Global J. Environ. Sci. Manage. 11(1): 1-20, Winter 2025, Serial #41

Global Journal of Environmental Science and Management
(GJESM)

Homepage: https://www.gjesm.net/

Podcasts

ORIGINAL RESEARCH PAPER

Modeling the shrimp aquaculture wastewater pollutant removals by clam shell using structural equation model

N.D. Takarina[1,*], O.M. Chuan[2], A. Adiwibowo[3], M.A. Adidharma[4]

[1] Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Indonesia, Gedung E FMIPA, Kampus UI Depok, Depok 16424, West Java, Indonesia

[2] Faculty of Science and Marine Environment, Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu, Malaysia

[3] Occupational Health and Safety Department, Faculty of Public Health, Universitas Indonesia, Depok 16424, West Java, Indonesia

[4] Department of Marine Science, Institut Teknologi dan Bisnis Muhammadiyah Kolaka, Jl. Pramuka, Lamokato, Kolaka 93511, Southeast Sulawesi, Indonesia

ARTICLE INFO

Article History:
Received 04 July 2024
Revised 07 September 2024
Accepted 09 October 2024

Keywords:
Adsorbent
Heavy metals
Pollutant
Shell
Structural equation model (SEM)

DOI: 10.22034/gjesm.2025.01.01

ABSTRACT

BACKGROUND AND OBJECTIVES: Aquaculture practices were emitting wastewater containing pollutants. The identified pollutants encompass heavy metals along with nitrite and nitrate. In this context, clam shells have emerged as a cost-effective and proficient adsorbent, demonstrating the ability to eliminate pollutants from water sources. This study aimed to model the removal efficiency of clam shell of Perna viridis on copper, zinc, nitrate, and nitrite pollutants from waste water. The model is using the structural equation model.

METHODS: The pollutants observed included copper, zinc, nitrate, and nitrite, considering that those pollutants are common pollutants occurring in aquaculture wastewater. To manufacture the clam shell adsorbent, the procedure entails the calcination of clam shells. The modeling analysis to model the pollutant removal efficiency by clam shell was done using the Structural Equation Model method using latent and observed variables. The primary water parameters that impacted removal efficiency were total suspended solids, total alkalinity, and hydrogen ion concentration. The model were then validated using the factor loadings.

FINDINGS: The result showed clam shell can reduce the heavy metals from water with a removal efficiency of 84–99 percent. Based on the results of the model and the factor loading values, it is evident that total alkalinity is the primary water variable influencing metal removal, while potential hydrogen is also a significant contributor. Metal that was affected significantly by those water variables was copperA similar pattern is observed with nitrite and nitrate concentrations in water, where nitrite is more significantly impacted.

CONCLUSION: In general, clam shell can adsorb diluted pollutants from aquaculture wastewater since there are portions of adsorbed pollutants. Employing a modeling approach is instrumental in elucidating and distinguishing various water parameters that may impact the efficiency of pollutant extraction by clam shells from wastewater.

This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

NUMBER OF REFERENCES 100

NUMBER OF FIGURES 7

NUMBER OF TABLES 8

*Corresponding Author:
Email: *noverita.dian@sci.ui.ac.id*
Phone: + 62217 721 7019
ORCID: 0000-0003-1766-7445

Note: Discussion period for this manuscript open until April 1, 2025 on GJESM website at the “Show Article”.

INTRODUCTION

According to John et al. (2020), aquaculture is one of the quickly expanding agricultural industries that accounts for 47 percent (%) of the world's fish consumption. According to the research conducted by Turcios and Papenbrock (2014), it is anticipated that aquaculture production will increase by an estimated 60% to 100% within the next two to three decades, driven by population growth and an increase in per capita fish consumption. Aquaculture production will need to intensify in order to employ more inputs, which will increase the amount of waste generated by the production systems. Regretfully, a lot of aquaculture systems produce a lot of effluent that is high in nitrite (NO_2), nitrate (NO_3) (Hastuti et al., 2019), copper (Cu), and zinc (Zn) (León-Cañedo et al., 2017) and is then dumped into environments (Chiquito-Contreras et al., 2022). Within the fishing industry of Indonesia, shrimp aquaculture is a vital segment. The national output of shrimp in Indonesia was recorded at 881,599 tonnes in 2020, which corresponds to 5.9% of the total aquaculture production across the nation. Of the various shrimp species cultivated in Indonesia, the vannamei (*Litopenaeus vannamei*) stands out as particularly prominent (Inayah et al., 2023). The growth of shrimp farming regions in Indonesia has elicited apprehensions regarding its possible socio-economic and environmental consequences (Bosman et al., 2021). The increase in the intensity of aquaculture will result in the proportional increase of waste (Iber and Kasan, 2021). Waste from shrimp aquaculture can reach 3.89 ton per year (ton/y) (Paena et al., 2020) and consists of solid and dissolved waste (Dauda et al., 2019). Solid waste can include food waste, fish waste, and bacterial colonies, while dissolved waste can include ammonia (NH_3), carbon dioxide (CO_2), phosphorus (P), hydrogen sulfide (H_2S), phosphate (PO_4^{3-}), and nitrogen (N). Several methods have been developed to remove NO_2 and NO_3. According to Wahyuningsih et al. (2015), the implementation of aquaponic systems presents a potential solution for alleviating the negative consequences associated with the accumulation of inorganic nitrogen in aquaculture environments. In an aquaponic system, plants can absorb nutrients from agricultural practices, whereas microorganisms function in decreasing the ammonia contents throughout the nitrification. Using this system, the removal efficiency of NO_2 and NO_3 was 22.86% and 34.41%. Saleem et al. (2011), confirmed the efficiency of an electrochemical removal procedure applied to NO_2 in simulated aquaculture wastewater. In comparison to various electrode materials, such as stainless steel, nickel (Ni) demonstrates the highest efficacy in the elimination of NO_2. At a starting potential hydrogen (pH) of 5 and a current density of 3.75 milliampere per square centimeter (mA/cm^2), the best NO_2 removal is accomplished. In 2021, a moving bioreactor have been used to remove NO_2. The bioreactor was able to remove NO_2 up to 99.6% (Tadda et al., 2021). A variety of methods have been recently introduced to eliminate heavy metals from water, such as membrane separation (Birniwa *et al*., 2024), chemical precipitation (Pohl, 2020), ion exchange (Jasim and Ajjam, 2024), and reverse osmosis (Kapepula and Luis, 2024). The implementation of these techniques has shown promising results. Studies emphasized on modes of either simple or combined precipitation treatment (Djedidi et al., 2009), physiochemical characteristics, and the higher ion exchange capacity of composite cation exchangers that can improve the efficiency of removal, separation, and adsorption of toxic metal has been used to elaborate the efficiency of either metal removal or dewatering ability of the resulting wastewater containing sludge (Al-Othman et al., 2011). The process of reverse osmosis is recognized as a potent method for metal separation (Aljendeel, 2011). Furthermore, the membrane separation technique enables the creation of innovative adsorbents from cellulose, which can be easily subjected to chemical alterations (O'Connell et al., 2008). However, these approaches are either not feasible for the treatment and disposal of wastewater containing secondary toxic metal sludge, consume time to treat, use the most energy, or are less effective when heavy metals are contained in the wastewater at low concentrations (Kabwadza-Corner et al., 2015). Current studies are looking into economical adsorbents for removing heavy metal, including sago waste (Wahi et al., 2022), rice husks (Okoro et al., 2022), zeolites (Velarde et al., 2023), sawdust (Meez et al., 2021), and chitosan beads (Rahmi et al., 2019). Currently, several studies have reported that shell adsorbents are effective in adsorbing several pollutants such

as PO_4^{3-} (Salim et al., 2021), ammonium (NH_4) (Zukri et al., 2018), NH_3 (Nguyen et al., 2021), and heavy metals (Bremner et al., 2020). The natural prevalence of shellfish waste has prompted an increase in the creation of adsorbents that utilize these resources (Nayagam and Prasanna, 2022). Comprising roughly 78% of their total makeup, the shells of green mussels are mainly made up of calcium carbonate (CaCO3) (Kaewprachu and Jaisan, 2023). The high concentration of $CaCO_3$ makes it an effective heavy metal adsorbent and gives it the potential to aid in reducing environmental pollution (Rahman et al., 2017). Various studies have demonstrated the ability of clam shells to absorb heavy metals. Wang et al. (2021) noted that calcined shellfish powder exhibits excellent lead ion: Pb(II) adsorption capacity, with adsorption levels reaching up to 102.04 milligram per gram (mg/g). In a specific study, shellfish waste was utilized for the removal of PO_4^{3-} from synthetic solutions and domestic wastewater treatment plant effluent. The application of structural equation modeling (SEM) methodologies has gained international traction, especially in research concerning pollutants. Schenone et al. (2024) asserted that Structural Equation Modeling (SEM) can effectively analyze the intricate relationships between air pollutants, which are frequently neglected in existing literature, and identify particular causal elements contributing to air pollution. In environmental pollution studies, SEM representing a group of statistical routines, allow one to determine link among various latent variables, for example, the association between causes and results or impacts of pollution events (Baja et al., 2013). In Indonesia, SEM studies in environmental contexts have been conducted by Listiana and Arianto (2024). The evaluation of aquaculture pollutant removal efficiency in water utilizing clam shell and SEM analyses remains insufficient in Indonesia. At the same time, there is a pressing requirement for reliable information on the pollutant removal capabilities of clam shells, given the rising concentrations of pollutants in aquaculture environments. Considering this situation, this study attempts to address the following questions: Can clam shell remove pollutants like NO_2, NO_3, Cu and Zn from water? And if clam shell can remove those pollutants, can SEM model the removal efficiency of clam shell? The aims of this study are to evaluate NO_2, NO_3, Cu, and Zn adsorption using clam shell and model the removal efficiency using SEM. The output of this study can benefit to water pollutant metal removal routines, in particular by presenting information on the pollutant concentration at which clam shell can be applied and informing the optimum removals. The study was carried out in Depok and Blanakan, West Java in 2023.

MATERIALS AND METHODS

Aquaculture wastewater collection

Liquid waste is collected from vaname culture area on the 6th month where the drain is open during harvest. A total of 20 liter (L) of wastewater from the siphon discharge was collected in a polyethylene dermis. The vannamei aquaculture was selected from Blanakan District, Subang, West Java, Indonesia. This culture practice an intensive system supported by a electric turbin wheel. There are three types of ponds in this cultivation system, namely reservoir ponds, growth ponds and drainage ponds. In this region, the ponds are characterized by a stocking rate of 1000 individuals per hectare (ind/ha). During the preliminary phase of wastewater collection, measurements of pollutant levels were conducted. The collected water samples were then placed in a cooler container and sent to the laboratory for further experimentation.

Extraction and characterization of shell powder

In this research, clam shell used was from *Perna viridis* species. This species is common in Indonesia water. Following this, the shells undergo a cleaning process with distilled water and are drained at room temperature. After drying, the shells are fragmented into smaller pieces with the aid of a mortar. The shrunken shells are subsequently placed into a milling apparatus. Following the milling procedure, the resulting material is passed through a stainless steel mesh sieve with a pore size of 500 micrometers (µm). The shell powder was then calcined using a furnace at a temperature of 1000 degree Celsius (°C) for 2 hours (h). After cooling for the 8 h, the powder is then transferred to a desiccator. Shell powder characterization includes morphological structure and chemical properties analyzed using scanning electron microscopy – energy dispersive x-ray (SEM – EDX) (Jeol JSM-IT200) (Ismail et al., 2022). The vibration properties of the shell were analyzed using

Table 1: Summary of water variable and pollutant measurement methods Metals in miligram per liter (mg/L)

Variable	Method
TSS	Gravimetric
TA	Titration
pH	pH meter
Cu	Inductively coupled plasma mass spectrometry
Zn	Inductively coupled plasma mass spectrometry
NO_2	Injection
NO_3	Injection

Fourier transform infrared (FTIR) (Thermo Scientific Nicolet iS50).

Adsorption experiments

In a Nalgene bottle, 20 grams (g) of shell powder were combined with 450 milliliters (mL) of liquid waste. The mixture was shaken on a shaker at a speed of 160 revolutions per minute (rpm) reciprocally. The parameter measurement time ranges are 10, 20, 30, 40, 50, and 60 minutes (min). In each time period, three repetitions were carried out and water variables and pollutants were measured.

Water variable measurements

Throughout the adsorption experiments, a range of water variable measurements were obtained. These variables were acknowledged for their potential impact on the adsorption processes associated with the shell. The variables include total suspended solid (TSS), total alkalinity (TA), and pH. Methods to measure the water variables were given in Table 1.

Water pollutant measurements

Under adsorption experiments, there were water pollutant measurements. These pollutants that were initially contained in the water will be reduced due to the shell applicationsThe assessment involved taking measurements before the introduction of the shells and again following their application, with intervals set at 10, 20, 30, 40, 50, and 60 minutes. The pollutants that were measured comprised copper (Cu), zinc (Zn), nitrite (NO_2), and nitrate (NO3) (Table 1).

Determine the metals adsorption using isotherm

The results of determining the variation in the final concentration of heavy metal ions (adsorbate) with the adsorption capacity (Q) are plotted in a linear regression equation graph (Paranjape and Sadgir, 2023). The determination of the type of adsorption isotherm involved in the adsorption process of heavy metal ions will be based on the correlation coefficient value, which should be close to 1, as calculated from the Langmuir and Freundlich isotherm equations (Nurhidayanti and Cahyanto, 2023).

Structural equation model

The structural equation model (SEM) was developed following Listiana and Arianto (2024). SEM serves as a statistical technique that enables researchers to quantify the effects of independent variables on dependent variables and to assess the degree of fit between proposed theoretical models and actual observed models (Fig. 1). In this study, the independent variables were variables affecting the pollutant adsorption of shell, and those variables included adsorption time, TSS, TA, and pH that were grouped as water variables. The dependent variables were the reduced pollutant contents, including NO_2, NO_3, Cu, and Zn. Following Stein et al. (2012), SEM data processing and analysis were conducted using the R statistical package version 3.6.1 and Lavaan. The hypothesis within this framework suggests that the levels of pollutants were shaped by the characteristics of water and the periods during which shells were utilized. The water variables were consisting observed variables of TSS, TA and pH (Table 2). Confirmatory factor analysis (CFA) was employed for model verification, and this analysis was incorporated during the execution of SEM.

RESULTS AND DISCUSSION

Character of adsorbent

The surface appearance of the powder shows a fine structure with broken aggregates, such as dry,

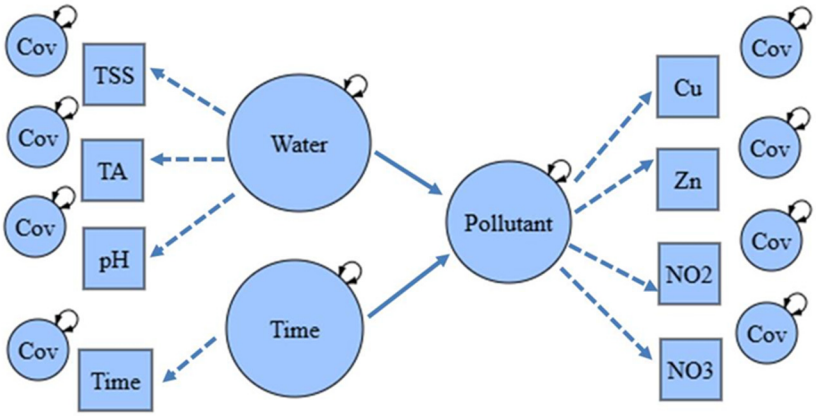

Fig. 1: Proposed SEM model

Table 2: Summary of variable types

Variables	Variable type
TSS	Observed
TA	Observed
pH	Observed
Cu	Observed
Zn	Observed
NO_2	Observed
NO_3	Observed
Pollutant	Latent
Wastewater	Latent
Contact time	Latent

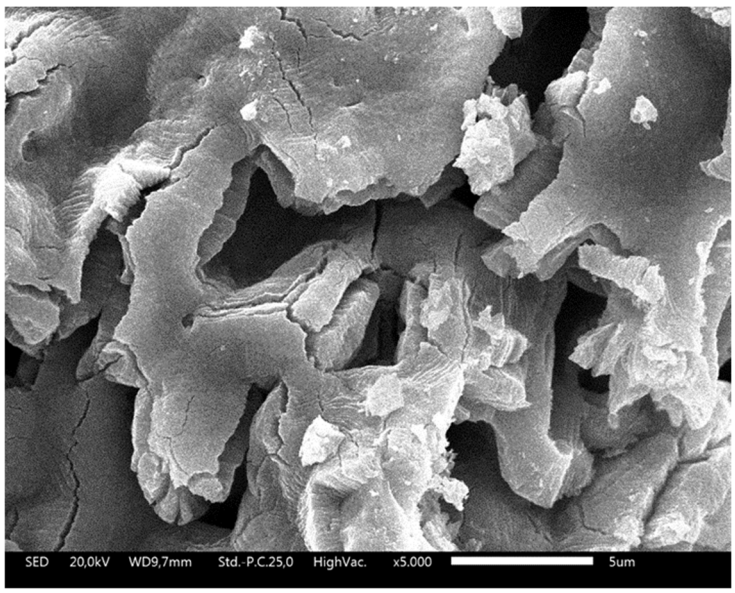

Fig. 2: Surface appearance of powder extracted from *P. viridis* shell after being calcinated

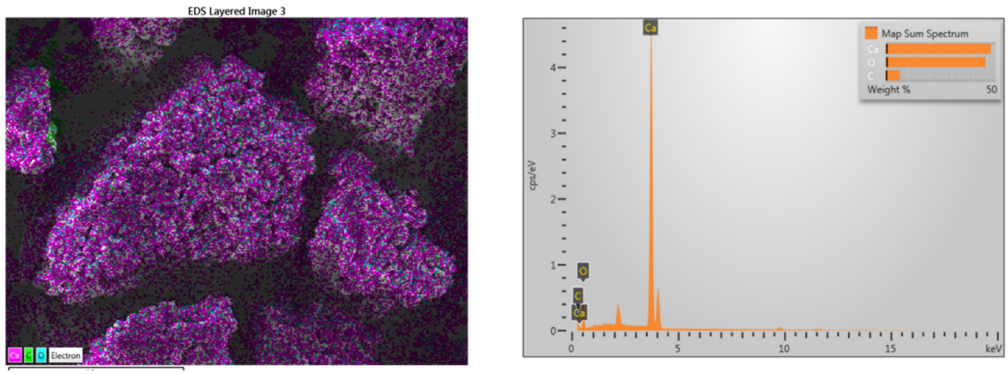

Fig. 3: a) Mapping and b) Spectra of powder extracted from *P. viridis* shell after being calcinated using EDX analysis

Table 3: Chemical composition of powder extracted from *P. viridis* shell after being calcinated

Element	Atomic %	Standard Label
C	11.98	CVit
O	61.94	SiO_2
Ca	26.08	Wollastonite

split soil (Fig. 2). The elemental mapping image accompanying the spectrum illustrates the spatial distribution of these elements across the surface of the adsorbent (Fig. 3). The colors assigned to each element are as follows: purple is associated with calcium (Ca), green is linked to carbon (C), and light blue is representative of oxygen (O). This mapping serves as a clear visual illustration of the extent to which elements are distributed uniformly or unevenly across the surface of the material, facilitating a deeper insight into the material's composition and its potential applications. The EDX spectrum reveals that The spectrum is dominated by a significant Ca peak located at approximately 4 kilo-electron-volt (keV), with an intensity of around 4.8 count per second per electron-Volt (cps/eV), indicating that calcium constitutes the majority of the material. Additional evidence for this statement is found in the weight percentage analysis, indicating that calcium constitutes almost 50% of the overall composition. O is the second most abundant element, as evidenced by a peak near 0.5 keV with an intensity of approximately 1.0 cps/eV, contributing to a weight percentage slightly below calcium, around 45%. In contrast, carbon (C) exhibits a much smaller peak at around 0.3 keV, with an intensity below 1.0 cps/eV, corresponding to a weight percentage of approximately 5%. These findings imply that the adsorbent material is mainly constituted of calcium-based compounds, likely comprising $CaCO_3$ and CaO, while also containing a smaller fraction of C-based materials. The greatest chemical composition based on its atomic percentage is O at 61.94%, followed by Ca at 26.08% and C at 11.98% (Table 3). The spectrum recorded based on FTIR analysis is the absorbance peak at the wavelength of 1943.89, 2147.34, 3639.71/cm (Fig. 4).

The peak observed at 1943.89/cm is relatively rare; however, it may be associated with the stretching of carbonyl (C=O) groups within a highly conjugated framework or could arise from overtone or combination bands. Carbonyl stretching typically appears in the 1700-1900/cm range, depending on the chemical environment of the C=O bond, and the observed peak could be the result of complex vibrational interactions, particularly in molecules with conjugated double bond. At 2147.34/cm, the observed peak is likely associated with the carbon-carbon triple (C≡C) or nitrile (C≡N) stretching modes, indicative of alkynes or nitriles, respectively. The presence of sharp absorption features in the 2100-

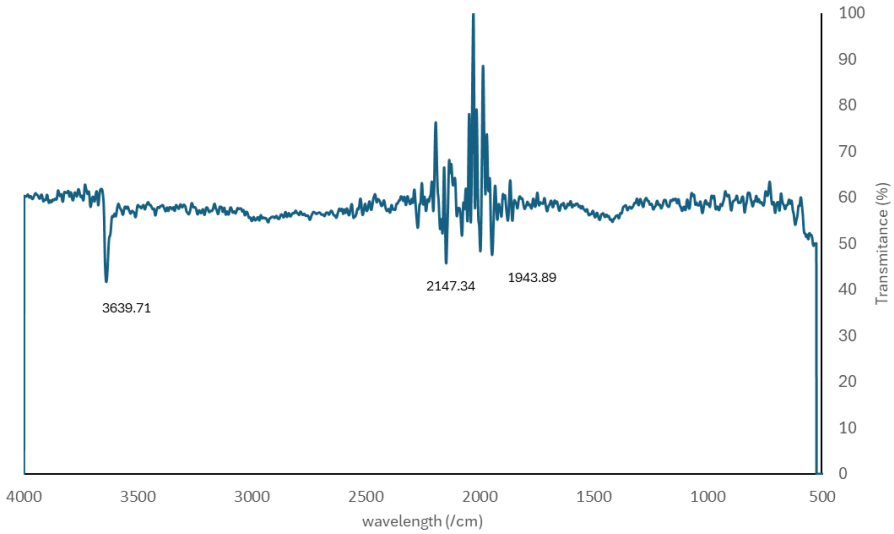

Fig. 4: FTIR spectrum of powder extracted from *P. viridis* shell after being calcinated

2260 cm^{-1} range is characteristic of alkynes and nitriles, which can be explained by the elevated bond energy of their triple bonds. Infrared spectra provide comprehensive documentation of these functional groups, which are characterized by medium to strong intensity peaks in this area. The FTIR spectrum provided reveals several key absorption peaks that correspond to specific functional groups within the sample. Notably, the broad absorption around 3639.71/cm can be attributed to the O-H stretching vibration, commonly found in hydroxyl (-OH) groups, such as those present in alcohols or water molecules. The expansive nature of this peak often signifies hydrogen bonding, which plays a role in altering the vibrational energy of the O-H bond. This assignment is consistent with known FTIR absorptions for O-H stretching, which generally occur between 3200-3600/cm. This gum is a group that is able to absorb water. The presence of moisture is known to facilitate the absorption of calcium oxide (CaO), leading to the formation of calcium hydroxide ($Ca(OH)_2$). This chemical reaction relies on the interaction of the CaO sample with its environment. To prevent the development of Ca(OH)2, which has the potential to alter the characteristics of CaO, it is prudent to reduce such exposure. This observation has been reported in a study conducted by Loy et al. (2016). The morphological structure from SEM analysis has the same structure as Ismail et al. (2022). portlandite crystallized in the shape of imperfect cubic and irregular shapes. The portlandite crystals' morphology in this study is consistent with the literature. This structure is formed due to contact of the CaO compound with humidity at room temperature. After 8 h, the furnace was turned off without opening it to cool down to room temperature. This approach is intended to lower the risk of compromising the integrity of the furnace walls due to abrupt variations in temperature. When the cooling process applied, a contact involving the CaO compound contained inside the clam shell with the air containing water vapor and this will produce hydration and formation of portlandite or $Ca(OH)_2$ throughout the reaction equation (Loy et al., 2016). The adsorbent, after being placed in a desiccator for multiple days, is reduced to a fine powder, attributable to the desiccator's capacity to absorb moisture. The results of the EDX analysis are also in line with Ismail et al. (2022), that the Ca, C and O components were detected after the calcination process. Elements Ca, C and O are probably derived from the $CaCO_3$. High temperatures can decompose these compounds into metal oxide, using Eq. 1 (Mohadi et al., 2016; Razali et al., 2022):

$$CaCO_3(s) \rightarrow CaO(s) + CO_2(g) \quad (1)$$

The main purpose of calcination is to increase the reactivity of the adsorbent before it is used in wastewater treatment (Tat Wai et al., 2024). The process of milling facilitates the reduction of clam shells into smaller fragments. Subsequently, screening ensures that the resulting particles are of uniform size. The size of this stage allows for more even calcination of the clam shell when compared to the intact shell. The calcination process on shells that have gone through milling and filtering shows changes in color and texture. The coloration of the shell powder resulting from the milling and sieving processes is akin to that of the original shell, presenting a combination of green and pearly white, and features a texture that is marginally rough. After calcination the resulting powder is white and has a fine texture. This is in accordance with Wang et al. (2021) study which reported that there are changes in appearance after the calcination process. In general, calcination is a technique that has been widely developed in creating adsorbents from calacerous shells. With respect to size and texture, it can be noted that particles that are diminutive and finely textured usually establish a significant bond with pollutants. The optimal calcination temperature for converting $CaCO_3$ to CaO in the shell is above 800°C, with 1000°C being the most effective temperature (Laskar et al., 2018). The shell catalyst, which includes CaO, becomes active at 1000°C and is usually composed of about 65% CaO (Nugroho et al., 2023). Additionally, this calcination temperature results in the formation of adsorbent particles with a diameter of 1 micrometer (µm) (Dampang et al., 2021), which provides a larger surface area and increases the adsorption capacity (Musthofa et al., 2023) especially for heavy metals and pesticide (Wang et al. 2021).

Contact time and pollutant trends

The effects of contact time within a duration of 0–60 minutes for 10-minute intervals on pollutant trends are available in Figs. 5, 6 and 7 also Tables 6, 7 and 8. The initial Cu contents in the wastewater were 2 mg/L. Then, after it was treated by clam shell, the contents were declined to a range of 0.08–0.02 mg/L, or equal to 96%–99% removals. Similar trends were also observed for Zn. Initially, the concentration was recorded at 0.05 mg/L, after which it diminished to levels between 0.08 and 0.02 mg/L, indicating a removal rate of 84% to 96%. Besides heavy metals, NO_2 and NO_3 pollutants were also declining due to the contact to the shell

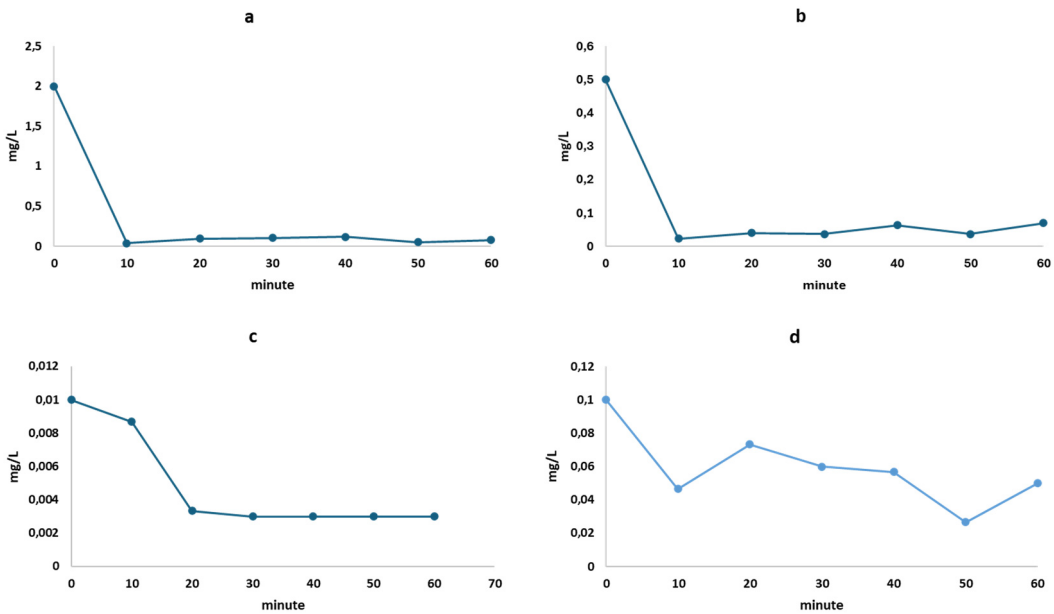

Fig. 5: Effects of contact times (0-60 minutes) to Cu (a), Zn (b), NO_2 (c) and NO_3 (d) contents in wastewater

Table 4: Summary of factor loadings based on confirmatory factor analysis

Variable	Factor Loading	Variance
TSS	0.001	1.000
TA	0.825	0.320
pH	1.000	0.073

Table 5: Summary of factor loadings based on SEM of Cu and Zn.

Variable	Factor loading	Variance
TSS	0.003	61.754
TA	6.027	-23.776
pH	0.144	6.171
Water	0.051	1.000
Time	-0.651	1.000
Cu	1.011	0.010
Zn	0.983	0.000

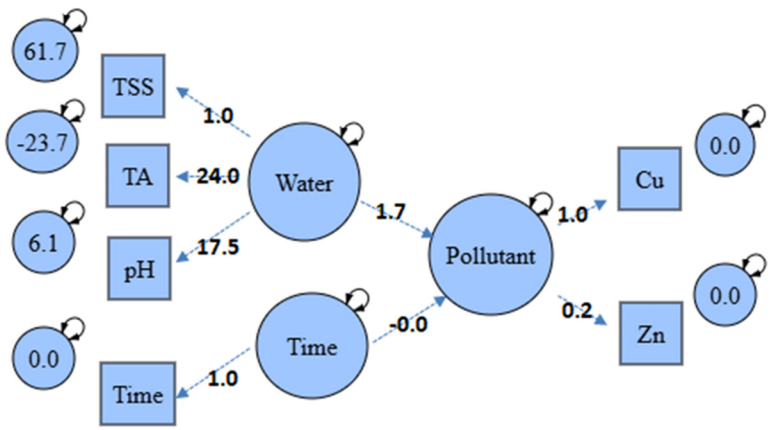

Fig. 6: SEM of copper and zinc with estimate and covariance values.

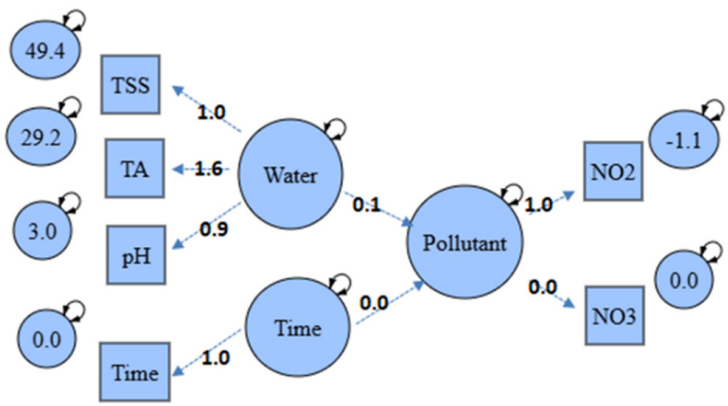

Fig. 7: SEM of nitrite and nitrate with estimate and covariance values

Table 6: Summary of factor loadings based on SEM of NO_2 and NO_3

Variable	Factor Loading	Variance
TSS	0.419	49.436
TA	0.710	29.246
pH	1.000	3.070
Water	0.002	10.000
Time	0.003	400.004
NO_2	15.901	-1.100
NO_3	-0.002	0.000

Table 7: Comparisons of shell removal efficiency

Species	Pollutant	Removal efficiency	Source
P. viridis	Iron (Fe)	96%-99%	Wahyuni *et al.*, 2023
Crab, bivalve, oyster	Mercury (Hg), lead (Pb), nickel (Ni), fluoride (Fl), cadmium (Cd), arsenic (As)	98%-99%	Weerasooriyagedra and Kumar, 2018.
Orbicularia orbiculata	Cd, Cu, Pb	64%-94%	Eljiedi *et al.*, 2019
P. viridis	Cu, Zn	84%–99%	The current study

Table 8: Comparisons of modeling methods

Modelling methods	Pollutants	Accuracy	Predictive power	Sources
Random forest, Bayesian additive regression tree	As, Cd, Cr, Hg, Pb	High (R^2 values ranging from 0.96 to 0.99)	High (low absolute error and strong alignment with real data)	Hafsa *et al.*, 2020
Random forest	As, Cu, Molybdenum (Mo), Strontium (Sr)	Not explicitly stated, but described as reliable	High (produce results with low absolute error)	Malygin and Lychagin, 2020
Artificial neural networks	Cd, Cu, Hg, Ni, Zn	Extremely High (R^2 values result 0.99 for zinc (Zn^{2+}) and 0.999 for copper (Cu^{2+})	High (Model's ability to learn complex patterns in the adsorption process efficiently)	Fiyadh *et al.*, 2023
SEM	Cu, Zn	High (R^2 values Cu and Zn closest to 1, namely 0.9995 and 0.9982)	High	The current study

treatments. NO_2 contents were declining from 0.01 mg/L to the range of 0.002–0.004 mg/L, or equal to 60%–80% removals. The similar trends were also observed for NO_3. With the initial concentrations of 0.1 mg/L, it was declined to the range of 0.02–0.06 mg/L, or equal to 40%–80% removals. The capacity of clam shells to adsorb pollutants aligns with findings from earlier research. Fajarwati et al. (2023) conducted a comparison utilizing a green mussel shell adsorbent mass of 0.5 to 1.5 grams, which yielded an adsorption percentage that spanned from 77.50% to 99.46%.

This study, in general, revealed promising results when juxtaposed with prior investigations that utilized a range of treatment systems or adsorbent types for the management of aquaculture wastewater. The results showed the highest Cu removal rate of 99%. When compared to the application of adsorbents from aquaculture residual feed which had a removal rate of 61.64% (Wang et al., 2024) and biochar with the removal of >70% (Wijeyawardana et al., 2022). However, it has approximately the same efficiency as the onion peel composite adsorbent, which is >95% (Aliyu et al., 2022). Zn demonstrated a lower

removal efficiency relative to Cu, which exhibited a removal efficiency of 96%. This efficiency is equivalent to that achieved by the onion peel composite adsorbent, which is >95% (Aliyu et al., 2022), but higher when compared to the efficiency of >70% from the application of biochar adsorbent (Wijeyawardana et al., 2022) and the combination of wetland systems, mussels and fish which has an efficiency of 87.07% (Saiya and Katoppo, 2015). The maximum efficiency for the removal of NO2 and NO3 was recorded at 80%. This performance is notably inferior to that of the wetland system, which boasts an impressive removal efficiency of 99% for both NO2 and NO3 (Lin et al., 2002). Better results for NO_2 removal were also obtained in the application of *Picochlorum maculatum* adsorbent, which is 89.6%, zeolite with 100% (Kristina et al., 2023) and polymer hydrogel 85% (Kioussis et al., 2000). Meanwhile, lower NO_2 removal efficiency of <80% was found in chitosan adsorbents (Zadinelo et al., 2018), immobilized bacteria (Ye et al., 2023), bacterial consortia (Huang et al., 2020), rice husk (Abdou et al., 2018), and nanofiber reactors (Iber and Kasan, 2021). NO_3 showed a lower removal rate than nitrite even though it achieved the same maximum efficiency of 80%. Findings from Zhang et al. (2024) suggest that the rate at which NO2 is reduced can be 1.63 times higher in comparison to the rate of nitrate reduction.. Using wetland system achieves better efficiency than shell powder, namely 82 - 99%. However, the efficiency of shell powder can be better than the use of several types of adsorbents (<80%), namely polymer hydrogel (50%) (Kioussis et al., 2000), rice husk (6.13%) (Abdou et al., 2018), microalgae *Picochlorum maculatum* (46.4%) (Kumar et al., 2016) or a combination of wetland systems, shellfish and fish (18.55%) (Saiya and Katoppo, 2015). Through a mechanism referred to as chemisorption, the shell powder chemically binds to nitrate and nitrite, which are compounds containing nitrogen (Xu et al., 2019). The monovalent nitrate and nitrite anions (NO_2^-, NO_3^-) (Nedilko et al., 2023) weakly bond to the divalent calcium cations (Ca^{2+}) (Daudzai et al., 2021) present in the clam shell. Nitrate removal is facilitated by the formation of a calcium nitrate-hydroxide (CaHNO4) complex. This process is influenced by the O-Ca-O group and the carbonate ion (CO32-) present in calcined clam shell (Daudzai et al., 2021). According to Xu et al. (2019) study, the removal of pollutants using natural adsorbents can be affected by various factors, including temperature. The findings of the study propose that increased temperatures can augment the performance of adsorption. The underlying reason for this effect is that an increase in temperature can facilitate a greater number of adsorption sites on the oyster shell adsorbent, resulting in an enhanced capacity for the binding of numerous metal ions.

Adsorption isotherm of heavy metals

The results derived from the Langmuir and Freundlich isotherm evaluations suggest that the Langmuir isotherm model is the most effective in representing the adsorption of heavy metals, namely Cu and Zn. This is evidenced by the R^2 values, which are notably high at 0.9995 for Cu and 0.9982 for Zn, demonstrating a close fit to the ideal value of 1. This is relevant to the report of Wang et al. (2023) where the Langmuir isotherm model reached an R^2 of 0.965 for Cu and 0.979 for Zn. Based on these results, it can be assumed that the adsorption of Cu and Zn occurs on a single layer of adsorbent whose entire active surface is homogeneous (Afandy and Sawali, 2024). The Langmuir isotherm model elucidates the mechanisms of chemical (chemisorption) or electrostatic adsorption, indicating that a singular molecular layer is created on the surface of the adsorbent, with all active binding sites exhibiting uniform potential for binding heavy metal ions (Prepilková et al., 2024). In contrast to the Langmuir isotherm, the Freundlich isotherm model describes physical adsorption (physisorption) that occurs on several layers (multilayer) (Chen et al., 2022) of the heterogeneous adsorbent surface (Priyadi et al., 2015). An examination of the regression coefficient reveals that the R^2 values for the Langmuir and Freundlich isotherm models are generally comparable, consistently exceeding 0.9. In the same case example as reported by Tonk and Rápó (2022), if there is only a slight difference between the Langmuir and Freundlich models, it will be unclear whether adsorption occurs on a homogeneous or heterogeneous surface.

Confirmatory factor analysis of water variables

The analysis employed confirmatory factor techniques to evaluate how observed variables

influence the latent variable, specifically water. The values of factor loadings of observed variables can be seen in Table 4. It is clear that pH of water has the highest factor loadings with values of 1.000, followed by TA with values of 0.825. It means that the water latent variables were influenced more significantly by pH and TA variables.

SEM of Cu and Zn

Fig. 6 informs the SEM of Cu and Zn. Among water variables, TA has more contributions to the pollutant reductions with factor loadings of 6.027 (Table 5), followed by pH with factor loadings of 0.144. Water variables played a more significant role in determining pollutant concentrations than the duration of treatment contact time. In the comparison of metals, Cu was more significantly impacted by water variables than Zn, as indicated by factor loadings of 1.011 and 0.983 for Zn. It indicates that the removals of Cu in water by clamshell were affected by water variables. The influences of alkalinity in the adsorption process and the elimination of metals corroborates earlier studies. In this scenario, the significance of alkalinity surpasses that of the micropore content of the adsorption medium, which is clam shell. The adsorption performance of an adsorbent clam shell is influenced by the synergistic effect of specific surface area of clam shell, total micropore volume, and water alkalinity. Then, water alkalinity is the main factor affecting the adsorption capacity (Zhou et al., 2021). Alkali treatment has the potential to substantially improve the heavy metal adsorption capabilities of sewage sludge (Hu et al., 2015). The alkalinity in the water can be regulated by adding acidic compounds and pH reducers.

SEM of NO_2 and NO_3

Fig. 7 presents the estimate and covariance values of NO_2 and NO_3 based on SEM indices. The analysis revealed that total TA and pH were critical water variables that played a substantial role in the removal of pollutants, with factor loadings recorded at 0.710 for TA and 1.000 for pH. Among pollutants, NO_2 is affected significantly by TA and pH. The factor loadings for NO_2 are 15.901 and -0.002 for NO_3 (Table 6). The analysis conducted through SEM indicates that pH plays a crucial role in the adsorption of nitrite by clam shells. This influence of pH on the removal of pollutants corroborates the conclusions drawn in prior studies. The interaction between the pH of the solution and the contact time was identified as a key factor affecting the adsorption processes. However, the results of this study suggest that the role of contact time is less pronounced as illustrated in Table 6. Optimum pH for nitrate sorption was between pH 2 and pH 4 (Lebrun et al., 2023) and another result was at arange of 3.36-8.45 (Chen et al., 2021). The efficiency of pH to remove nitrite was tend to decrease when pH increased (El Ouardi et al., 2015). High pH levels make it difficult for bacteria to reduce NO_2, leading to an increase in NO_2 concentration (Albina et al., 2021).

Challenge and Limitations of clam shell adsorbent study

The present study examines the use of adsorbents sourced from natural materials, particularly clam shells obtained from *P. viridis*. The removal efficiency exhibited by these clam shells is found to be similar to that of other natural-based adsorbents, as evidenced in Table 7. As highlighted in earlier studies, the application of shells as an adsorbent proves to be quite effective. First, the availability of shells in nature is abundant. Second, since the shell is consisting of durable materials then the shell will be long lasting. The utilization of clam shells is considered sustainable, as the clams will eventually decompose into organic matter within aquatic ecosystems. Despite the clam shell's ability to adsorb, the use of shells also has limitations, as observed in this study. The limitation is the efficiency of the clam shell to adsorb depends on water variables. Then, in the future, those variables should be regulated to obtain optimum results. The nature of this study is experimental, which could pose limitations to its findings. In response to this challenge, the study employs water that has been directly obtained from aquaculture operations. In the future, it is recommended to apply the treatment directly in the aquaculture facilities to scale up the results. This study uses SEM as an approach to represent real world situations by incorporating numerous variables that have contribution effects. Despite the ability of SEM to distinguish contributions of particular variables, SEM also has several limitations. Various limitations associated with SEM encompass sensitivity to limited sample

sizes, challenges posed by multicollinearity, and the risk of measurement inaccuracies.

The SEM used in this study is comparable to the modeling method used in other studies, as can be seen in Table 8. Yassen (2021) elicited that the use of the modeling method may contain some limitations. Future advancements are necessary to enhance the application of modeling techniques in the study of pollutants. Improvements are necessary in several domains, particularly concerning biases associated with the selection of suitable optimization algorithms, the requisite number of data sets, the types of data utilized, the defining characteristics of the water catchment, and the optimization steps undertaken prior to the model-building phase.

Utilizing adsorbents made from natural waste, particularly shell powder, offers a viable and sustainable method for decreasing pollutant levels. This is largely due to the extensive presence of shell waste in nature, where the conversion rate from shell waste to shell powder is approximately 1:1. For instance, 1 kg of *P. viridis* shells can produce 960 g of calcined shell powder (Suhaera et al., 2021). Additionally, shells are environmentally friendly organic materials (Sophia and Sakthieswaran, 2019). In terms of its impact on the environment, shell powder can improve several sediment quality parameters such as pH and dissolved oxygen levels, while reducing the concentration of NH_4^+-N and T-N (Khirul et al., 2020). In light of its relatively recent introduction as an adsorbent, monitoring the effectiveness of shell powder in pollutant retention is essential. It is significant to highlight that shell powder does not function as a reusable adsorbent (Pu et al., 2019) and is prone to settling at the bottom (Pitriyani et al., 2024). Moreover, there is insufficient information concerning the discharge of pollutants from the shell powder adsorbent. This gap in knowledge prompts concerns that pollutants contained in the shell powder could settle and potentially release harmful substances into the sediment. The degradation of shells typically occurs over an extended period of time and may even begin within 3 years, depending on the size of the shell and its environment (Říhová et al., 2018). Factors in the environment, particularly pH and ambient temperature, play a crucial role in the degradation process. Shells degrade more rapidly under low pH conditions (Waldbusser et al., 2011) and high temperatures (Babarro et al., 2023). Lagos et al. (2016) report that the rate of shell degradation tends to increase at a pH of 7.7 and a temperature of 18°C. Powdered shell adsorbent is more easily dissolved in water because the CaO form is known to be more soluble than the $CaCO_3$ form (Abeynaike et al., 2011). Additionally, powdered adsorbents are inclined to form clusters in water (Zhou et al., 2022), which facilitates a more rapid sedimentation to the bottom (Meslard et al., 2018). To gain a complete understanding of the possible implications for aquatic systems, further investigation is needed into the release of pollutants associated with shell powder adsorbents. Scaling up the adsorbents from this study could be conducted by considering several aspects (Tat Wai et al., 2024). Aquaculture wastewater is a chemically complex water (Nhung et al., 2023) which consists of organic and inorganic content. Mostly adsorption studies used synthetic waste water whose contents were already known, while this study performed interesting results that adsorbent potential removed both contents without separation. Aquaculture is also built as a business practice that involves more data sets and monitoring (Tat Wai et al., 2024). Consequently, there is a necessity for a greater quantity of shells. Moreover, with appropriate management strategies, the recovery of shells from waste generated by the food industry may serve as a viable solution to this challenge. Aquaculture cannot be separated from seasonal and weather conditions which influence surrounding conditions, including ponds/disposal areas. To prevent the limitations imposed by seasonal and weather-related factors on the utilization of adsorbents, it is crucial to adopt specific strategies, especially in the realm of indoor waste treatment. A further aspect worth noting is that the adsorbent is not soluble in water; this characteristic, when paired with deposition techniques, facilitates the development of a blend of sediment and adsorbent that can be employed as a medium for planting or as a material for construction. This study promotes water variables, namely pH and TA, which are related to each other, and in particular pH is closely related to adsorption.

CONCLUSION

This study succeeded in presenting first the removal of Cu, Zn, NO_2, and NO_3 from aquaculture

wastewater using shell of *P. viridis* and also modeling the impacts of water variables that affect those pollutant removals using SEM. T The successful extraction and calcination of clam shells resulted in the production of shell powder, which is noted for its white appearance. Character analysis shows that the powder has a crystalline form that can easily bind with water due to the presence of -OH groups comprising of Ca, O, and C. This confirms that the calcination process changes $CaCO_3$ compounds into CaO, with Ca elements reaching 20%. The aquaculture wastewater contains heavy metals, including Cu and Zn, NO_2 and NO_3. The results imply that aquaculture may be at risk of contamination from pollutants, which could be derived from both external and internal origins. The water involved in aquaculture operations has the potential to introduce heavy metals into the environment. The NO_2 and NO_3 are presumably generated from aquaculture practices resulting from the metabolism process of cultured shrimps. Addressing this issue calls for a groundbreaking method to purify water by removing pollutants. It is essential that this solution is not only affordable but also aligns with environmental sustainability principles. In this regard, the feasible solution is using nature-based removals. Here, this study offered the uses of clam shell as nature-based removal agents for heavy metals, NO_2 and NO_3. The result showed clam shell can reduce the heavy metals from water with a removal efficiency of 84%–99%. Clam shell is more effective in reducing Cu and followed by Zn. For reducing NO_2 and NO_3, the removal efficiency was within the range of 40%–80%. The best removal performances were achieved for NO_2 with removal efficiency up to 60% or 20% higher than NO_3. Ultimately, clam shell powder proves to be an effective agent for the extraction of copper and nitrogen dioxide from wastewater associated with aquaculture. An additional obstacle in the evaluation of removal efficiency pertains to the analytical methods used to examine the removals. These methods can encompass both calculations and modeling frameworksThe present study contributes a novel perspective to removal analysis by employing structural equation modeling (SEM). According to SEM results and factor loading values, water variables that contributed significantly to the metal removals were TA, followed by pH. Metal that was affected significantly by those water variables was Cu. This is also similar for NO_2 and NO_3 in water, with NO_2 being more affected. Based on SEM, pH was the contributor to NO_2 adsorption by clam shells. SEM is very useful to inform which variables that should be incorporated and regulated to optimize the removal of pollutants from aquaculture wastewater. Based on the results obtained from the SEM analysis, it is evident that pH and total TA are critical water variables that require careful management to ensure maximum pollutant removals from aquaculture wastewater. This research explores the potential use of food waste for managing environmental waste. Food waste, specifically clam shells, can be repurposed as an absorbent material through extraction and calcination processes. By integrating this powder, it is possible to alleviate the environmental waste associated with vaname shrimp farming operations. This study, while still in the laboratory phase, demonstrates considerable potential for practical implementation in various field applications. Further experimentation could involve adjusting the ratio of absorbent mass to waste volume to achieve greater reductions in waste parameters such as TSS, TA, and pH values.

AUTHOR CONTRIBUTIONS

N.D. Takarina as corresponding author has contributed the research proposal making, sample collection, manuscript drafting, O.M. Chuan conducted in preparation of manuscript, reviewing proposals and data verification, A. Adiwibowo performed data analysis and interpretation using SEM and helped drafting the manuscript, M.A. Adidharma data collection and tabulation.

ACKNOWLEDGEMENT

The authors thank Directorate of Reseach and Development, University of Indonesia (Risbang UI) for its funding through PUTI Q2 Research Grant with contract number NKB- number [NKB-756/UN2.RST/HKP.05.00/2023].

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication

and/or submission, and redundancy have been completely observed by the authors.

OPEN ACCESS

©2025 The author(s). This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made. The images or other third-party material in this article are included in the article's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this license, visit: http://creativecommons.org/licenses/by/4.0/

PUBLISHER'S NOTE

GJESM Publisher remains neutral with regard to jurisdictional claims in published maps and institutional afflictions.

ABBREVIATIONS

%	Percent
^{o}C	Degree Celcius
µm	Micrometer
6th	Sixth
/cm	Reciprocal centimeter
As	Arsenic
C	Carbon
C≡C	Carbon-carbon triple
C=O	Carbonyl
C≡N	Nitrile
Ca	Calcium
$CaHNO_4$	Calcium nitrate-hydroxide
$Ca(OH)_2$	Calcium hydroxide
$CaCO_3$	Calcium carbonat
CaO	Calcium oxide
Cd	Cadmium
CO_2	Carbon dioxide
CO_3^{2-}	Carbonate ion
cps/eV	Count per second per electron-Volt
Cr	Chromium
Cu	Copper
CVit	Carbon Volume in time
Fe	Iron
FTIR	Fourier Transform Infrared
g	Gram
H_2S	Hydrogen sulfide
h	Hour
Hg	Mercury
Ind/ha	Individual per hectare
keV	kilo-electron-volt
L	Liter
mA/cm^2	Milliampere per square centimeter
mg/g	Milligram per gram
mg/L	Miligram per liter
Min	Minute
mL	Milliliter
Mo	Molybdenum
N	Nitrogen
NH_3	Ammonia
NH_4	Ammonium
Ni	Nickel
NO_2	Nitrite
NO_2^-	Monovalent nitrite anions
NO_3	Nitrate

NO_3^-	Monovalent nitrate anions
O	Oxygen
-OH	Hydroxyl
P	Phosphorus
Pb(II)	Lead (II)
pH	Potential hydrogen
PO_4^{3-}	Phosphate
P. viridis	*Perna viridis*
R	Software for statistical analysis
rpm	Revolutions per minute
SEM-EDX	Scanning electron microscopy – energy dispersive X-ray
SEM	Structural equation model
SiO_2	Silicon dioxide
Sr	Strontium
TA	Total alkalinity
Tons/y	Tons per year
TSS	Total suspended solids
Zn	Zinc

REFERENCES

Abdou, K.A.; Mohammed, A.N.; Moselhy, W.A.E.R.; Farghali, A.A., (2018). Assessment of modified rice husk and sawdust as bio-adsorbent for heavy metals removal using nano particles in fish farm. Asian J. Anim. Vet. Adv., 13: 180-188 **(10 Pages)**.

Abeynaike, A.; Wang, L.; Jones, M.I.; Patterson, D.A., (2011). Pyrolysed powdered mussel shells for eutrophication control: effect of particle size and powder concentration on the mechanism and extent of phosphate removal. Asia Pac. J. Chem. Eng., 6(2): 231-243 **(13 Pages).**

Afandy, M.A.; Sawali, F.D.I., (2024). Studi isotherm adsorpsi Cu(II) dalam larutan menggunakan zeolit teraktivasi. J. Teknol. Kimia Min., 3(1): 25-32 **(8 Pages)**.

Albina, P.; Durban, N.; Bertron, A.; Albrecht, A.; Robinet, J.-C.; Erable, B., (2021). Nitrate and nitrite bacterial reduction at alkaline pH and high nitrate concentrations, comparison of acetate versus dihydrogen as electron donors. J. Environ. Manage., 280: 111859 **(10 pages)**.

Aliyu, A.O.; Musa, F.K.; Fururuwa, M.D.; Okunola, O.J., (2022). Evaluation of the potential of onion peel composite as an adsorbent for the removal of cations in fish pond wastewater. Fudma J. Sci. 6(4): 266-273 **(8 Pages)**.

Aljendeel, H.A., (2011). Removal of heavy metals using reverse osmosis. J. Eng., 17(3): 647–658 **(12 Pages).**

Al-Othman, Z.A.; Naushad, M.; Inamuddin, (2011). Organic–inorganic type composite cation exchanger poly-o-toluidine Zr (IV) tungstate: Preparation, physicochemical characterization and its analytical application in separation of heavy metals. Chem. Eng. J., 172: 369-375 **(7 Pages)**.

Babarro, J.M.F.; Velo, A.; Peteiro, L.G.; Darriba, S.; Broullon, D.; Pérez, F.F., (2023). Taphonomy and dissolution rates of the razor clam Ensis magnus shells: Current status and projected acidification scenarios. Estuarine Coastal Shelf Sci., 289: 108372 **(14 Pages)**.

Baja, E.S.; Schwartz, J.D.; Coull, B.A.; Wellenius, G.A.; Vokonas, P.S.; Suh, H.H., (2013). Structural equation modeling of parasympathetic and sympathetic response to traffic air pollution in a repeated measures study. Environ. Health. 12(1): 81 **(13 Pages)**.

Bosman, O.; Susilo, T.E.B.; Rahardjo, S., (2021). Pollution index and economic value of vannamei shrimp (*Litopenaeus vannamei*) farming in Indonesia. Indo. Aquac. J., 16(1): 51-60 **(10 pages)**.

Birniwa, A.H.; Habibu, S.; Abdullahi, S.S,; Mohammad, R.E.A.; Hussaini, A.; Magaji, H.; Al-dhawi, B.N.S; Noor, A.; Jagaba, A.H., (2024). Membrane technologies for heavy metals removal from water and wastewater: A mini review. Case Stud. Chem. Environ. Eng., 9: 100538 **(15 Pages)**.

Bremner, C.; Cochrane, T.A.; McGuigan, P.; Bello-Mendoza, R., (2020). Removal of dissolved heavy metals from stormwater by filtration with granular recycled glass and mussel shell with and without microalgae biofilm. Environ. Technol. Innovation. 18: 100662 **(12 Pages)**.

Chen, J.; Wei, Y.; Ji, H.; Guo, P., (2021). Adsorption of nitrate and nitrite from aqueous solution by magnetic Mg/Fe hydrotalcite. Water Supply. 21(8): 4287–4300 **(14 Pages)**.

Chen, X.; Hossain, M.F.; Duan, C.; Lu, J.; Tsang, Y.F.; Islam, M.S.; Zhou, Y., (2022). Isotherm models for adsorption of heavy metals from water - A review. Chemosphere. 307: 135545 **(14 Pages)**.

Chiquito-Contreras, R.G.; Hernandez-Adame, L.; Alvarado-Castillo, G.; Martínez-Hernández, M.D.J.; Sánchez-Viveros, G.; Chiquito-Contreras, C.J.; Hernandez-Montiel, L.G., (2022). Aquaculture—Production system and waste management for agriculture fertilization—A Review. Sustainability. 14(12): 7257 **(13 Pages)**.

Dampang, S.; Purwanti, E.; Destyorini, F.; Kurniawan, S.B.; Abdullah, S.R.S.; Imron, M.F., (2021). Analysis of optimum temperature and calcination time in the production of cao using seashells waste as CaCO3 source. J. Ecol. Eng., 22(5): 221-228 **(8 Pages)**.

Dauda, A.B.; Ajadi, A.; Tola-Fabunmi, A.S.; Akinwole, A.O., (2019). Waste production in aquaculture: Sources, components and managements in different culture systems. Aquac. Fish. 4(3): 81-88 **(8 Pages)**.

Daudzai, Z.; Dolphen, R.; Thiravetyan, P., (2021). Simultaneous

removal of phosphate and nitrate from synthetic and real wastewater by *Meretrix lusoria* as an efficient and novel material. Water Air Soil Pollut., 232, 186 **(21 Pages)**.

Djedidi, Z.; Boudaa, M.; Souissi, M.A.; Cheikh, R.B.; Mercier, G.; Tyagi, R.D.; Blais. J.F., (2009). Metals removal from soil, fly ash and sewage sludge leachates by precipitation and dewatering properties of the generated sludge. J. Hazard. Mater., 172: 1372–1382 **(11 Pages)**.

Eljiedi, A.A.A.; Kamari, A.; Sunardi.; Fatinah, I., (2019). Lala clam (*Orbicularia orbiculata*) shell as an eco-friendly adsorbent for Cd(II), Cu(II) and Pb(II) ions. Arab J. Basic Appl. Sci., 26(1): 462–475 **(14 Pages)**.

El Ouardi, M.; Qourzal, S.; Alahiane, S.; Assabbane, A.; Douch, J., (2015). Effective removal of nitrates ions from aqueous solution using new clay as potential low-cost adsorbent. J. Encapsulation Adsorpt. Sci., 5(4): 178-190 **(13 Pages)**.

Fajarwati, F.I.; Mahanani, A.; Anugrahwati, M., (2023). Kinetics study of copper (Cu) and chromium (Cr) adsorption using green mussel shells (*Perna viridis*) adsorbent. J. Pijar MIPA. 18(1): 118- 125 **(8 Pages)**.

Fiyadh, S.S.; Alardhi, S.M.; Al Omar, M.; Aljumaily, M.M.; Al Saadi, M.A.; Fayaed, S.S.; Ahmed, S.N.; Salman, A.D.; Abdalsalm, A.A.; Jabbar, N.M.; El-Shafi, A., (2023). A comprehensive review on modelling the adsorption process for heavy metal removal from waste water using artificial neural network technique. Heliyon. 9(4): e15455 **(13 Pages)**.

Hafsa, N.E.; Rushd, S.; Al-Yaari, M.; Rahman, M., (2020). A generalized method for modeling the adsorption of heavy metals with machine learning algorithms. Water. 12(12):3490 **(22 Pages)**.

Hastuti, Y.P.; Rusmana, I.; Nirmala, K.; Affandi, R.; Tridesianti, S., 2019. Identification and characterization of nitrifying bacteria in mud crab (*Scylla serrata*) recirculation aquaculture system by 16S rRNA sequencing. Biodiversitas. 20(5): 1339-1343 **(5 Pages)**.

Hu, J.; Yang, X.; Shao, L.; He, X.; Men, K., (2015). Effect of alkali treatment on heavy metals adsorption capacity of sewage sludge. J. Geoscience Environ. Prot., 3(2): 33-39 **(7 Pages)**.

Huang, F.; Pan, L.; He, Z.; Zhang, M.; Zhang, M., (2020). Culturable heterotrophic nitrification-aerobic denitrification bacterial consortia with cooperative interactions for removing ammonia and nitrite nitrogen in mariculture effluents. Aquaculture. 532: 735211 **(9 Pages)**.

Iber, B.T.; Kasan, N.A., (2021). Recent advances in shrimp aquaculture wastewater management. Heliyon. 7(11): e08283 **(9 Pages)**.

Inayah, Z.N.; Musa, M.; Arfiati, D., (2023). Growth of vannamei shrimp (*Litopenaeus vannamei*) in intensive cultivation systems. J. Penelit. Pendidik. IPA. 9(10): 8821-8829 **(9 Pages)**.

Ismail, R.; Cionita, T.; Shing, W.L.; Fitriyana, D.F.; Siregar, J.P.; Bayuseno, A.P.; Nugraha, F.W.; Muhamadin, R.C.; Junid, R.; Endot, N.A., (2022). Synthesis and characterization of calcium carbonate obtained from green mussel and crab shells as a biomaterials candidate. Materials. 15(16): 5712 **(15 Pages)**.

Jasim, A.Q.; Ajjam, S.K., (2024). Removal of heavy metal ions from wastewatr using ion exchange resin in a batch process with kinetic isotherm. South Afr. J. Chem. Eng., 49: 43-54 **(12 Pages)**.

John, E.M.; Krishnapriya, K.; Sankar, T.V., (2020). Treatment of ammonia and nitrite in aquaculture wastewater by an assembled bacterial consortium. Aquaculture. 526: 735390 **(6 Pages)**.

Kabwadza-Corner, P.; Johan, E.; Matsue, N, (2015). pH dependence of lead adsorption on zeolites. J. Environ. Prot., 6(1): 45-53 **(9 Pages)**.

Kaewprachu, P.; Jaisan, C., (2023) Physicochemical properties of chitosan from green mussel shells (*Perna viridis*): A comparative study. Polymers. 15(13): 2816 **(14 Pages)**.

Kapepula, V.L.; Luis, P., (2024). Removal of heavy metals from wastewater using reverse osmosis. Front. Chem. Eng., 6:1334816 **(17 Pages)**.

Khirul, M.A.; Kim, B.-G.; Cho, D.; Yoo, G.; Kwon, S.H., (2020). Effect of oyster shell powder on nitrogen releases from contaminated marine sediment. Environ. Eng. Res., 25(2): 230-237 (8 Pages).

Kioussis, D.R.; Wheaton, F.W.; Kofinas, P., (2000). Reactive nitrogen and phosphorus removal from aquaculture wastewater effluents using polymer hydrogels. Aquac. Eng., 23(4): 315-332 **(18 Pages)**.

Kristina, T.; Assiddiqi, T.D.; Setiawan, B.I.; Arif, C.; Kurniawan, A., (2023). Kinerja unit dan isoterm adsorpsi filtrasi multimedia pada sistem resirkulasi akuakultur ikan hias berdasarkan variasi ketebalan media dan debit aliran. J. Ilmu Lingkungan. 21(4): 933-945 **(13 Pages)**.

Kumar, S.D.; Santhanam, P.; Park, M.S.; Kim, M.-K., (2016). Development and application of a novel immobilized marine microalgae biofilter system for the treatment of shrimp culture effluent. J. Water Process Eng., 13: 137–142 **(6 Pages)**.

Lagos, N.A.; Benítez, S.; Duarte, C.; Lardies, M.A.; Broitman, B.R.; Tapia, C.; Tapia, P.; Widdicombe, S.; Vargas, C.A., (2016). Effects of temperature and ocean acidification on shell characteristics of Argopecten purpuratus: implications for scallop aquaculture in an upwelling-influenced area. Aquac. Environ. Interactions. 8: 357-370 **(14 Pages)**.

Laskar, I.B.; Rajkumari, K.; Gupta, R.; Chatterjee, S.; Paul, B.; Rokhum, S.L., (2018). Waste snail shell derived heterogeneous catalyst for biodiesel production by the transesterification of soybean oil. RSC Adv., 8: 20131–20142 **(12 Pages)**.

Lebrun, M.; Renouard, S.; Morabito, D., (2023). Sorption capacities of various activated carbons towards nitrates: effects of nitrate concentration, pH, time and co-existing ions. Int. J. Environ. Sci. Technol., 20: 13033–13044 **(12 Pages)**.

León-Cañedo, J.A.; Alarcón-Silvas, S.G.; Fierro-Sañudo, J.F.; Mariscal-Lagarda, M.M.; Díaz-Valdés, T., Páez-Osuna, F., (2017). Assessment of environmental loads of Cu and Zn from intensive inland shrimp aquaculture. Environ. Monit.

Assess., 189(2):69 **(8 Pages)**.
Lin, Y.-F.; Jing, S.-R.; Lee, D.-Y.; Wang, T.-W., (2002). Nutrient removal from aquaculture wastewater using a constructed wetlands system. Aquaculture. 209(1-4): 169-184 **(16 Pages)**.
Listiana, I.; Arianto, D., (2024). Structural equation modeling for social capital empowerment in supporting mangrove rehabilitation. Global J. Environ. Sci. Manage., 10(4): 2031-2044 **(14 Pages)**.
Loy, C.W.; Matori, K.A.; Lim, W.F.; Schmid, S.; Zainuddin, N.; Wahab, Z.A.; Alassan, Z.N.; Zaid, M.H.M., (2016). Effects of calcination on the crystallography and nonbiogenic aragonite formation of ark clamshells under ambient conditions. Adv. Mater. Sci. Eng., 2016: 2914368 **(8 pages)**.
Malygin, E.; Lychagin, M., (2020). Machine learning approach for simulation of heavy metal concentration in river water: the Crimean peninsula case study. E3S Web of Conferences 163: 06009 **(6 Pages)**.
Meez, E.; Rahdar, A.; Kyzas, G.Z., (2021). Sawdust for the Removal of Heavy Metals from Water: A Review. Molecules. 26(14): 4318 **(21 Pages)**.
Meslard, F.; Bourrin, F.; Many, G.; Kerhervé, P., (2018). Suspended particle dynamics and fluxes in an Arctic fjord (Kongsfjorden, Svalbard). Estuarine, Coastal and Shelf Sci., 204: 212-224 **(13 Pages).**
Mohadi, R.; Anggraini, K.; Riyanti, F.; Lesbani, A., (2016). Preparation of calcium oxide (CaO) from chicken eggshells. Sriwijaya J. Environ., 1(2): 32-35 **(4 Pages)**.
Musthofa, A.M.H.; Syafila, M.; Helmy, Q., (2023). Effect of activated carbon particle size on methylene blue adsorption process in textile wastewater. Indones. J. Chem., 23(2): 461-474 **(14 Pages)**.
Nayagam, J.O.P.; Prasanna, K., (2022). Utilization of shell-based agricultural waste adsorbents for removing dyes: A review. Chemosphere. 291(1): 132737 **(17 pages)**.
Nedilko, S.; Reznichenko, E.; Sherbatskii, V.; Nedielko, M., (2017). Luminescent behaviour of monovalent metals nitrite/nitrates incorporated to microcrystalline cellulose matrix by sorption from water solutions. Thai J. Nanosci. Nanotechnol., 2(2): 31-42 **(12 Pages)**.
Nhung, N.T.H.; Long, V.D.; Fujita, T. A., (2023). Critical review of snail shell material modification for applications in wastewater treatment. Materials. 16: 1095 **(17 Pages)**.
Nguyen, V.Q.; Van, H.T.; Sy, H.L.; Nguyen, T.M.L.; Nguyen, D.K., (2021). Application of Mussell-derived biosorbent to remove NH4+ from aqueous solution: Equilibrium and Kinetics. SN Appl. Sci., 3: 496 **(12 Pages)**.
Nugroho, B.S.; Wahyuni, D.; Asri, A.; Mustafa, U., (2023). Effect of calcination temperature on the powder of freshwater snail shells (Sulcospira testudinaria) properties. Positron. 13(2): 158-165 **(8 Pages)**.
Nurhidayanti, N.; Cahyanto, A.D., (2023). Isotherm Study, Adsorption kinetics and thermodynamics of lead using combination adsorbent of chitosan and coffee ground activated carbon. J Riset Teknol. Pence. Pencemar. Industri 14(SI): 1-11 **(11 Pages)**.
O'Connell, D.W.; Birkinshaw, C.; O'Dwyer, T.F., (2008.) Heavy metal adsorbents prepared from the modification of cellulose: A review. Bioresource Technol., 99(15): 6709–6724 **(16 Pages)**.
Okoro, H.K.; Alao, S.M.; Pandey, S.; Jimoh, I.; Basheeru, K.A.; Caliphs, Z.; Ngila, J.C., (2022). Recent potential application of rice husk as an eco-friendly adsorbent for removal of heavy metals. Appl. Water Sci., 12: 259 **(8 Pages)**.
Paena, M.; Syamsuddin, R.; Rani, C.; Tandipayuk, H., (2020). Estimation of organic waste loads from shrimp pond superintensive that was disposed in the Labuange Bay Waters. J. Ilm. Teknol. Kel. Tropis. 12(2): 507-516 **(10 Pages)**.
Paranjape, P.; Sadgir, P., (2023). Linear and nonlinear regression methods for isotherm and kinetic modelling of iron ions bioadsorption using Ocimum sanctum Linn. leaves from aqueous solution. Water Pract. Technol., 18(8): 1807-1827 **(21 Pages)**.
Pitriyani; Devi, D.S.; Febryandi, (2024). Effect of cockle shell powder on the compressive strength of concrete with viscocrete 3115 n additive. Fondasi: Jurnal Teknik Sipil. 13(1): 22-33 **(12 Pages)**.
Prepilková, V.; Poništ, J.; Belčáková, I.; Ďuricová, A.; Salva, J.; Schwarz, M.; Samešová, D., (2024). Comparison of copper and zinc sorption depending on temperature and sorbents. Pol. J. Environ. Stud., 33(3): 2241-2254 **(14 Pages)**.
Priyadi; Iskandar; Suwardi; Mukti, R.R., (2015). Characteristics of Heavy Metals Adsorption Cu, Pb and Cd using synthetics zeolite Zsm-5. J. Trop. Soils. 20(2): 77-83 **(7 Pages)**.
Pohl, A., (2020). Removal of heavy metal ions from water and wastewaters by sulfur-containing precipitation agents. Water Air Soil Pollut., 231: 503 **(17 pages)**.
Pu, L.; Xie, Y,; Qiu, W.; Li, L., (2019). Thermoplastic foaming mechanism and Pb2+ adsorption of poly(vinyl alcohol)/ shell powder porous composite. Polym. Compos., 40: 4658–4668 **(11 Pages)**.
Rahman, N.A.A.; Said, M.I.M.; Azman, S., (2017). Carbonized green mussel shell as heavy metal removal. Malays. J. Civ. Eng., 29(1): 56-68 **(13 Pages)**.
Rahmi; Fathurrahmi; Lelifajri; Purnamawati, F.; Sembiring, R., (2019). Preparation of magnetic chitosan beads for heavy metal ions removal from water. IOP Conf. Ser.: Earth Environ. Sci., 276: 012004 **(8 Pages)**.
Razali, N.; Jumadi, N.; Jalani, A.Y.; Kamarulzaman, N.Z.; Pa'ee, K.F., (2022). Thermal decomposition of calcium carbonate in chicken eggshells: study on temperature and contact time. Malays. J. Anal. Sci., 26(2): 347-359 **(13 Pages)**.
Říhová, D.; Janovský, Z.; Horsák, M.; Juřičková, L., (2018). Shell decomposition rates in relation to shell size and habitat conditions in contrasting types of Central European forests. J. Molluscan Stud., 84(1): 54-61 **(8 Pages)**.
Saiya, H.G.; Katoppo, D.R., (2015). Waste management of shrimp farms as starting point to develop integrated farming systems (case study: Kuwaru Coast, Bantul, Yogyakarta, Indonesia). J. Degraded Mining Land Manage. 3(1): 423-432 **(10 Pages)**.

Saleem, M.; Chakrabarti, M.H.; Hasan, D.B., (2011). Electrochemical removal of nitrite in simulated aquaculture wastewater. African J. Biotechnol., 10(73): 16566-16576 **(11 Pages)**.

Salim, N.A.A.; Fulazzaky, M.A.; Zaini, M.A.A.; Puteh, M.H.; Khamidun, M.H.; Yusoff, A.R.M.; Abdullah, N.H.; Ahmad, N.; Lazim, Z.M.; Nuid, M., (2021). Phosphate removal from wastewater in batch system using waste mussel shell. Biointerface Res. Appl. Chem., 11(4): 11473-11486 **(14 Pages)**.

Schenone, M.B., Grimaccia, E., Vichi, M., (2024). Structural equation models for simultaneous modeling of air pollutants. Environmetrics. 35(3): e2837 **(22 pages)**.

Sophia, M.; Sakthieswaran, N., (2019). Waste shell powders as valuable bio- filler in gypsum plaster – Efficient waste management technique by effective utilization. J. Clean. Prod., 220: 74-86 **(13 Pages)**.

Stein, C.M.; Morris, N.J.; Nock, N.L., (2012). Structural Equation Modeling. In Elston, R., Satagopan, J., Sun, S., (Eds.), Statistical Human Genetics. Methods Mol. Biol., 850: 495-512 **(18 Pages)**.

Suhaera; Rachmayanti, A.S.; Dewi, S.S.; Mursyidah, S.; Dachriyanus, (2021). Uji senyawa bioaktif dan toksisitas limbah cangkang kerang hijau (Perna viridis). J. Ilmu Kedokteran dan Kesehatan Indonesia. 1(3): 191-205 **(15 Pages)**.

Tadda, M.A.; Li, C.; Gouda, M.; Abomohra, A.E.; Shitu, A.; Ahsan, A.; Zhu, S.; Liu, D., (2021). Enhancement of nitrite/ammonia removal from saline recirculating aquaculture wastewater system using moving bed bioreactor. J. Environ. Chem. Eng., 9(5): 105947 **(11 Pages)**.

Tat Wai, K.; O'Sullivan, A.D.; Bello-Mendoza, R., (2024). Nitrogen and phosphorus removal from wastewater using calcareous waste shells—A systematic literature review. Environments. 11(6):119 **(21 Pages)**.

Tonk, S.; Rápó, E., (2022). Linear and Nonlinear Regression analysis for the adsorption of remazol dye by romanian brewery waste by-product, *Saccharomyces cerevisiae*. Int. J. Mol. Sci., 23(19): 11827 **(20 Pages)**.

Turcios, A.E.; Papenbrock, J., (2014). Sustainable treatment of aquaculture effluents—what can we learn from the past for the future?. Sustainability. 6(2): 836-856 **(21 Pages)**.

Velarde, L.; Nabavi, M.S.; Escalera, E.; Antti, M.-L.; Akhtar, F., (2023). Adsorption of heavy metals on natural zeolites: A review. Chemosphere. 328: 138508 **(16 Pages)**.

Wahi, R.; Zuhaidi, N.F.Q.; Yahaya, S.A.; Lam, S.S.; Imran-Shaukat, M.; Aziz, S.M.A.; Ngaini, Z.; Pauzan, A.S.M, (2022). Engineered microwave biochar from sago bark waste for heavy metals adsorption. Materials Today: Proceedings. 57(3): 1403-1414 **(12 Pages)**.

Wahyuni, E.U.; Pramono, B.; Syarifuddin., (2023). Utilization of shell waste as an adsorbent to reduce Fe (Iron) Metal. Asian J. Pharm. Res. Dev., 11(2): 25-27 **(3 Pages)**.

Wahyuningsih, S.; Effendi, H.; Wardiatno, Y., (2015). Nitrogen removal of aquaculture wastewater in aquaponic recirculation system. AACL Bioflux. 8(4): 491-499 **(9 Pages)**.

Wang, Q.; Jiang, F.; Ouyang, X.-K.; Yang, L.-Y.; Wang, Y., (2021). Adsorption of Pb(II) from aqueous solution by mussel shell-based adsorbent: preparation, characterization, and adsorption performance. Materials. 14(4): 741 **(17 Pages)**.

Wang, Z.; Li, W.; Wang, L.; Zhang, Y.; Li, J.; Liu, Y., (2023). Adsorption of Zn(II), Pb(II), and Cu(II) by residual soil-derived zeolite in single-component and competitive systems. Sustainability. 15(18): 13515 **(16 Pages)**.

Wang, S.; Wang, Z.; Zhang, W.; Li, J.; Lin, M.; Chen, L., (2024). The adsorption effect of aquaculture residual feed on heavy metals and its impact on microbial metabolism of feed. Ecol. Process., 13: 38 **(14 Pages)**.

Waldbusser, G.G.; Steenson, R.A.; Green, M.A., (2011). Oyster shell dissolution rates in estuarine waters: effects of ph and shell legacy. J. Shellfish Res. , 30(): 659-669 **(11 Pages)**.

Weerasooriyagedra, M.S.; Kumar, S.A., (2018). A review of utilization of Mollusca shell for the removal of contaminants in industrial waste water. Int. J. Sci. Res. Pub., 8(1): 282-287 **(6 Pages)**.

Wijeyawardana *et al.*, 2022 Wijeyawardana, P.; Nanayakkara, N.; Gunasekara, C.; Karunarathna, A.; Law, D.; Pramanik, B.K., (2022). Removal of Cu, Pb and Zn from stormwater using an industrially manufactured sawdust and paddy husk derived biochar. Environ. Technol. Innovation. 28: 102640 **(13 Pages)**.

Xu, D.; Cao, J.; Li, Y.; Howard, A.; Yu, K., (2019). Effect of pyrolysis temperature on characteristics of biochars derived from different feedstocks: A case study on ammonium adsorption capacity. Waste Manage., 87: 652–660 **(9 Pages)**.

Xu, X.; Liu, X.; Oh, M.; Park J., (2019). Oyster shell as a low-cost adsorbent for removing heavy metal ions from wastewater. Pol. J. Environ. Stud., 28(4): 2949-2959 **(12 Pages)**.

Yaseen, A.M., (2021). An insight into machine learning models era in simulating soil, water bodies and adsorption heavy metals: Review, challenges and solutions. Chemosphere. 277: 130126 **(22 Pages)**.

Ye *et al.*, 2023 Ye, T.; Li, M.; Lin, Y.; Su, Z., (2023). An effective biological treatment method for marine aquaculture wastewater: Combined treatment of immobilized degradation bacteria modified by chitosan-based aerogel and macroalgae (Caulerpa lentillifera). Aquaculture. 570: 739392 **(11 Pages)**.

Zadinelo, I.V.; dos Santos, L.D.; Cagol, L.; de Muniz, G.I.B.; Ellendersen, L.D.S.N.; Alves, H.J.; Bombardelli, R.A., (2018). Adsorption of aquaculture pollutants using a sustainable biopolymer. Environ. Sci. Pollut. Res., 25: 4361–4370 **(20 Pages)**.

Zhang, R.; He, J.; Wang, M.; Duan, S.; Zhang, J., (2024). Nitrate and nitrite utilization during denitrifying phosphorus removal: Electron acceptor preference and feasible process combinations. Biosour. Technol., 406: 131081 **(10 Pages)**.

Zhou, Y.; Wang, J.; Hu, X., (2021). Adsorption of CO_2 by alkali metals and weak alkali rare earth metals supported on aluminum pillared diatomite. E3S Web of Conferences. 352: 03039 **(9 Pages)**.

Zhou, Z.; Wang, Y.; Sun, S.; Wang, Y.; Xu, L., (2022). Preparation of PVA/waste oyster shell powder composite as an efficient adsorbent of heavy metals from wastewater. Heliyon. 8(12): e11938 **(12 Pages)**.

Zukri, N.I.; Khamidun, M.H.; Sapiren, M.S.; Abdullah, S.; Rahman, M.A.A., (2018). Lake water quality improvement by using waste mussel shell powder as an adsorbent. IOP Conf. Ser.: Earth Environ. Sci., 140: 012057 **(7 Pages)**.

AUTHOR (S) BIOSKETCHES

Takarina, N.D., Ph.D., Professor, Department of Biology, Faculty of Mathematic and Natural Sciences, Universitas Indonesia, Gedung E FMIPA, Kampus UI Depok, Depok 16424, West Java, Indonesia
- Email: *noverita.dian@sci.ui.ac.id*
- ORCID: 0000-0003-1766-7445
- Web of Science ResearcherID: GPX-2701-2022
- Scopus Author ID: 6505460222
- Homepage: https://scholar.ui.ac.id/en/persons/noverita-dian-takarina

Chuan, O.M., Ph.D., Associate Professor, Faculty of Science and Marine Environment, Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu, Malaysia.
- Email: *ong@umt.edu.my*
- ORCID: 0000-0003-0095-6849
- Web of Science ResearcherID: H8919–2018
- Scopus Author ID: 57220668305
- Homepage: https://fssm.umt.edu.my/ongmengchuan/

Adiwibowo, A., M.Sc., Assistant Professor, Occupational Health and Safety Department, Faculty of Public Health, Universitas Indonesia, Depok 16424, West Java, Indonesia.
- Email: *awbio2021@gmail.com*
- ORCID: 0000-0001-7787-5735
- Web of Science ResearcherID: NA
- Scopus Author ID: 57226558692
- Homepage: https://staff.ui.ac.id/andrio.adiwibowo

Adidharma, M.A., M.Sc., Assistant Professor, Department of Marine Science, Institut Teknologi dan Bisnis Muhammadiyah Kolaka, Jl. Pramuka No. 87, Lamokato, Kolaka 93511, Southeast Sulawesi, Indonesia.
- Email: Afdhal.adidharma*@gmail.com*
- ORCID: 0000-0003-0913-6513
- Web of Science ResearcherID: KXR-2918-2024
- Scopus Author ID: 58576981700
- Homepage: https://www.researchgate.net/profile/Mohammad-Afdhal-Adidharma

HOW TO CITE THIS ARTICLE

Takarina, N.D.; Chuan, O.M.; Adiwibowo, A.; Adidharma, M.A., (2025). Modeling the shrimp aquaculture wastewater pollutant removals by clam shell using structural equation model. Global J. Environ. Sci. Manage., 11(1): 1-20.

DOI: 10.22034/gjesm.2025.01.01

URL: https://www.gjesm.net/article_716473.html