sorbents in the container but is not the most optimal value for bulk density. In this light, a tetrahedral-shaped frame served as the rigid structure of the sorbent container, considering that it has the largest surface area among the convex bodies in n-dimensional space [41]. Meanwhile, in attaining a constant volume for the packed sorbents, a mesh net made of nylon was used to wrap around the tetrahedral frame and contain the sorbents for the standardization of the oil sorption test. In the three-dimensional networks of the nylon, the intertwined fibers allowed oil to penetrate into the sorbents [25].

Limitations. Due to limited access to specialized instruments, the determination and in-depth analysis of the mechanisms that specifically occurred during the sorption procedures (i.e. absorption and adsorption) and the characterization of the sorbents using Langmuir isotherm model, SEM analysis, FTIR analysis, etc. were not conducted. Moreover, considering the varying physical shapes of both RRH and RRS, the particle size ranging from 3 mm to 5 mm did not guarantee an equal width and length between samples. Their particle size was solely based on the particles that passed through the 5 mm sieve and remained on top of the 3 mm. Moreover, due to the lack of sieve shakers, the use of hand-sieving procedures did not guarantee uniformity in terms of the rate of strokes and intensity. With regards to the dripping time, the point where no point of further dripping is observed cannot be determined in this study. Lastly, the raw data in four decimal places recorded from the analytical balance were reduced as the statistical software allows the expression of data only in three decimal places. With this, the percent sorption values only represent the rounded-off values obtained from the experiment.

Conclusion. - In evaluating oil sorption capabilities, RRS was found to be a more effective sorbent than RRH, owing to the significantly higher

percent sorption of the former in diesel oil. However, RRS is not comparable with the commercially available sorbent pad as the latter displayed prominently higher percent sorption owing to its main design which is intended for industrial oil spills. Nevertheless, RRS can still serve as an alternative sorbent in oil spill emergencies with the significant amount of oil it can sorb. By maintaining a uniform bulk density with the use of tetrahedral frames, this study provided an improved method for gathering more reliable data for sorption studies.

Recommendations. - To further provide an in-depth analysis of the sorption mechanism and the properties of the sorbents, it is recommended to conduct further analysis (e.g. SEM, FTIR microscopy, etc.) and utilize mathematical models (e.g. Langmuir isotherm model). To establish uniformity in the particle size, future studies may opt to use machines for uniform cutting and sieving of the materials.

Additionally, to assess the full dripping profile of the sorbent, it is recommended to determine and report the value at the “point of no dripping” since the values will not be overestimated or over-reported [8]. A different statistical software is recommended to ensure consistent decimal places from obtaining raw data until analysis. The use of a water-oil system could also be considered to mimic real-life scenarios. In actual oil spill incidents, dry rice husk and rice straw may be contained in a material similar to the mesh net used in the TFMN for easy retrieval after use. In cases where the samples require drying, sun drying until a constant weight for at least two consecutive days is achieved, may be used as an alternative to oven drying as a means of removing any excess moisture from the samples.

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Comparison of diesel oil removal properties of primary and secondary leaf fibers of *Ananas bracteatus*

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Article Info	Abstract
Submitted: June 27, 2023 Approved: Sept. 28, 2023 Published: Dec. 31, 2023 Keywords: oil spill diesel oil sorberent pineapple leaf fibers fiber diameter	The increasing dependence of humans on oil-based energy constitutes the risk of oil spills which pose hazards to the environment. Some existing oil spill cleanup methods apply chemicals that are harmful to marine life. Pineapple leaf fibers (PALFs) have been used as a sorberent and they showed excellent oil sorption, but are yet to be separated into primary and secondary leaf fibers. <i>Bastos</i> are coarse while <i>liniwan</i> are fine fibers which affect their oil sorption capacity since they have varying fiber diameters and surface area. In this study, primary (<i>bastos</i>) and secondary (<i>liniwan</i>) PALFs were used as sorberents and subjected to diesel oil. The mean sorption capacity by <i>bastos</i>, <i>liniwan</i>, and sorberent pad were 13.76 g/g, 14.09 g/g, and 4.43 g/g, respectively. <i>Bastos</i> and <i>liniwan</i> were found to have no significant difference between their mean oil sorption capacity and exhibited a significantly higher mean oil sorption capacity than the sorberent pads. This implies that both the <i>bastos</i> and <i>liniwan</i> can be used as sorberents for potential diesel oil spills. It is suggested to use <i>bastos</i> more as an alternative in diesel oil removal since it is not used in other industries as compared to <i>liniwan</i>.

Introduction. - The Philippines is an archipelagic country, and shipping is the primary mode of inter-island transportation. Marine transport is also the backbone of international trade and the global economy [1]. It is also located at the Coral Triangle, which is an area of importance as it is recognized as the global center of marine biodiversity [2]. The increasing dependence of humans on oil-based energy has raised concerns about the risk of increasing oil spills.

The International Tanker Owners Pollution Federation recorded a total of 15,000 tonnes of spilled oil in 2022 which was caused by tanker incidents globally [3]. The Philippine Coast Guard, as secured by the National Operation Center for Oil Pollution (NOCOP), has recorded 553 oil spills as of 2019, more than half of which are caused by vessel oil spills (55.15%). Vessels usually transport petroleum products including diesel oil, which is also the top-imported petroleum product in the country in 2022 [2,4]. Moreover, MT Princess Empress was carrying 800,000 liters of industrial fuel oil when it sank in February 2023. This resulted in threats to fishing communities and biodiversity in 20 marine protected areas [5].

Oil spills can have catastrophic consequences for both the environment and human health. Oil spills are major water pollutants that kill marine organisms; with some that are suitable for human consumption [6]. These pollutants may spread and reach rivers and other aquatic habitats, posing a hazard to our environment [7]. Ecological changes, primarily the loss of key organisms from a community, may also be observed as a result of oil spills [8].

Dispersion and in-situ burning are some of the current solutions to oil spills. However, dispersion uses chemicals that are harmful to marine life and in-situ burning produces gases that are harmful to our atmosphere and toxic to human bodies, so it is important to find methods to mitigate the effect of oil pollution and also recover the spilled oil simultaneously such as the process of sorption through organic sorberents [9,10]. Organic sorberents have been emerging as possible alternatives for oil spill cleanup due to their availability, eco-friendliness, and low cost [11].

Oil sorption is an alternative method used to recover oils with the help of sorberent materials that act like a sponge [12]. Synthetic sorberents such as polypropylene are commonly used in oil sorption because they have a high sorption potential, but they are non-biodegradable and expensive [13]. This led researchers to study biodegradable and low-cost sorberents such as lignocellulosic materials.

Plant waste fibers, which are characterized as lignocellulosic materials, are resources composed primarily of cellulose, hemicellulose, and lignin. These can be derived from plant substances such as agricultural residues [14]. The Philippines is the world's second-largest producer of pineapple plant residue, wherein the fibers derived from the pineapple leaves are usually dumped for composting, thus making them agricultural wastes which would make them useful for biowaste utilization [15]. Previous studies have utilized pineapple leaf fibers (PALFs) as biosorberents for oil such as the study of Gomes et al. [16] who found that the peat (commercial sorberent) and the curaua PALF showed similar sorption capacity. Moreover, utilized PALFs



blended with polyethylene/polypropylene sheath core composites (ES) from Ekwonu et al. [17] were utilized as sorbents for diesel and automotive gas oil. Cheu et al. [18] also used pineapple leaves but are chemically pretreated to exhibit higher oil sorption capacity.

According to the study of Sena Neto et al. [19], leaves of *Ananas bracteatus*, more commonly known as Red Spanish Pineapple, have been found to have higher cellulose content than other genotypes of pineapple. As higher cellulose content contributes to higher sorption potential [20], *Ananas bracteatus* leaf fibers can provide more alternative sorbent materials to other genotypes of PALFs that had already been utilized as oil sorbents [16,17,18].

PALFs are classified according to their fineness: the coarse fiber with a higher fineness value (primary PALF or *bastos*) and the fine fiber with a lower fineness value (secondary PALF or *liniwan*) [21]. Fineness is related to the fiber thickness or diameter [22]. As fineness decreases, the diameter of individual fiber decreases and therefore increases the surface area available for sorption. *Liniwan*, having a lower fineness makes it a more ideal material in the textile industry compared to *bastos*.

Studies on oil removal using PALF have not separated the *bastos* and *liniwan* [16,17,18]. Due to their difference in fiber fineness, which affects their surface area [22], the individual sorption performance of *bastos* and *liniwan* must be investigated to provide an alternative sorbent material for oil sorption instead of using all fiber parts of the pineapple leaf.

This study aimed to determine and compare the percent diesel oil removal of *bastos*, *liniwan*, and sorbent pads. Specifically, this research sought to:

- (i) determine the mean fiber diameter (μm) of *bastos* and *liniwan* through ImageJ analysis based on scanning electron microscopy (SEM);
- (ii) determine the mean difference between the mean fiber diameters (μm) of *bastos* and *liniwan* using independent samples t-test;
- (iii) determine the mean oil sorption capacity (g/g) and mean percent oil removal of the control (sorbent pads) and treatment groups (*bastos* and *liniwan*);
- (iv) determine the mean difference of the oil sorption capacity (g/g) and percent oil removal (%) of the control and treatment groups using one-way ANOVA.

Methods. - The fibers were sent for SEM imaging and the fiber diameter of *bastos* and *liniwan* was measured using an image processing software (ImageJ). Ten replicates of sorbent from the treatment and control groups were allowed to sorb oil at a constant contact time. The mass of sorbent before and after sorption was measured to get the sorption capacity and percent oil removal.

Materials. *Bastos* and *liniwan* were procured from

a pineapple fiber-weaving business in Balete, Aklan as thread-like fibers which are readily available for utilization while sorbent pads were obtained from Philippine Environmental & Technical Systems and Services, Inc. Diesel oil was procured from SEAOIL - Tagbac in Jaro, Iloilo.

Preparation. *Bastos*, *liniwan*, and sorbent pads were cut into 1 to 2 cm [23], and 0.5 grams of each sample was placed in a 50-cm³ metal mesh bag [9,10,24,25]. Diesel oil with a volume of 200 mL was poured into each 250 mL beaker (Pyrex, Germany) [26]. Three samples of empty metal mesh baskets were immersed in the oil under the same experimental conditions. The mass of oil removed was then taken and averaged. It was then subtracted from the mass of the sorbents after sorption. The average mass of oil removed by the mesh basket was subtracted from the mass of oil removed by the sorbents encapsulated in the metal basket with sorbed oil.

Fiber diameter. Dry fiber samples of *bastos* and *liniwan* were sent to the University of the Philippines Visayas Regional Research Center laboratory in Miagao, Iloilo for scanning electron microscopy (SEM, Hitachi SU3500) imaging. The mean diameter of each fiber type was calculated by measuring it three times at different sections of the SEM image using ImageJ software (Version 1.54f).

Preliminary Test. Three samples for each sorbent type were prepared to determine the dripping time of the samples and the amount of oil removed by the metal mesh baskets. Beakers with 200 mL of oil were prepared for each sample. Sorbents were hung on a metal stand for 60 minutes [16]. Then, sorbents were hung above the beakers and the dripping time was recorded until no further dripping [27]. The sorbents were then weighed and recorded.

Sorption test. The *bastos* sorbent was soaked in 200 mL of diesel oil for 60 minutes and was allowed to drip until the point when no further dripping was observed (50 minutes). Finally, the resulting sorbent was weighed using a calibrated analytical balance (KERN ABJ 320-4NM). Similar procedures were followed for the *liniwan* and sorbent pads. Ten samples were tested for each sorbent.

Data Analysis. The oil sorption capacity and percent oil removal [24] for each sorbent were calculated using the following formula:

$$\text{Sorption capacity (g/g)} = \frac{S_T - S_o}{S_o}$$

$$\text{Percent removal (\%)} = \frac{S_T - S_o}{O_i} \times 100$$

Where:

S_T = the mass (in grams) of the sorbent after sorption

S_o = the mass (in grams) of the sorbent before sorption

O_i = the mass (in grams) of the sorbate before sorption



Statistical Analysis. ImageJ and Microsoft Excel 2016 were used to calculate the mean fiber diameter, mean sorption capacity, and mean oil percent removal of the sorbents, respectively. An Independent t-test was conducted to compare the mean difference between the mean fiber diameters in Jamovi 2.3.18. One-way ANOVA and Games-Howell post hoc test were conducted to compare the three mean sorption capacities and oil percent removal using Jamovi 2.3.18.

Safety Procedure. Excess diesel oil and used sorbents were stored in a closed container and handed over to the Chemistry Science Research Assistant for proper disposal.

Results and Discussion. - The surface morphology of both fibers was found to be closely similar to each other in reference to their microfibrillar structure, exhibiting rectangular, rough surfaces as can be seen in Figures 1 and 2. *Bastos* and *liniwan* revealed defined block-like structures which contribute to a rougher surface [25]. According to Ekwonu et al. [17], this unique block-shaped structure contributed to the excellent oil retention property of the PALF. This block-like structure is the leaf epidermal tissue fragments which are characterized by a reticular aspect pattern [28].

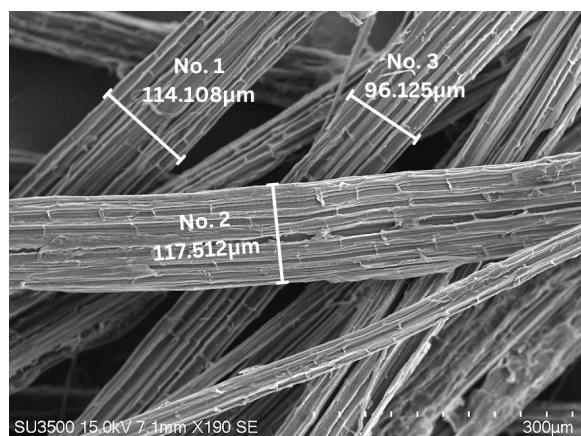


Figure 1. SEM image of primary PALF (*bastos*) at 190x magnification.

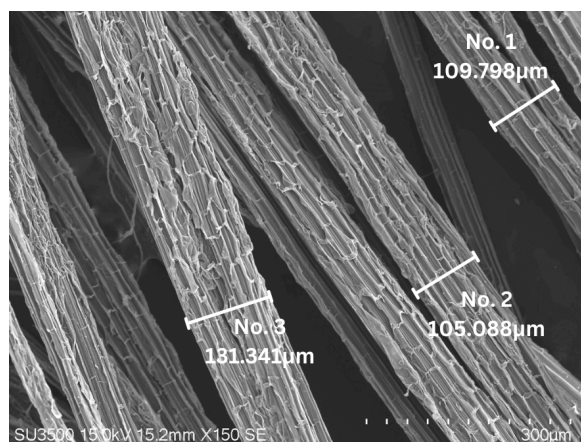


Figure 2. SEM image of secondary PALF (*liniwan*) at 150x magnification.

Based on the results of the ImageJ analysis, the mean fiber diameters of *bastos* and *liniwan* were $109.25 \pm 11.49 \mu\text{m}$ and $115.41 \pm 14.00 \mu\text{m}$, respectively. No statistically significant difference was found between the fiber diameters of both fibers based on their t-test results ($p = 0.587$). *Bastos* and *liniwan* were found to have similar fiber fineness as described by their similar mean fiber diameters. Fiber fineness is a factor in the sorption mechanism as finer fibers constitute more surface area for higher oil uptake [22]. According to Carvalho et al. [21], the secondary PALF or *liniwan* is used in textile production because of its low fiber fineness while the primary PALF or *bastos* are not being used in textile production; however, the ImageJ results contradict this as *bastos* and *liniwan* showed similar fiber diameters. In their optical microscopic images, *bastos* and *liniwan* were found to have similar fiber diameters, which have some correlation to fiber fineness [22]. Finer fibers contribute to smaller fiber diameters, allowing them to have higher surface area and more available sorption sites for sorption [29].

The sorption capacity and percent removal values of *bastos* and *liniwan* have been found to be significantly higher than those of the sorbent pads, while it was also found that there is no significant difference between *bastos* and *liniwan*. *Bastos* yielded a mean sorption capacity of $13.76 \pm 1.53 \text{ g/g}$. The *liniwan* sorbent, on the other hand, had a mean sorption capacity of $14.09 \pm 0.84 \text{ g/g}$. Furthermore, the sorbent pad yielded a mean oil sorption capacity of $4.43 \pm 0.34 \text{ g/g}$.

Bastos yielded a mean percent oil removal of $4.15 \pm 0.46\%$. *Liniwan*, on the other hand, had a mean percent oil removal of $4.25 \pm 0.25\%$. Finally, for the sorbent pad, the mean percent oil removal was $1.34 \pm 0.10\%$. Figure 3 shows the respective mean percent oil removal (%) of the three samples for diesel oil.

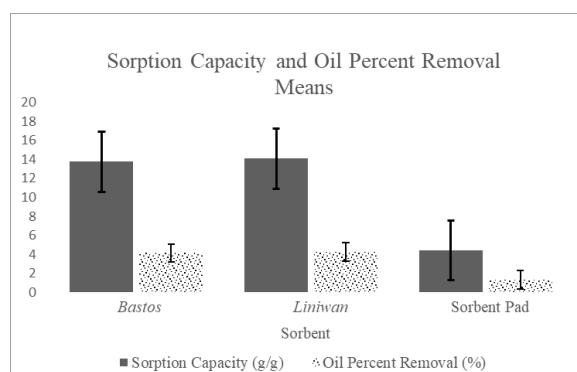


Figure 3. Mean sorption capacity (g/g) and mean percent oil removal (%) of *bastos*, *liniwan*, and sorbent pads for diesel oil.

There was a statistically significant difference between groups as determined by One-way ANOVA ($F(2,27) = 668.5725$, $p = 0.0001$). Games-Howell post hoc test revealed that *bastos* and *liniwan* have no significant difference in their sorption capacity and percent oil removal ($p = 0.8277$). *Bastos* exhibited a significantly higher sorption capacity and mean percent oil removal than the sorbent pad ($p < 0.001$). In addition, *liniwan* ($p < 0.001$) exhibited a



significantly higher sorption capacity and mean percent removal than the sorbent pad ($p < 0.001$). *Ananas bracteatus* PALFs have significantly higher mean sorption capacity and percent oil sorption than commercial sorbent pads, thus, they can be used as a sorbent for potential diesel oil spills. Additionally, the results imply that both the *bastos* and *liniwan* have similar levels of effectiveness in terms of oil sorption.

Both *bastos* and *liniwan* are capable of sorption for diesel oil. The mechanism of oil sorption by *bastos* and *liniwan* can be either by absorption, adsorption, capillary action, or a combination of the aforementioned. The fiber diameter has some correlation with the fiber cross-sectional areas which affects the sorption mechanism of PALFs. Finer fibers contribute to a smaller diameter [22], which leads to more available sorption sites leading to a higher sorption capacity [29]. The sorption process in natural fibers can be a product of physical factors, transport of oil molecules to the surfaces of the sorbent, and chemical factors, which involve the Van der Waals interaction between the oil and the sorbents [18,30]. As *bastos* and *liniwan* are both natural fibers collected from *Ananas bracteatus* leaves, the mechanism involved in the sorption process can be explained by the said factors. Sample granulometry is a significant factor in the percent oil removal of PALFs for diesel oil as it affects the surface area of the samples [16].

This study was able to determine the sorption capacity and percent oil removal of *bastos* and *liniwan* collected from *Ananas bracteatus* comparing it to sorbent pads. The sorption capacity and percent oil removal of *liniwan* do not have a significant difference from that of *bastos*. In addition, there is a significant difference between the sorption capacity and percent oil removal of the treatment (PALFs) and the control group (sorbent pads). The fiber diameters from the SEM imaging correlate with the sorption capacity and percent oil removal of the fibers since the sorption capacity and percent oil removal of *bastos* and *liniwan* have no statistical mean difference and their mean fiber diameters also have no statistical mean difference. The results showed that both *bastos* and *liniwan* may be used as alternative materials for the removal of diesel oil. Although *bastos* and *liniwan* were found to have no significant mean difference, *bastos* may be used as an alternative sorbent to oil spills rather than *liniwan* since the latter is used as raw materials for textile production.

Limitations. Even though the fiber diameter of raw *bastos* and *liniwan* was determined, only partial areas of the fiber samples were assessed for SEM analysis. Moreover, this study only utilized 1-2 cm lengths of cut PALFs, the optimal granulometric sizes for the maximum sorption capacity of PALFs were not determined due to the absence of sorption tests of varying granulometric sizes.

Conclusion. - As *bastos* and *liniwan* have the same performance in the removal of oil, *bastos* may be utilized as an alternative sorbent material for oil spills as *liniwan* already have their use in the textile industry.

Recommendations. - Future studies may utilize more areas of the PALFs to be subjected to SEM imaging to minimize error in randomization and to have a more accurate presentation of the surface morphology of PALFs. Moreover, sorption tests may include quantifying for fiber fineness and varying sample granulometry to determine which granulometric category constitutes the optimal sorption capacity of PALFs. In addition, other statistical tools which include more decimal places for calculations such as SPSS and RStudio may be used for the data analysis since Jamovi 2.3.18 can only cater to up to three decimal places. Furthermore, future studies can also test the sorption capacity of the samples in an oil-water mixture and test more oil types such as bunker fuel, jet fuel, and others.

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Water quality assessment of post-chlorinated wells in San Juan, Molo, Iloilo City following acute gastroenteritis (AGE) outbreak

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Article Info	Abstract
Submitted: Jul 11, 2023 Approved: Jan 24, 2024 Published: Feb 25, 2024 Keywords: water wells physicochemical microbiological PNSDW	Groundwater wells in areas like San Juan, Molo, Iloilo City are important water sources for domestic use. However, these wells are susceptible to contamination, leading to waterborne illnesses. Following an outbreak of acute gastroenteritis (AGE) in Iloilo City in August 2022, water sources in affected communities were examined and treated with chlorine. Despite these efforts, the number of AGE cases continues to rise in San Juan, Molo, one of the most affected areas in the city. This study aimed to evaluate the water quality of post-chlorinated wells in San Juan, Molo, Iloilo City, focusing on physicochemical and microbiological properties. The assessment revealed that the analyzed wells exceeded the maximum allowable level (MAL) set by the Philippine National Standards for Drinking Water (PNSDW) of 2017 in terms of turbidity, color, residual chlorine content, and total coliform count. Consequently, the water from these post-chlorinated wells is unsuitable for domestic use. These findings suggest that disinfection strategies for wells in San Juan, Molo, Iloilo City are ineffective in eliminating pathogens and maintaining water quality.

Introduction. - The addition of a substance to water that adversely affects and changes its properties is called water pollution [1]. Water pollution has been a present and imminent threat to the health and livelihoods of many people all over the globe with over 780 million people having no safe and secure water sources and 2.5 billion having no proper water sanitation [2]. Pollutants are categorized as: chemical, physical, physiological, and biological. [1]. Physical pollutants include any effect on color, turbidity, temperature, suspended solids, foam, and radioactivity, while physiological pollutants include any change in taste and odor. Chemical pollutants include inorganic and organic materials that affect the Biological Oxygen Demand (BOD), pH, and toxicity of a particular body of water. Biological pollutants include the presence of bacteria, viruses, protozoa, and helminths.

Pollutants that lead to adverse effects to water supply are considered as contaminants. All contaminants are considered to be pollutants; however, not all pollutants can be considered contaminants. Contamination is the presence of a pollutant, where it should not be, or at abnormal concentrations, making it a contaminant [3]. The proliferation of waterborne biological contaminants such as microorganisms that include bacteria, viruses, protozoa, is seen as the primary root of waterborne diseases. Instances of waterborne contamination are prevalent and waterborne disease epidemics can still occur even when drinking water is piped but not disinfected [4]. Moreover, within a five-year span, exposure to waterborne biological contaminants was the cause of approximately one third of illnesses in the Philippines, such as acute gastroenteritis (AGE) [5].

Acute gastroenteritis (AGE) is a common and potentially serious infectious illness characterized by diarrhea, vomiting, and abdominal cramps. It is most often caused by a variety of pathogens, including bacteria, viruses, and parasites. AGE is transmitted through the fecal-oral route, meaning that the pathogen is ingested from contaminated food, water, or surfaces, or through direct contact with an infected individual. Symptoms typically develop within 1-3 days of exposure and can range from mild to severe. Severe cases can lead to dehydration, electrolyte imbalances, seizures, coma, and even death [6].

Waterborne outbreaks of enteric disease occur either when public drinking water supplies are not adequately treated after contamination with surface water, or when surface waters that are contaminated with enteric pathogens, have been used for recreational and/or domestic purposes.

Water quality analysis is an important step to identify water contamination of biological contaminants. Studies that focused on analyzing the quality of drinking water in the Philippines have been conducted in different regions of the country, such as the analyzing of the physicochemical and biological properties of water samples from selected barangays in Laoang, Northern Samar, Philippines [7], as there were existing cases of waterborne diseases from the specific barangays they collected water samples from. Another study also examined the drinking water quality of different schools in Tarlac City, Philippines, through its physicochemical and biological properties [8].



Last August 30, 2022, a sudden surge of cholera cases was reported in Iloilo City, causing an outbreak [8] that resulted in over 777 cases of Acute Gastroenteritis (AGE) as of October 4, 2022 [10]. The district in Iloilo City with the highest number of cases was Molo, Iloilo City with 165 cases; and Barangay San Juan, Molo having the most with 30 cases as of October 4, 2022 [10]. The City Health Office had already begun examining and treating different water sources around the city's localities where Acute Gastroenteritis cases were starting to rise in numbers [11]. However, according to the CHO acting officer, the chlorination efforts in Iloilo City remain ineffectual since the cases of AGE keep on rising, which is probably due to recontamination, the proximity of water well systems to canals and septic tanks, ineffectiveness of chlorination protocols, and the water table itself being contaminated [12]. As of October 4, 2022, the district of Molo has reached 30 cases of AGE, the highest in the whole city of Iloilo. More specifically, Barangay San Juan, Molo had the highest number of AGE cases [10] in the district which placed a huge risk towards the health and well-being of citizens residing in the community.

Domestic water is termed as water coming from domestic water supplies that provides water for households for their daily use such as cooking, bathing, washing the dishes and utensils, cleaning the house, and doing laundry [13]. According to the Department of Environment and Natural Resources (DENR) Administrative Order (DENR-AO or DAO) No. 08, series of 2016, different water bodies are classified depending on where it is sourced, how it is used, and on what standards should the water source be compared to [14]. In the Administrative Order, domestic water is classified as Class A and listed as Public Water Supply Class II which is intended as sources of water supply requiring conventional treatment that includes processes such as coagulation, sedimentation, filtration, and disinfection which are all processes that are conducted in wells supplying water in Barangay San Juan, Molo, Iloilo City. Furthermore, Class A water sources are compared with the Philippine National Standards for Drinking Water (PNSDW) of 2017 [15] to determine if they are viable for public use. In this study, the modified PNSDW mandatory parameters are used to assess if the wells comply with the given standard.

The knowledge obtained from this research would assist in providing a comprehensive water quality assessment of post-chlorinated wells using an evidence-based analysis that outlines the physicochemical and microbiological properties [16] which is especially useful to localities that fall short in observing well water monitoring, and will serve as a basis for future well disinfection and recovery protocols that can properly inactivate water pathogens [17]. This study sought to record water quality parameters such as the physical properties consisting of color (apparent) and turbidity; the chemical properties consisting of nitrate, pH, total dissolved solids (TDS) and residual chlorine; and the microbiological properties specifically total coliform count. These parameters are modified from the

Philippine National Standards for Drinking Water (PNSDW) of 2017 [15], with the exclusion of the heavy metals consisting of lead, cadmium and arsenic. Heavy metal contamination usually occurs due to human activities such as mining, industrial discharge from steel plants, battery factories and thermal power plants, sites for traffic, municipal and hazardous wastes and lastly, agricultural runoff from the overuse of fertilizers containing heavy metals [18, 19, 20]. San Juan, Molo, Iloilo City is a residential area that lacks any present factory, farmland nor mining areas which makes heavy metal contamination uncommon; hence it was excluded from the study in favor of studying parameters that are more relevant given the conditions and the environment.

The data and results would be most significant to the citizens of Barangay San Juan, Molo, Iloilo City, the Iloilo City Epidemiological Surveillance Unit, the Iloilo City Health Office, and Department of Health Region 6 since it would provide them with the information on the water quality of selected post-chlorinated wells in terms of the physicochemical and microbiological properties. Lastly, it would provide baseline information that would be significant in providing clean water and sanitation to developing communities, which is in accordance with Sustainable Development Goal number 6.

Methods. - This study is categorized as descriptive as it sought to assess the water quality of post-chlorinated wells in San Juan, Molo, Iloilo City (10.6856°, 122.5449°) on January 11, 2023 following the Acute Gastroenteritis outbreak in August 2022. The data gathering procedure of the research consisted of: sampling site selection, water sample collection, transportation of water samples, onsite physicochemical analysis, laboratory microbial analysis, the data analysis and safety precautions and disposal methods. The timespan of the data gathering procedures was two weeks to ensure that an adequate sample of data was collected.

Site Selection. The selected sampling site was Zone 3 barangay San Juan, Molo, Iloilo City due to its high incidence of acute gastroenteritis (AGE) cases. Three well samples were selected, with three replicates varying in depth as water quality can vary with depth, due to factors such as temperature, salinity, and the presence of different organisms and chemicals. (top, middle and bottom) were followed, with the well samples being the well attributed to the highest number of AGE cases (10.68844° 122.54146°), the well that has no cases of AGE (10.68882° 122.54298°), and a well that has a moderate number of AGE cases (10.68786° 122.54126°); serving as the median, and distilled water as the control sample.

Materials. The materials used were derived from the guide by the Department of Science and Technology Regional Standard and Testing Laboratory (DOST RSTL) Region VI specifically for collecting water samples from wells. The physicochemical analysis utilized the bucket found in the selected wells for the collection of water. Other materials included a clean, disinfected plastic bucket where collected water was poured in for



physicochemical analysis. The following equipment was used for the physicochemical analysis: YSI ProDSS multiparameter water meter, and TDS meter. The microbiological analysis also followed the aforementioned guide in which an autoclaved 400mL glass bottle with a metal cap was used. Other materials included a 20-meter rope for sample collection, a cooler box for transport, masking tape and a pen for labelling. The total amount of water collected for the physicochemical analysis was not strictly measured as long as the YSI ProDSS's probes were able to be fully submerged. The microbiological analysis used 400mL of water as prescribed by the DOST RSTL Region VI.

Water Sample Collection. An autoclaved and sterilized bottle was prepared for water sample collection by tying a rope around the neck of the bottle and attaching a weight underneath the bottle for it to descend faster. The bottle was then slowly lowered into the well, whilst avoiding hitting the sides, to fill and collect the water sample. After the bottle is almost full, it is pulled back up, making sure to leave an air gap within the bottle before sealing. The bottle was then labeled with the sample number, time collected, and researcher name before being stored in an ice box to preserve its contents.

Physicochemical Analysis. Physicochemical analysis did not follow strict guidelines in the volume of water used as the YSI ProDSS multiparameter water meter only required its probes to be fully submerged. The Physicochemical analysis was done onsite using a YSI ProDSS multiparameter water meter and a TDS meter to measure the physicochemical parameters: pH, turbidity, TDS, residual chlorine content and nitrate content. Each probe for the corresponding parameters was calibrated using distilled water. Color was personally evaluated [14] for any discernible discoloration that affects the opinion of the consumer.

Microbiological Analysis Microbiological analysis utilized 400mL of water per replicate. The research followed a triplicate approach in which 1,200 mL of water was collected from each well. The microbiological analysis involved the Multiple Tube Fermentation Test (MPN) to confirm and specify the microbial presence within the water samples. A presumptive test involving the culture of water sample bacteria in Lactose Broth was done and followed by a confirmatory test involving the same culture in Brilliant Green Lactose Bile (BGLB) broth. The total coliform count of the water samples is determined using the table below.

Table 1. Most Probable Number (MPN) Index in a Five 10-mL Water sample (Standard Method for the Examination of Water and Wastewater, APHA, AQA, 2012 22nd Ed.)

No. of Tubes with Positive results in 5 tubes with 10 mL Each	MPN Index/100 mL
0	<1.1
1	1.1
2	2.6
3	4.6
4	8.0
5	>8.0

Data Analysis. The means of the parameters (pH, turbidity, TDS, residual chlorine content, nitrate content and total coliform count) were equated and compared with the PNSDW [13]. Color was instead evaluated wherein any noticeable discoloration will affect a consumer's opinion, rendering it unable to comply with the standards for drinking water. The results are then tabulated and are highlighted where the wells comply or do not comply with the established standard.

Safety Procedure. To ensure safety, personal protective equipment (PPE) such as gloves, face masks and laboratory coats were worn at all times, especially when handling possibly contaminated water and hot objects. The contaminated water and the culture tubes were autoclaved to get rid of possible recontamination before the water and broth is poured into the drain.

Results and Discussion. - The study focused on the physicochemical and microbiological properties of the selected wells. The results were then compared with the Philippine National Standards for Drinking Water (2017) [15].

Physicochemical Analysis. The physicochemical properties taken from the sampling sites were: pH, color, turbidity, TDS, residual chlorine content and nitrate content. Table 2 below presents the pH, color, turbidity, TDS, residual chlorine content and nitrate content of the selected wells. There is noticeable discoloration of water (yellowish) in all the selected wells.

pH. As observed from Table 2, the pH of the three selected wells are slightly basic, nearing the pH of 8. The allowable limits set by the PNSDW 2017 [15] for pH is 6.5 - 8.5. This makes the three wells compliant with the standards set for pH. The mean pH of the selected wells is under 8.0, which resembles seawater (pH 8.1). This alkaline pH can irritate the skin and eyes, and may also affect the absorption of nutrients. In addition, some microorganisms, such as bacteria and parasites, can thrive in alkaline environments, which could increase the risk of waterborne diseases. [21] The normal range for pH in surface water systems is 6.5-8.5 and 6.0-8.5 for groundwater systems. When pH becomes too high, water becomes caustic and can clog or damage water systems by creating coatings, films and precipitates [22]. Although the results are within the standards for drinking water, the WHO recommends a pH of water to be less than 8.0, stating that basic water inhibits effective chlorination [23].

Turbidity. The mean turbidity of the wells ranges from 7-10 Formazin Nephelometric Units (FNU) which makes them non-compliant with the limit of 5 FNU by the PNSDW 2017 [15]. The turbidity of the wells is observed to increase with depth, attributable to the free-floating particles near the middle and bottom of the well, including the composition of the well bottom which is mostly silt, clay and sand particles. The particles scatter light which contributes to the rise of turbidity. Turbidity influences the clarity/murkiness of well water, indicating contamination from a septic system, presence of algae, or other suspended particles. Turbidity and



chlorine-demanding solutes also inhibit the disinfection of free chlorine [24]. High turbidity levels, such as the ones recorded in the selected wells, protect microorganisms during decontamination and stimulate their growth, significantly increasing the chlorine demand [24].

Total Dissolved Solids (TDS). Two of the three wells are compliant with the standards set for the total TDS of drinkable water which is 600 ppm [14]. The TDS of the selected wells also increase with depth and are most often contributed to the application of chlorine. However, as observed from Table 2, the mean TDS of the samples are not in correlation with the residual chlorine content. Total dissolved solids (TDS) indicate the presence of inorganic salts (commonly being calcium, magnesium, potassium, sodium, carbonates, nitrates, bicarbonates, chlorides & sulfates) and a small amount of organic material in well water [23]. Humans contribute to the increase of TDS through agricultural (fertilizers) and urban runoffs (industrial wastewater); the latter being the most probable factor in the high amount of TDS recorded from the selected wells [23]. High amounts of TDS are not necessarily a health hazard when ingested, but it can produce hard water, potentially accompanying a health risk [25].

Color. The results indicate that all of the sampled wells show signs of yellowish discoloration which is not compliant with the PNSDW standards for apparent color. Despite the slight discoloration of water found in the selected wells, it is not enough to dissuade some consumers. Consumer perceptions and aesthetic properties of water should always be considered alongside the health-related guidelines whenever developing and administering regulations and standards. The wells were sampled during the rainy season, with flooding in some areas of the research locale, which may have drastically altered the water properties prior to observation and testing. These alterations most notably affect the physical properties including color. [24]

Residual Chlorine Content. The residual chlorine content of the samples notably exceeds the PNSDW limits which is 0.3-1.5 ppm [15]. This can be attributed to the chlorine application process of the well owners as well as the frequency and the date of chlorination wherein the last chlorination occurred on the same day that the well samples were tested. Residual chlorine partially provides a safeguard to low-level bacterial contamination and growth but has limitations against protozoans and viruses [26]. Chlorine can be monitored and controlled with ease as a disinfectant, and frequent monitoring is recommended whenever chlorination is practiced. The lack of monitoring after chlorination, which is observed in the selected wells, increases the risk of waterborne illnesses stemming from very high concentrations of harmful compounds to the presence of water pathogens. Residual chlorine is not only affected by dose but is also heavily dependent on the frequency and date of the last chlorination. The selected wells significantly surpassed the MAL of the PNSDW 2017 which is most probably due to them being chlorinated a week prior to testing. In addition, factors such as high turbidity and alkalinity (pH) influence the effectiveness of chlorination; but as the pH of the selected wells were within the allowable limits, the residual chlorine content and its effects may not have been affected by the water alkalinity [24].

The nitrates content was undetectable and yielded 0.00 ppm for every single well sample. This is understandable as nitrate content in well water is mostly attributed to industrial or agricultural runoff, which is highly unlikely to occur in San Juan, Molo, a residential area. Nitrates are inorganic salts [23] which, as previously mentioned, contribute to an increase of TDS in water. However, the results yielded little to no nitrate content, rendering these effects negligible.

Table 2. Physicochemical Data of selected wells.

Sampling Site	Mean pH	Color (apparent)	Turbidity (FNU)	TDS (ppm)	Residual Chlorine Content (ppm)	Nitrate Content (ppm)
Well A (Well with no attributed AGE cases)	7.99	Light straw	10.12	542.00	207.11	0.00
Well B (Well with most attributed AGE cases)	7.99	Light yellow	7.28	146.30	852.08	0.00
Well C (Well with moderate attributed AGE cases)	7.89	Light yellow	9.33	677.67	291.79	0.00

Microbiological Analysis. Table 3 exhibits the microbiological data of the sampled wells. When compared with the PNSDW 2017 [15] maximum allowable level for total coliform count of 1.1 MPN/100 mL, the data presented on Table 3 shows that the three selected wells are beyond the standard. The number of coliforms in the water samples makes the wells unfit for domestic use. The microbiological analysis used distilled water as its control to indicate water free from coliform bacteria.

Table 3. Microbiological Data Table (Multiple Tube Fermentation Technique)

Sampling Site	Presumptive Test	Confirmatory Test	Total Coliform Count (MPN/100 mL)
Well A	5	5	>8.0
Well B	5	5	>8.0
Well C	5	5	>8.0
Control	0	0	<1.1



Table 4. Overall analysis of the Selected wells in comparison to the PNSDW

Sampling Site	Parameters						
	Mean pH	Turbidity (FNU)	Color (apparent)	TDS (ppm)	Residual Chlorine Content (ppm)	Nitrate Content (ppm)	Total Coliform Count (MPN/100 mL)
Well A	7.99	10.12	Light straw	542.00	207.11	0.00	>8.00
Well B	7.99	7.28	Light yellow	146.30	852.08	0.00	>8.00
Well C	7.89	9.33	Light yellow	677.67	291.79	0.00	>8.00
PNSDW 2017 Maximum Allowable Level (MAL)	6.50-8.00	5.00	No noticeable discoloration	600	0.30-1.50	50.0	<1.1

Overall Analysis. Table IV presents a comprehensive comparison of the selected wells against the Maximum Allowable Limits (MAL) set by the Philippine National Standards for Drinking Water (PNSDW), considering both physicochemical and microbiological properties.

Limitations. Water collection sampling and onsite physicochemical testing were done in the rainy season of January, which may directly or indirectly affect the content and properties of the well through rainwater intrusion, possibly introducing foreign objects, sediments and bacteria to the well. There was also a lack of consistency on the well depth as the top, middle and bottom portions of the wells were only estimated instead of using a standard depth. The study is restricted to three wells, making it unable to provide a general well profile of the area.

Conclusion. From the comparison between the data obtained from the selected wells and the PNSDW 2017, it can be concluded that the water from the wells are not fit to be used domestically by the residents. The majority of the wells are highly turbid, with noticeable yellowish tint and an extremely high residual chlorine and coliform presence.

Recommendations. It is recommended for the well owners to follow a robust and technical procedure in the application of chlorine in order to avoid over chlorination of wells. Post-chlorination monitoring should also be implemented in order to confirm the presence or absence of coliforms and other harmful bacteria in the well water before being used for drinking or domestic purposes. Proper shock chlorination methods should be adequately followed such as properly measuring the volume of the well water together with measuring the diameter of well casings. Relying only on the amount of well casings and the well casings filled with water is insufficient in providing an effective amount of chlorine for chlorination. In addition to proper stewardship and by following proper methods in shock chlorination, the physicochemical and

microbiological properties of wells can be preserved, promoting the well-being of citizens.

Additionally, future well water assessment studies perform the on-site physicochemical and microbiological testing multiple times over a long period of time to observe the effects of chlorination with respect to time and to determine if weather circumstances or seasons affect well properties. Increasing the sample size is also recommended to create a more general well profile of San Juan, Molo, Iloilo City. Other non-mandatory parameters should also be included such as salinity, BO, Dissolved Oxygen (DO), phosphorus, and total hardness of water.

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