Global J. Environ. Sci. Manage. 11(1): 93-112, Winter 2025, Serial #41

Global Journal of Environmental Science and Management
(GJESM)

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

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ORIGINAL RESEARCH PAPER

Removing metals concentration in water and common carp using sheet type adsorbent reared in modified aquarium

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ARTICLE INFO

Article History:
Received 07 August 2024
Revised 11 October 2024
Accepted 13 November 2024

Keywords:
Adsorption
Copper
Cyprinus carpio
Lead
Zeolite

DOI: 10.22034/gjesm.2025.01.06

ABSTRACT

BACKGROUND AND OBJECTIVES: The increasing pollution of aquatic environments due to heavy metals has raised concerns over recent decades. Heavy metal contaminants in the aquaculture water of common carp (Cyprinus carpio) jeopardizes aquatic organisms and poses potential health risks to individuals who consume these fish. Zeolite is known for its potential to adsorb heavy metals in water, thereby reducing their accumulation in fish. The current study explored how a zeolite-embedded sheet influences the concentrations of copper and lead in water and common carp. The goal is to present a comprehensive analysis of the influence of the zeolite-embedded sheet on heavy metal levels in both the aquatic environment and the common carp cultivated in modified glass aquariums.

METHODS: This study involved the fabrication and characterization of zeolite-embedded sheets, aquarium modification, fish acclimatization, preparation and dosing of test solutions, adsorption experiments, and the measurement of heavy metal levels in water and fish samples. A range of metal concentrations was assessed in aquariums equipped with zeolite-embedded sheets compared to those without. The aquarium configuration was optimized to improve the process of metal extraction.

FINDINGS: The fabrication of the sheet adsorbent has been successfully accomplished, showing properties that are in agreement with prior studies. Heavy metal levels in both water and carp were higher in the control group (without zeolite-embedded sheets) than in the treatment group (with zeolite-embedded sheets). Copper removal in water ranged from 49.12 to 55.56 percent, while removal in carp ranged from 8.08 to 52.33 percent. Lead removal was higher, with rates of 50.8 to 91.78 percent in water and 82.03 to 88.07 percent in carp. Key water quality indicators, including temperature, potential of hydrogen, and levels of dissolved oxygen, were maintained within the optimal thresholds necessary for successful fish farming. A two-way analysis of variance showed that while the combination of dose and adsorbent did not significantly impact metal content. In contrast, the adsorbent alone exhibited a notable impact, particularly on lead levels in both water and carp, along with copper levels in water.

CONCLUSION: Sheet-type adsorbents effectively reduced metal levels in water and common carp. Although the metal concentrations utilized in this study were relatively low, the adsorbent showed remarkable sorption performance. Future studies should explore its application with higher metal concentrations and on a larger scale, such as in commercial carp cultivation.

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NUMBER OF REFERENCES
100

NUMBER OF FIGURES
6

NUMBER OF TABLES
5

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

INTRODUCTION

The common carp, or *Cyprinus carpio*, is a commercially viable fish frequently raised in cages within aquaculture systems throughout Indonesia (Samara *et al*., 2024). Common carp accounts for roughly 5.65 percent (%) of the total 76.6 million tonnes produced worldwide from the top ten cultivated species (Adámek *et al*., 2019). It is estimated that nearly 80% of the global production of cultured fish originates from Asia, where the majority of the 1.5 million metric tons (MMT) of common carp aquaculture production currently occurs (Bajaj, 2017). The production of common carp in Indonesia for the year 2020 was recorded at 535,932.92 tons, which constituted 11.77% of the total cultivated fish output, establishing it as the leading commodity during that period (Ningsih *et al.*, 2023). Besides being economically significant (Fahturohman *et al.*, 2022), common carp is recognized for its health benefits due to its high protein and low-fat content (Sobczak *et al.*, 2021). Common carp aquaculture contributes to 47% of the world's fish consumption, making it one of the fastest-growing agricultural sectors (John *et al*., 2020). According to a study by Turcios and Papenbrock (2014), population growth and increased per capita fish consumption are projected to lead to a 60% to 100% increase in common carp aquaculture output over the next 20 to 30 years. The expansion of common carp aquaculture to meet greater production demands will require supplementary inputs, consequently leading to an increase in waste generated by the involved systems. As the popularity of cultured common carp rises, large-scale aquaculture becomes increasingly susceptible to pollution, particularly from heavy metals. In aquatic environments, heavy metals are prevalent hazardous inorganic pollutants. Their non-biodegradable characteristics pose a serious danger to aquatic ecosystems, as elevated concentrations can become toxic to both humans and other living organisms (Kabwadza-Corner *et al.*, 2014). Heavy metals can accumulate in biota through bioaccumulation and biomagnification, which allows them to move through the food chain from polluted environments to organisms and then to higher trophic levels (Adhani and Husaini, 2017). Heavy metal concentrations in aquatic ecosystems are largely a consequence of industrial expansion and other anthropogenic actions. Waste produced from various activities releases different types of heavy metals into water. Copper (Cu) and lead (Pb) are two metals frequently found as pollutants in aquatic environments (Yap and Al-Mutairi, 2022). While Cu is known as an essential element, high concentrations can be toxic to fish and other aquatic organisms (Mebane, 2023). Cu can enter through the digestive tract or gills and causing abnormal locomotor responses to fish (Malhotra *et al.*, 2020). The bioaccumulation of Cu has been observed in the gills, brain, liver, kidneys, and skeletal muscles of fish and other aquatic organisms (Chen *et al*., 2022). In contrast, Pb is a non-essential heavy metal that is produced from industrial waste materials, such as those found in batteries and paint (Mahurpawar, 2015). Pb has neurotoxic effects, prompting several countries to strengthen biosecurity measures to prevent lead exposure in humans, especially children (Hou *et al.*, 2013). The human body can be exposed to Pb through several means, including inhaling it, absorbing it through the skin, and primarily through the ingestion of via contaminated food (Charkiewicz and Backstrand, 2020). Numerous studies have been conducted on the reduction of heavy metals through adsorption using zeolites, including mercury (Hg) adsorption by zeolites and montmorillonite (Abdillah *et al.*, 2019), as well as the removal of metal cations from water using zeolites (Zamzow and Murphy, 1992). A range of approaches can be utilized to eliminateremove copper ions (Cu^{2+}) from aqueous solutions, including precipitation, membrane filtration, biological processes, oxidation, reduction, ion exchange, and adsorption (Kabwadza-Corner *et al.*, 2014). Among the various methods available, adsorption stands out as the most effective technique for the removal of toxic metals from wastewater, primarily due to its operational simplicity and straightforward design (De Gisi *et al*., 2016). Many researchers have investigated affordable adsorbents for removing heavy metals, with zeolites proving to be particularly effective for positively charged pollutants, such as heavy metals (Perić *et al.*, 2004; Mishra and Tiwari, 2006). Apart from water, natural zeolites have been widely used to reduce metals, namely cadmium, in several types of fish including common carp (Ghiasi *et al.*, 2011), Prussian carp (Nicula *et al.*, 2010); Cu in Javanese tilapia (James and Sampath, 2003), and Pb in stinging catfish (Mishra and Jain 2009). According to Gharib *et al*. (2022), the application of diverse

adsorbents, including raw date nuclei (RDN), led to a significant reduction in zinc levels in common carp raised. Sorbent–embedded sheet is an integration between non-woven fabric/sheet and adsorbent. This approach known as zeolite-embedded sheet (ZES) was initially used for small-scale use in reducing Pb levels in drinking water/tap water (Botoman *et al.*, 2018). Furthermore, this approach was successfully used to reduce cesium (Cs) levels (Sadia *et al.*, 2021) and *E. coli* (Johan *et al.*, 2022). Optimization of this approach was carried out by Takarina *et al.* (2024), on Pb, Cu and Zn metals in water using machine learning and random forest. As water is a crucial habitat for fish species, notably common carp, it raises the question of whether the ZES would similarly affect the concentration of metals in these fish. The objective of this research is to examine the influence of the impact of ZES on Cu and Pb concentrations in both water and common carp. To enhance the study, common carp are raised in modified glass aquariums that are engineered to replicate pond-like conditions. The expansive chamber represents the pool, the perforated glass divider is utilized as a ZES attachment, and the small chamber as metal dosage/source. This study was conducted at the Department of Biology, University of Indonesia, in 2023.

MATERIALS AND METHODS

ZES fabrication

ZES served as the primary materials for assessing heavy metal adsorption in aquariums. This composite is made up of synthetic zeolite powder (LTA) and non-woven sheets (NWS). The fabrication process began with the preparation of a non-woven sheet measuring 40 × 30 centimeters (cm), which was numbered on top and weighed. Following this, the sheet was arranged in a tray, coated with LTA, and compressed until the powder thoroughly covered its entire surface. The LTA-coated sheet was subsequently heated in an oven at 160 degrees Celsius (°C) for 8 minutes (min) (Sadia *et al.*, 2021). After the cooling phase, the sheet underwent a gentle patting to ensure the removal of any unbound LTA powder. It was then rinsed by shaking in a 2-liter (L) polypropylene (PP) bottle containing distilled water for 2 minutes to eliminate any remaining unattached LTA powder, and the rinse water was discarded. Distilled water was reintroduced for a subsequent washing process. The second washing phase was executed at a rate of 160 revolutions per minute (rpm) with the aid of a shaker for a period of 1 hour. The third wash was conducted in the same manner as the second (Sadia *et al.*, 2021). The sandwich method involves the steps of pressing, heating, and then washing and rinsing twice . This strategy is implemented to boost the effectiveness of ZES production while enabling the simultaneous production of various sheets (Botoman *et.al.*, 2018). During the process, the material is pressed to ensure that a significant amount of LTA adheres to the sheets. It is then heated to melt the polyethylene (PE), allowing LTA to bond with the sheets. During the rinsing process, any zeolite powder that did not bond with the sheets is washed away. After washing, each sheet was oven-dried at 40 °C. Once the sheets were dry and had reached room temperature, they were weighed. The mass difference recorded before and after the LTA powder was applied was used to determine the quantity of LTA that adhered to the sheet. The resulting filter sheets were then used as ZES for heavy metal adsorption.

Characterization of ZES

Scanning electron microscopy and energy-dispersive x-ray spectroscopy (SEM-EDX) using a JEOL JSM IT 200 were employed to observe the surface morphology and chemical composition of the ZES. The chemical bonds of the ZES were identified using fourier transform infrared (FTIR) spectroscopy with a Thermo Scientific Nicolet iS50.

Preparation of copper and lead solution

The Cu solution for the experiments was prepared using copper(II) sulfate pentahydrate ($CuSO_4 \cdot 5H_2O$) from MERCK. Three different concentrations of stock solutions were formulated, with 1 L of each metal stock solution. After mixing the stock solutions, the planned initial concentration doses for Cu were 0.06, 0.08, and 0.1 milligrams per liter (mg/L). Pb solutions were prepared with lead(II) nitrate ($Pb(NO_3)_2$) at three different concentrations: 0.09, 0.12, and 0.15 mg/L. A stock solution was prepared by dissolving the lead compound to achieve a concentration of 0.1 millimolar (mM) for the desired final concentrations. The dilution procedure was carried out utilizing the Solution Dilution Calculator available on the Sigma Aldrich website. As a correction, the prepared solutions were tested using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES),

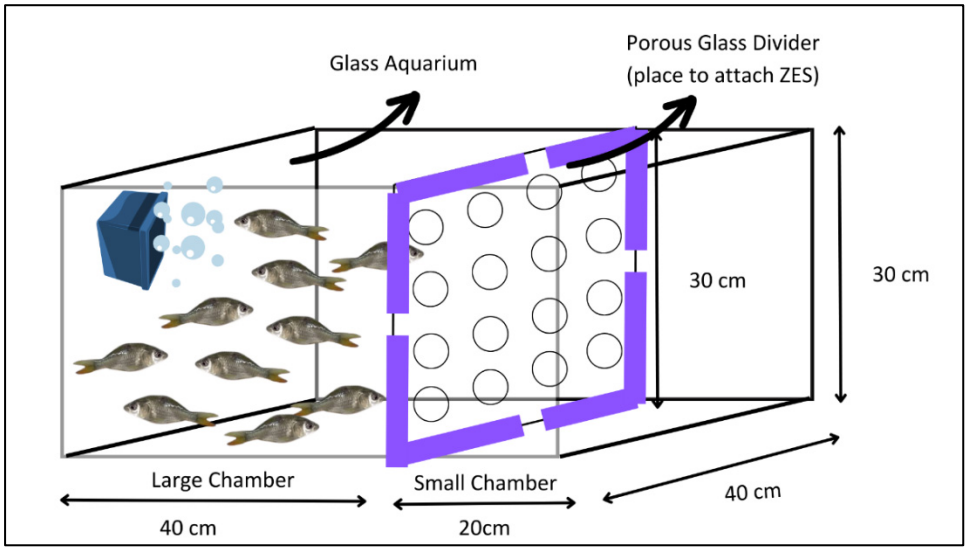

Fig. 1: Aquarium design

yielding results of 0.05, 0.06, and 0.07 mg/L for Cu, and 0.02, 0.03, and 0.04 mg/L for Pb.

Aquarium design

The test aquarium was designed as a block with dimensions of 60 x 40 x 30 cm and was constructed from glass (Fig. 1). It consisted of three sections: a small chamber, a glass partition with holes, and a large chamber. The small chamber, measuring 20 x 40 x 30 cm, was designated for the test solution. The glass partition, 3 millimeters (mm) thick, facilitated the attachment of the ZES. The large chamber, measuring 40 x 40 x 30 cm, was used to house the fish.

Prior to use, the aquarium was meticulously cleaned. The ZES was secured to the glass partition using nano magic double-sided tape. Thirty-nine liters of water were subsequently added to the aquarium. To maintain oxygen circulation during the experimental period, an aerator was installed in the middle of the large chamber. After the ZES was installed and the fish were removed from the acclimatization pond, the test solution was applied.

Fish collection and acclimatization

A total of 420 common carp (var. Majalaya) were obtained from the Center for Freshwater Aquaculture Fisheries (BBPBAT) in Sukabumi. For transportation to the laboratory, the fish were placed in two layers of transparent bags that contained water and oxygen. The common carp selected measured between 3.5 and 6.5 cm in length and weighed approximately 2 to 4.5 grams (g) (Sulawesty *et al.*, 2014). The samples were placed in a tarpaulin-holding pond measuring 300 × 100 × 50 cm, using aerated well water for a one-week acclimatization period (Ergonul *et al.*, 2012). The tarpaulin pool was situated in an open area that was fully exposed to sunlight. Acclimatization conditions included a temperature of 25 °C, a potential hydrogen (pH) of 7 to 8, and dissolved oxygen (DO) levels of 5 to 8 mg/L (Abedi *et al.*, 2012). During this timeframe, the fish were fed pellet food containing 40% crude protein twice daily (Patil *et al.*, 2019). After a week, each test aquarium received ten individual carps, which were then allowed to re-acclimatize for a duration of 24 hours. The day before the transfer to the aquarium and until the conclusion of the research, the fish were not fed. This initiative was designed to mitigate data bias associated with the absorption of organic materials resulting from overfeeding or fish waste (Delahaut *et al.*, 2020; Dhara *et al.*, 2021).

Adsoprtion experiment

During the experimental period, environmental parameters, including pH, DO, and temperature in the aquarium, were measured. As shown in Fig. 2, the experimental groups were distinguished by the

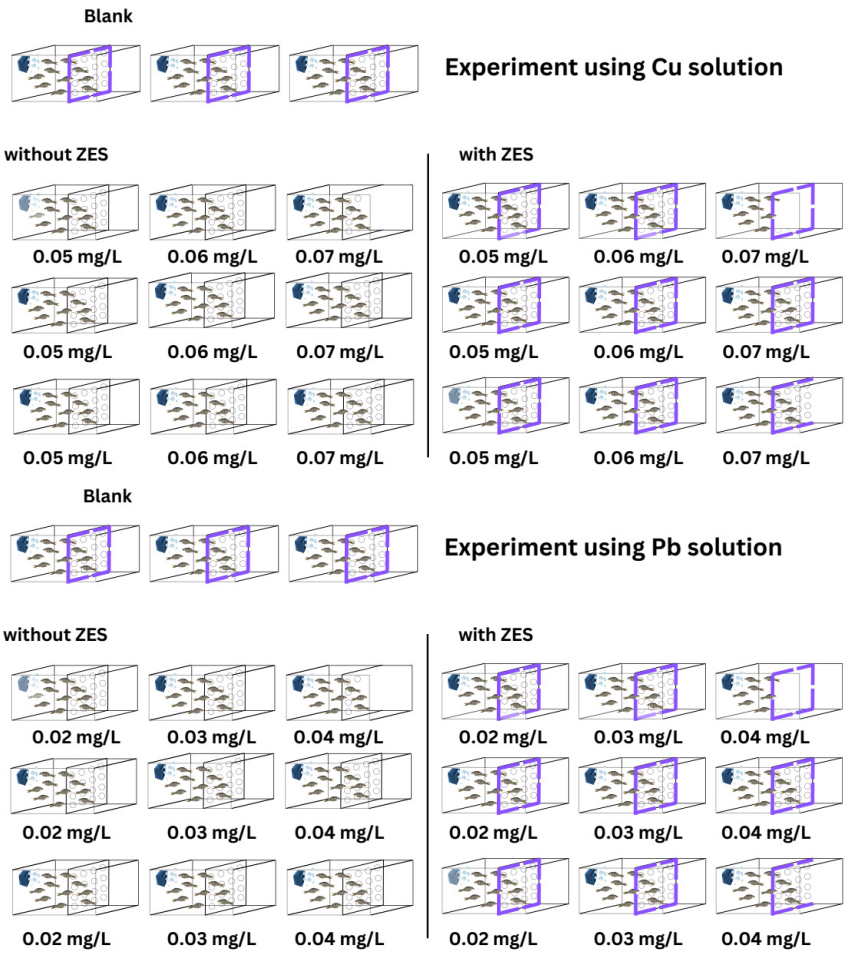

Fig. 2: Experimental design of this study

levels of metal dosage and the positioning of ZES. The experiments were carried out in a controlled environment, where the room temperature was kept at approximately 25–26 °C. The heavy metal adsorption tests were conducted over a span of four days (Farhangi and Jafaryan, 2019). A control blank was subjected to ZES treatment without the addition of metal solutions.

Heavy metal measurements

The assessment of heavy metal levels was carried out in two distinct phases: prior to the experiment and following its completion. Tests were conducted to evaluate the heavy metal concentrations in both the fish and water samples prior to the commencement of the experiment. Ten fish and 200 milliliters (mL) of water samples were sent to PT. Saras-wanti Indo Genetech (SIG) in Bogor for heavy metal testing to establish baseline levels. This initial test was designed to confirm the precise concentrations of heavy metals and to avoid inaccuracies in the data. It also functioned as a correction mechanism should any Pb and Cu levels be found in the outcomes. After the experiment, heavy metal testing was conducted on both the water and fish samples. A 200 mL water sample was taken from the experimental aquarium, and ten fish samples were used for metal analysis. The heavy metal content in the water and fish samples was analyzed using ICP-OES.

Percent of removal

The percentage of removal was calculated, using Eqs. 1 and 2 (Mustapha *et al.*, (2019):

$$R_{ZW} = \frac{(C_{OW} - C_{EW})}{C_{OW}} \times 100\% \quad (1)$$

$$R_{ZC} = \frac{(C_{OC} - C_{EC})}{C_{OC}} \times 100\% \quad (2)$$

R_{ZW} = percentage removal of metal concentration in water

R_{ZC} = percentage removal of metal concentration in fish

C_{ow} = metal concentration in water without ZES,

C_{ew} = metal concentration in water with ZES,

C_{oc} = metal concentration in fish without ZES,

C_{ec} = metal concentration in fish with ZES

Data analysis

The study utilized a two-way analysis of variance (ANOVA) test, supplemented by post hoc Tukey's test, to examine how ZES installation and metal dosage influence water quality and the metal levels present in fish and water. Normality test using Shapiro wilk indicated data was normal. Statistical analysis was performed using GraphPad Prism 10.3.3.

RESULTS AND DISCUSSION

Morphological appearance, vibrational and chemical properties of ZES

The SEM image of ZES (Fig. 3) shows that the LTA particles have successfully adhered to the NWS fibers. A slight shrinkage in the ZES material is evident due to the heating procedure during fabrication. The adsorbent filter used in this research was NWS containing PE and PP. As reported by Sadia *et al.* (2021), the heat treatment applied during the preparation resulted in the embedding of MOR (mordenite) zeolite particles within the outer polyethylene (PE) layer, whereas the polypropylene (PP) layer in the center exhibited stability at the same temperature. In this study LTA zeolite was used, and it is assumed that the same mechanism was occurred. The process of thermal bonding requires the application of heat to melt the polyethylene outer layer of the sheet. This method enhances the attachment of zeolite to the surface, ensuring that the inner layer, composed of polypropylene, remains unaffected. A significant advantage of this method is the elimination of adhesive materials, which ensures that the adsorption capacity for heavy metals and similar contaminants is preserved. Saleem *et al.* (2023) added that annealing the sheet require specific and exact time duration and heat temperature as it affect the strength and porous of material.

The spectrum of ZES, depicted in Fig. 4, shows peaks at 3363.88, 3271.01, 2914.97, 2847.74, and 977.71 reciprocal centimeters (/cm). The peaks at 3363.88 to 3271.01/cm indicate a connection with strong hydroxyl (OH-) groups attached to silica (Si) and aluminum (Al) (Hashemian *et al.*, 2013). The spectral peaks ranging from 2914.97 to 2847.74 cm are associated with the carbon-hydrogen (C-

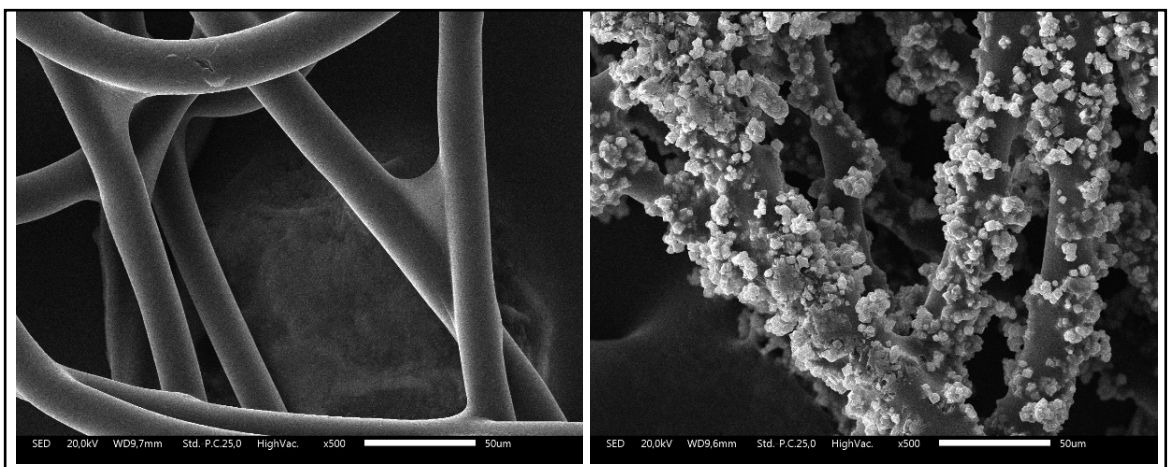

Fig. 3: SEM images of NWS (a) and ZES (b)

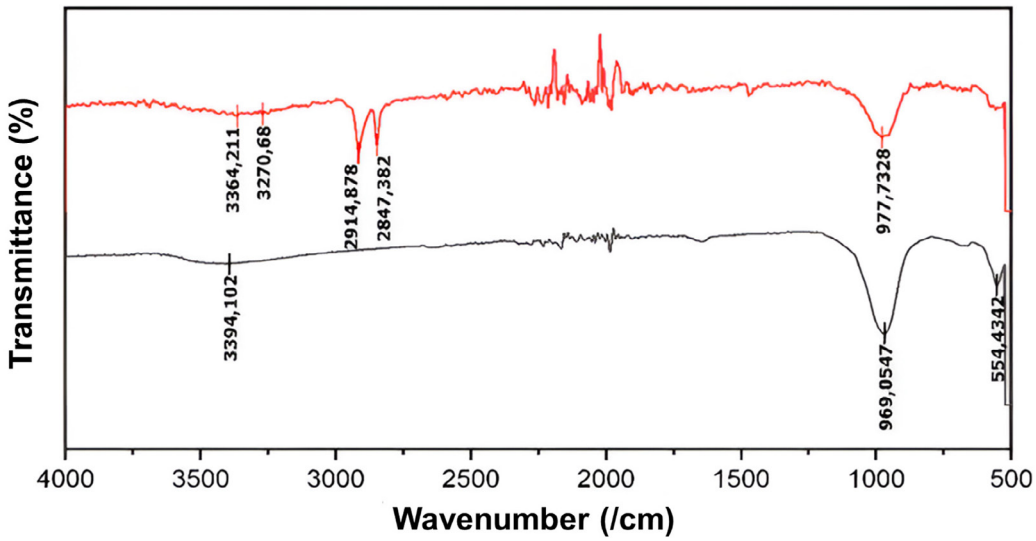

Fig. 4: Spectrum on ZES (red) and powder (black) of zeolite Linde type A

Table 1: Chemical properties of powder, NWS, and ZES

Element	Atomic concentration (%)		
	Powder	NWS	ZES
C	-	92.18	65.84
O	63.52	7.82	27.70
Na	13.22	-	2.42
Al	11.73	-	2.12
Si	11.53	-	1.92

H) stretching of alkane groups found in the NWS content, particularly in PP and PE, both of which are known to exhibit characteristic stretching peaks around the 2900/cm spectrum (Nandiyanto *et al.*, 2019). The peak at 977.71/cm can be attributed to the asymmetric vibrational overlap of the siloxane (O-Si-O) bonds (Kwakye-Awuah *et al*., 2013). The FTIR spectrum results for the ZES sample indicate that the ZES contained LTA which is ~~its~~ suitable as a heavy metal adsorbent in the research process.

As summarized in Table 1, the findings from the EDX analysis reveal differences in theelemental composition between LTA, NWS, and ZES. The LTA powder sample contains the highest elemental content, with oxygen (O) at 63.52%, followed by sodium (Na) at 13.22%, Al at 11.73%, and Si at 11.53%. The NWS sample consists of 92.18% carbon (C) and 7.82% O. The order of elemental content in the ZES sample is as follows: C 65.84%, O 27.70%, Na 2.42%, Al 2.12%, and Si 1.92%. The Si/Al elemental ratio of the LTA content found in the NWS fiber is in accordance with the findings reported in the literature (Tounsi *et al.*, 2009). According to the literature, the chemical formula for LTA is dodekasodium aluminosilicate heptakosahydrate ($Na12[(AlO_2)12(SiO_2)12]\cdot27H_2O$), with a silicon to aluminum ratio (Si/Al) of 1:1 (Collins *et al*., 2020).

Water quality parameters

The results of the water quality measurements taken during the experiment are shown in Fig. 5. In the aquarium that received Cu treatment, the temperature fluctuated from 29.29 to 29.68 °C. The DO concentration ranged from 6.44 to 6.99 mg/L, and the pH at each concentration ranged from 7.63 to 7.69. During the Pb adsorption experiments,

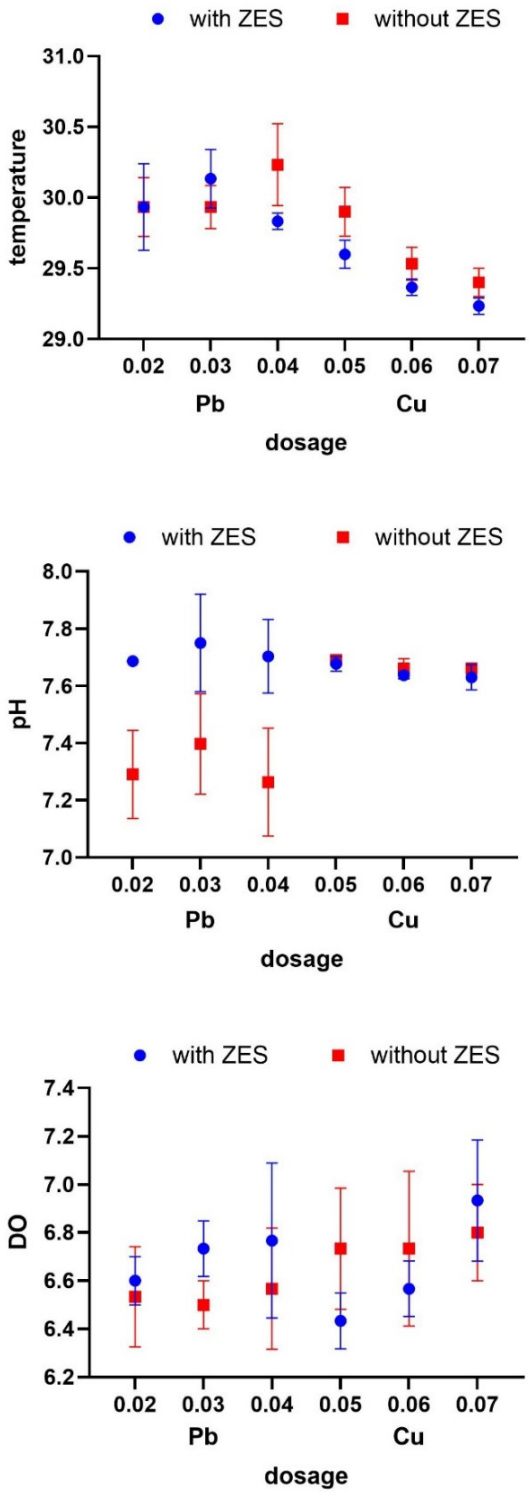

Fig. 5: Water quality during the experiment

the average pH ranged from 7.2 to 7.5, the DO concentration ranged from 6.5 to 6.6 mg/L, and the temperature ranged from 29.8 to 30.2 °C.

The temperatures observed in this study were within the optimal range for freshwater tropical fish, as outlined by Latuconsina (2020), which indicates that the ideal water temperature for fish in tropical environments is approximately 28–32 °C, while common carp thrive best at water temperatures between 23–30 °C (FAO, 2023). The increased temperatures could be a result of heat exposure from sunlight during the measurements taken at 09:00 in the morning (Temprasit *et al.*, 2014). Dayrit *et al.*, (2023) added that in nonshaded pond which exposed to sunlight, the water temperatura considerably increase. Fish, classified as poikilothermic organisms, are largely affected by environmental temperature changes, with temperature increases causing a rise in their metabolic rates (Neubauer and Andersen, 2019). Elevated temperatures and heavy metal pollution significantly impact fish life (Shahjahan *et al.*, 2022). The pH measurement was maintained within the preferred range of 6 to 9, demonstrating that the water quality is suitable for aquaculture purposes. According to Heydarnejad (2012) and Latuconsina, (2020), common carp can thrive at water pH levels of 6.5–9, although the pH tends to decrease at higher concentrations. The DO levels in the water met quality standards (>4 mg/L), according to Government Regulation of Republic of Indonesia (PPRI) No. 22 of 2021. As Boyd (2000) highlighted, the preferred range for DO is between 5 and 7 mg/L, serving as a crucial measure of pollution in aquatic environments. Effendi (2003) highlighted that DO is essential for the metabolic processes of fish. Insufficient levels of DO can harm a fish's respiratory system and elevate toxicity, presenting considerable risks to survival that could ultimately lead to death (Ali *et al.*, 2022). Factors such as sunlight intensity during measurements can influence DO levels. Elevated levels of DO are usually associated with excellent water quality, while diminished DO can negatively affect fish feeding and growth rates (Latuconsina, 2020).

Metal concentration and removal

Preliminary tests for Cu in water and common carp samples, obtained directly from BBPBAT in Sukabumi, indicated that Cu was present in both water (0.01 mg/L) and common carp (0.975 mg/kg). Conversely, there was no detection of Pb in the water or in the common carp samples from the identical location. In the blank treatment, Cu was not present in the water, although it was identified at a concentration of 0.445 mg/kg in common carp. This indirectly indicates that without additional metal dosage, ZES helps in reducing Cu in common carp or other factor. In fish, the liver is integral to Cu homeostasis, functioning as the key reservoir and distribution center for Cu. Cu can be ingested by fish through their food and also taken in via their gills from the ambient water. Gills restrict Cu uptake from water, while the intestine regulates dietary uptake and reabsorption (Wang and Wang, 2016). Similarly, Pb was not detected in either the water or the common carp. Fig. 6 shows the heavy metal concentrations in water and common carp during the experiment. The concentrations of Cu and Pb in water treated with ZES were lower compared to those not treated with ZES, and the same trend was observed for Cu and Pb concentrations in common carp. The heightened presence of Cu and lead in common carp subjected to treatment without ZES is alarming, particularly for the long term. Alvarado *et al.* (2019) reported a slight increase in the levels of Cu and Pb in common carp over a 500-day observation period in both the pool and the lake. Common carp exposed to Cu may experience damage to several organs, particularly the gills, liver, and intestines. Notably, structural modifications can take place in the gills, characterized by the separation of the epithelial layers in the secondary lamellae, hyperplasia, and necrosis (Hassan, 2022). Liver disorders resulting from Cu exposure include alterations in malondialdehyde content and antioxidant enzyme levels, which can damage the liver structure and intestines, reduce antioxidant profiles, and impair lipid metabolism (Zhang *et al.*, 2022). In contrast, Pb exposure causes detrimental effects that lower hemoglobin levels in blood cells (Dezfuly *et al.*, 2020), while also leading to modifications in both behavior and physical characteristics. Additionally, it results in decreased total protein levels, along with increased glucose, lipids, and liver enzyme activity (Habib *et al.*, 2024).

Metals removal in water and common carp are presented in Table 2. The analysis demonstrated that treatment 2 led to the most significant Cu removal in water, with a percentage of 55.56%. This was closely followed by treatment 1 at 54.9% and treatment 3 at

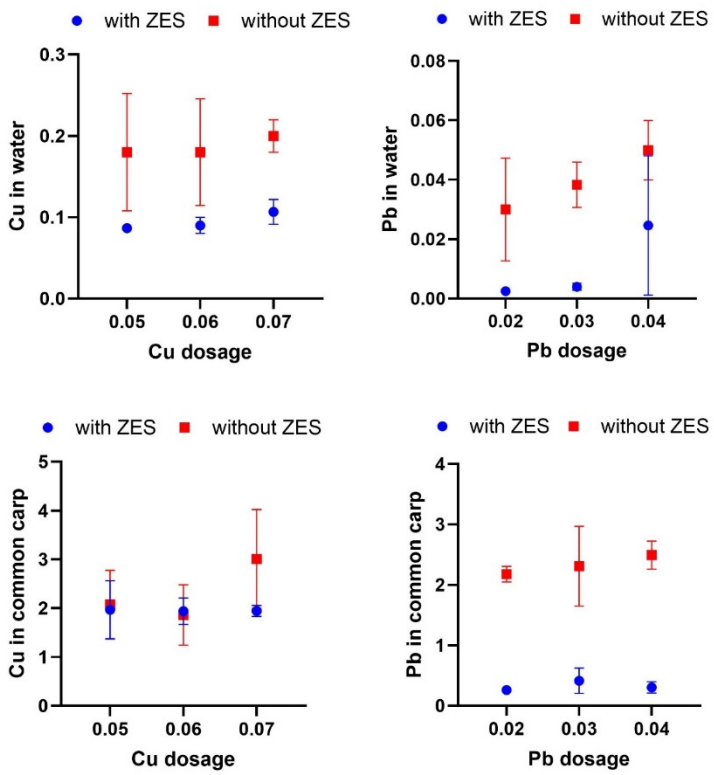

Fig. 6: Cu and Pb concentration in water and common carp in this study

Table 2: Metals removal (%) in water and carp during experiment

metal	dosage	water	Common carp
Cu	0.05	54.9	10.12
	0.06	55.56	8.08
	0.07	49.12	52.33
Pb	0.02	91.78	88.07
	0.03	89.61	82.03
	0.04	50.80	87.77

49.12%. For Pb removal in water, the first treatment achieved a remarkable reduction of 91.78%, followed by the second treatment at 89.61% and the third at 50.80%. In terms of removal efficiency, Cu levels in water were reduced by 49.12% to 55.56%, while Pb removal rates were significantly higher, ranging from 50.80% to 91.78%. The results of this study demonstrate better values compared to the findings of Hamed *et al*. (2022), which reported Cu removal rates between 11.2% and 34.1% and Pb removal rates between 16.4% and 42.1% in water using natural zeolite. According to the findings of Ghan and Deshpande (2014), clinoptilolite, a mineral present in zeolite, effectively removes 97% of lead (Pb) and 86% of Cu from water. Additionally, Shreadah *et al*. (2019) reported that the removal rate of Cu in water ranged from 9.8% to 95% using a composite adsorbent of zeolite and manganese oxide. In the context of Cu removal in common carp, the most substantial decrease was noted in treatment 3, which reached 52.33%. This was followed by treatment 1 with a reduction of 10.12% and treatment 2, which showed

an 8.08% reduction. The Pb removal percentages in common carp for each treatment were all above 80%. Overall, the highest reduction percentage for Pb was obtained from the first treatment at 88.07%, followed by treatment 3 at 87.77% and treatment 2 at 82.03%. Compared to the application of natural zeolite as reported by Hamed *et al*. (2022), these results show a substantial enhancement, with Cu and Pb removal in fish ranging from 28.37% to 48.33% and 24.82% to 55.85%, respectively. Aly *et al*. (2020) applied zeolite in the feed of *Dicentrarchus labrax* and revealed that zeolite significantly reduced heavy metal concentrations of Pb and Cu in pond water and fish tissue. Kalak *et al.* (2021) confirmed this observation, reporting Pb removal rates of 99.76%, while Cu removal was recorded at 99.49% with doses ranging from 3 to 5 gram per liter (g/L), which higher dosage than this study. These results demonstrate that zeolite's effectiveness in controlling heavy metals in water can effectively reduce their accumulation in fish (Sallam *et al*., 2024).

Effect of ZES and metal dosage to water quality, metal concentration and metal removal

Table 3 presents a two-way ANOVA for water quality. The analysis revealed that significance was noted solely in the dosage treatment associated with temperature, suggesting that the quantity of metal introduced influences the water temperature. Additionally, the two-way ANOVA of metal concentration in water and common carp showed that ZES treatment significantly influences the Cu content in water, as well as Pb levels in both water and common carp (Table 4). This implies that the deployment of ZES is instrumental in lowering reducing metal concentrations.

Tukey's test revealed that at a Pb dose of 0.04 mg/L, there was a temperature difference between ZES and no ZES treatment ($P < 0.05$). In treatment with ZES, temperature was significantly different between Pb doses of 0.02 mg/L ($P < 0.05$) and 0.03 mg/L ($P < 0.01$) with Cu doses of 0.05 mg/L and 0.07 mg/L, and Pb 0.04 mg/L with Cu 0.07 mg/L ($P < 0.05$). In

Table 3: Two-way ANOVA summary for water quality

Source of Variation	% of total variation	P value	P value summary	Significant
		Temperature		
Dosage	69.57	<0.0001	****	Yes
ZES	4.266	0.2137	Ns	No
Dosage x ZES	8.470	0.1971	Ns	No
Data summary				
Number of columns (Column Factor)	2			
Number of rows (Row factor)	6			
Number of subjects (Subject)	3			
Number of missing values	0			
		pH		
Dosage	18.25	0.1401	Ns	No
ZES	25.88	0.0721	Ns	No
Dosage x ZES	32.87	0.0680	Ns	No
Data summary				
Number of columns (Column factor)	2			
Number of rows (Row factor)	6			
Number of subjects (Subject)	3			
Number of missing values	0			
		DO		
Dosage	19.91	0.1634	Ns	No
ZES	0.3885	0.6710	Ns	No
Dosage x ZES	19.29	0.3600	Ns	No
Data summary				
Number of columns (Column factor)	2			
Number of rows (Row factor)	6			
Number of subjects (Subject)	3			
Number of missing values	0			

Ns: Means $P \geq 0.05$, or not significant. *: Means $P < 0.05$. **: Means $P < 0.01$.
: Means $P < 0.001$. *: Means $P < 0.0001$.

Table 4. Two-way ANOVA summary or metal concentration

Source of Variation	% of total variation	P value	P value summary	Significant
Cu in water				
Cu dosage	2.451	0,6913	Ns	No
ZES	63.48	0,0317	*	Yes
Cu dosage x ZES	0.01843	0,9972	Ns	No
Data summary				
Number of columns (Column factor)	2			
Number of rows (Row factor)	3			
Number of subjects (Subject)	3			
Number of missing values	0			
Cu in common carp				
Cu dosage	14,74	0,3479	Ns	No
ZES	8.017	0,1100	Ns	No
Cu dosage x ZES	14.97	0,4869	Ns	No
Data summary				
Number of columns (Column factor)	2			
Number of rows (Row factor)	3			
Number of subjects (Subject)	3			
Number of missing values	0			
Pb in water				
Pb dosaje	19.82	0,0619	Ns	No
ZES	51.82	0,0017	**	Yes
Pb dosage x ZES	0.8919	0,7912	Ns	No
Data summary				
Number of columns (Column factor)	2			
Number of rows (Row factor)	3			
Number of subjects (Subject)	3			
Number of missing values	0			
Pb in common carp				
Pb dosage	0.5622	0,4182	Ns	No
ZES	93.25	0,0070	**	Yes
Pb dosage x ZES	0.4129	0,6282	Ns	No
Data summary				
Number of columns (Column factor)	2			
Number of rows (Row factor)	3			
Number of subjects (Subject)	3			
Number of missing values	0			

Ns: Means P ≥ 0.05, or not significant. *: Means P < 0.05. **: Means P < 0.01.
: Means P < 0.001.*: Means P < 0.0001

treatment without ZES, temperature was significantly different at doses of Pb 0.04 mg/L with Cu 0.06 mg/L (P < 0.05) and 0.07 mg/L (P < 0.01). In contrast to the findings of Lazăr *et al*. (2024), this study suggests that higher concentrations of Pb are associated with low pH levels and reduced water temperatures. One possible assumption is that the metal may affect temperature. The outcomes might be shaped by the restricted environmental scope of the study and the low dosage used, potentially influencing temperature. Additionally, while water quality does not appear to be related to metal concentration and removal, another study by Marium *et al.* (2023) indicated that higher temperature can increase the metabolic rate, including metal adsorption (Guinot *et al.*, 2012). The rise in metabolic activity could cause a greater demand for oxygen, which may subsequently lower the oxygen concentrations in the aquatic environment.

Tukey's test on metal concentration showed that installation of ZES affected water Pb levels at doses of 0.05 mg/L (P < 0.05) and 0.06 mg/L (P < 0.05). ZES treatment showed differences in Pb levels in common carp at a dose of 0.02 mg/L (P < 0.01) and a dose of 0.04 mg/L (P < 0.001). According to the study results, ZES has an effect on the concentrations of Pb and Cu, which in turn affects the removal rates. This may be related ro several aspect. It is known that LTA

which attached in ZES, possesses the ability to trap heavy metals such as Pb and Cu due to its porous structure. The size of the adsorbent particles plays a significant role in determining the effectiveness of metal removal. Șenilă *et al.* (2022) reported that adsorbent particles with a size of 0 – 0.05 mm were more efficient in removing metals than particles sized 1 – 3 mm. Adsorbents that possess OH- groups exhibit the ability to transfer ions, indicating a significant adsorption capacity (Akhtar *et al.*, 2024). This study confirms that ZES contains OH- groups. Chen *et al.* (2020) added that adsorbents with these properties perform better with ions such as Pb^{2+} and Cu^{2+}. Complex connections form between metal ions and silicon monoxide ion (SiO^{-}) and alumnium monoxide ion (AlO^{-}) (Takarina *et al.*, 2024). The adsorption mechanism also involves other ions, such as Na^{+}, which are crucial for metal removal (Kobayashi *et al.*, 2020). In the assessment of heavy metals, Pb showed a higher removal rate relative to Cu, despite having a lower initial concentration than Cu. The superior adsorption of Pb compared to Cu can be attributed to the properties of the LTA zeolite adsorbent, which exhibits a greater affinity for Pb, even in the presence of multiple heavy metals in solution (Küçük *et al.*, 2023). The ability to adsorb Pb^{2+} relies on cation exchange mechanisms, which are shaped by the composition of LTA. The negative charge of the zeolite is balanced by cations, one of which is lead ions (Inglezakis *et al.*, 2002). Elwakeel *et al.* (2017, 2018) noted that Cu adsorption is of the endothermic type, while Pb adsorption is exothermic, indicating differing energy dynamics in the adsorption processes for these two metals. In this study, the design of glass aquariums also supports metals adsorption. One can draw a parallel between the design of the aquarium and that of a pond. In this analogy, the expansive chamber symbolizes a pool for common carp, whereas the perforated glass divider operates as the inlet gate, enhanced with ZES (an adsorbent). The small chamber serves as the water source. Although it does not serve as a precise imitation of a natural pond, the aquarium is constructed to effectively employ ZES for the removal of metals before they can enter the pool. As a result, metals will be removed efficiently. Bayani *et al.* (2017) stated that a transparent divider with 90 perforations, each with a diameter of 5 mm, enables water movement from one compartment to another, thereby supporting chemical contact. Kratochwil *et al.* (2023) also noted that perforated baffles facilitate water exchange, which improves mixing between compartments. Combining polymeric materials such as NWS with zeolite LTA is an example of a polymeric adsorbent (Maleki *et al.*, 2021). This procedure allows the material to have a higher adsorption capacity (Maleki *et al.*, 2021) and usage duration (Wei *et al.*, 2021). In Table 5, a comparison is made between the combining techniques utilized by various researchers and those applied in this study.

Zeolite-based composite adsorbents generally show greater effectiveness in removing heavy metal ions compared to raw zeolite due to their enhanced physicochemical stability and adsorption capacity (Abdelwahab and Thabet, 2023). Several critical factors influence the utilization of non-woven materials derived from polypropylene (PP) and zeolite LTA. As synthetic materials, the levels of each have been clearly established (Gorade *et al.*, 2021; Botoman *et al.*, 2018). Non-woven materials have features such as high porosity, antistatic properties, and excellent mechanical strength, making them suitable for use as sorbents (Wei *et al.*, 2021). However, PP nonwoven fabrics are known to be hydrophobic (Wei *et al.*, 2021), which impacts water

Table 5: Comparison approach and adsorbent linked to non-woven material

Method	Adsorbent	Metals	Source
Radiation-induced graft polymerization	Phosphorous non-woven fabric	As (Arsenic)(V)	Hoshina *et al.*, 2012
Graft polymerization and amina immerse	aminated-GMA polypropylene adsorbent	Co (Cobalt)(II), with removal up to 90%	Maleki *et al.*, 2021
Graft polymerization	Chitosan and PP non-woven	Cu(II)	Wei *et al.*, 2021
Alkali treatment and low thermal coating	silica/alkali-treated zeolite coated fabric	Cr (Chromium) up to 86%, Mn (Mangan) up to 67%	Wang *et al.*, 2021
Graft polymerization	L serine PE/PP non-woven fabric	Pb(II) with removal up to 90%	Feng *et al.*, 2024
Thermal bonding	ZES	Cu up to 50% Pb up to 90%	This study

permeability. Incorporating LTA zeolite imparts a hydrophilic character to the nonwoven material, facilitating the water adsorption process (Wang *et al.*, 2021). This modification in structure could improve the performance of zeolite-based sorbents as filtration agents. Uddin *et al.* (2022) noted that utilizing nonwoven PP increases metal adsorption by providing more space and increasing the surface area for attachment. In terms of longevity, adsorbents produced from PP non-woven polymer material can be effectively employed up to five times (Feng *et al.*, 2024). According to the study's findings, ZES could provide advantages for aquaculture. In addition to their function in metal absorption, zeolite components are acknowledged for their role in decreasing ammonia levels in aquatic environments (Adam *et al.*, 2023). Kwakye-Awuah *et al.* (2014) reported that zeolite LTA could remove ammonia at rates of 72.99 milligram per gram (mg/g) and 72.87 mg/g, which are significantly higher than the values for natural zeolite clinoptilolite, which were recorded at 15.16 mg/g and 15.36 mg/g (Ashrafizadeh *et al.*, 2008). This possible function will advance ZES as a filtration solution for organic and inorganic compounds. Furthermore, ZES has achieved a reduction in metal content. Studies that incorporate zeolite-based adsorbents indicate favorable effects on the length, width, survival rate, and physiological aspects (including decreased blood glucose) of Tilapia fish (Hasan *et al.*, 2023). Zain *et al.* (2019) reported that the addition of zeolite to water can increase fish weight by between 0.6 and 6.8 g and fish length by between 0.1 and 1.4 cm. Furthermore, the inclusion of 5 g/L zeolite in aquaculture media can enhance the blood characteristics of common carp (Farhan and Naser, 2024). These results align with those reported by Gharib *et al.* (2022), which demonstrated that the aquarium treated with RDN 6 and 4.5 g improve final biomass, weight gain, daily weight gain of common carp.

Future study and limits

The findings of this study indicate that sheet adsorbents, such as ZES, have potential for diverse applications, especially in the field of aquaculture, targeting the cultivation of common carp. However, several limitations must be considered. The study made use of well water for laboratory purposes, ensuring that its levels were regularly monitored and assessed. In freshwater aquaculture, water can be derived from multiple sources (Mulokozi *et al.*, 2021), including wells, irrigation systems, lakes, and other environments that may harbor different metals and compounds. The duration of this study was limited to 4 days, whereas aquaculture typically requires a longer period (Araujo *et al.*, 2022), encompassing nursery, rearing, and harvesting stages. Another limitation is that the fish used in this study were of fingerling size. The size of fish is a crucial factor in aquaculture, influencing production outcomes and market pricing (Šmejkal *et al.*, 2021), which generally involves sizes larger than fingerlings. Another limitation of the study is that it analyzes heavy metals in the whole body of the fish. Several studies on heavy metal monitoring in fish (Alvaro *et al.*, 2019; Hasan *et al.*, 2023) have emphasized the importance of measuring metals in various parts, including the gills, liver, and muscle. Serving as a respiratory pathway, the gills can potentially allow soluble heavy metals to bind to this organ (Olsson *et al.*, 1998). In addition, the muscle is a consumable portion that humans eat, rendering it particularly important in relation to health risks (Kabede and Geleta, 2023). Scaling up the application of this adsorbent in aquaculture can be achieved by considering several aspects. The efficiency of zeolite in metal absorption is noteworthy, facilitating the maintenance of fish health with reduced metal exposure and consequently reducing the risk of metal toxicity (Ghasemi *et al.*, 2018). The presence of ZES minimizes the need for water replacement due to its filtration properties, which contributes to water conservation (Uddin *et al.*, 2022). However, the zeolite used in this study was commercially processed and probably incurs a high cost, raising concerns regarding increased production expenses. Therefore, it is essential to further investigate cheaper zeolite alternatives. In addition, it is crucial to manage this sheet-type adsorbent effectively during its operational phase and after it has been utilized.

CONCLUSION

This study signifies an important development through the creation of a tailored sheet adsorbent that is specifically formulated to effectively eliminate heavy metals from both water and common carp in aquarium settings. This innovative adsorbent is produced through a meticulous heating and filtering process that facilitates the binding of zeolite to the sheet material. Characterization analyses have

validated the reliability of this method. SEM-EDX provided detailed insights, revealing that zeolite LTA is successfully integrated into NWS. The elemental analysis reveals the presence of C, O, Na, Si, and Al, emphasizing the complexity inherent in the materials examined. Additionally, FTIR analysis yielded spectra confirming the presence of functional group, which play a crucial role supporting the adsorptive properties of the sheet adsorbent. Testing of ZES demonstrated its significant effectiveness in reducing levels of Cu and Pb in both water and common carp. Aquariums utilizing ZES demonstrated consistently reduced concentrations of Cu and Pb when compared to aquariums that did not adopt this system. Specifically, the removal efficiency for Pb in the water samples and common carp exceeded an impressive threshold of 80%, indicating a robust capacity for metal extraction. In contrast, the removal rates for Cu varied, showing a range between 49% and 55%, still reflecting a substantial reduction in metal concentration. This study's findings distinctly indicate that ZES significantly contributes to the reduction of metal contamination in both water environments and the living organisms present in those habitats. Furthermore, it is important to note that the installation and use of ZES did not produce any negative effects on critical water quality parameters. Measurements of DO, pH levels, and temperature remained stable, illustrating that ZES does not compromise the ecological balance of the water. Overall, the data from the experiments demonstrated that the water quality parameters were consistently within acceptable ranges, both in setups that included ZES and those that did not. These findings correspond with established water quality criteria for the cultivation of freshwater fish, demonstrating that ZES is not only efficient in metal extraction but also poses no risk to aquatic life. This combination of advanced techniques ensures a thorough understanding of the adsorbent's characteristics and its capabilities in purifying water and supporting the health of aquarium inhabitants. These findings indicate that ZES holds promise for application in aquaculture activities. The findings of the study provide a foundation for the creation of eco-friendly adsorbents aimed at managing heavy metal contamination. Furthermore, effective use of these adsorbents requires not only advancements in the absorption of non-metallic organic and inorganic materials but also strong collaboration and easy accessibility.

AUTHOR CONTRIBUTIONS

N.D. Takarina funding, drafting manuscript, sample collection; N. Matsue drafting manuscript, data verification; E. Johan interpretation and ZES fabrication, A. Adiwibowo drafting manuscript, data analysis.

ACKNOWLEDGEMENT

The authors thank the Research and Innovation Bureau of Universitas Indonesia (RISBANG UI) for its funding through the Research Grants scheme PUTI Q2, with contact number [NKB-758/UN2.RST/HKP.05.00/2023]. The authors would like to thank BPPAT for assisting in providing fish. The authors also extend their gratitude to Mr. Titis Busono for helping prepare the acclimatization pool, and to Mr. Purwanto and the team who assisted in preparing the aquarium and table mats.

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.

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ABBREVIATIONS

%	Percent
^oC	Degree Celsius
Al	Aluminium
AlO^-	Alumnium monoxide ion
ANOVA	Analysis of variance
As	Arsenic
BBPBAT	Balai Besar Perikanan Budidaya Air Tawar in Indonesia
	Center for Freshwater Aquaculture in English
C	Carbon
C_{carp}	Metal concentration in carps
C-H	Carbon-hydrogen
C_{EC}	Final concentration in carps
C_{EW}	Final concentration in water
cm	Centimeter
/cm	Reciprocal centimeter
C_{OC}	Metal concentration in fish without ZES
C_{OW}	Metal concentration in water without ZES
C_{EW}	Metal concentration in water with ZES
C_{EC}	Metal concentration in fish with ZES
Co	Cobalt
Cr	Chromium
Cu	Copper
Cu^{2+}	Copper ion
$CuSO_4{\cdot}5H_2O$	Copper sulfate pentahydrate
DO	Dissolved oxygen
FAO	Food and Agriculture Organization
FTIR	Fourier-transform infrared spectroscopy
g	Gram
g/L	gram per liter
h	Hour
Hg	Mercury
ICP-OES	Inductively coupled plasma - optical emission spectrometry
L	Liter
LTA	Linde Type A
min	Minute
mg/g	Milligram per gram
mg/kg	Milligram per kilogram
mg/L	Milligram per liter
mL	Milliliter
mM	Millimolar
mm	millimeter
MMT	Million metric tons
Mn	Manganese
MOR	Mordenite
Na	Sodium
$Na12[(AlO_2)$ $12(SiO_2)12]{\cdot}27H_2O$	Dodekasodium aluminosilicate heptakosahydrate
Ns	Not siginificant
NWS	Non woven sheet
O	Oxygen
OH-	Hydroxyl
O-Si-O	Siloxane
Pb	Lead
Pb^{2+}	Lead ion
$Pb(NO_3)_2$	Lead II nitrate
PE	Polyetilene
pH	Potential hydrogen
PP	Polipropylene
PPRI	Peraturan Pemerintah Republik Indonesia, in Indonesia
	Government Regulation of Republic of Indonesia, in English
RDN	Raw date nuclei
rpm	Rotation per minute

R_{ZW}	Percent removal of metal concentration in water
R_{ZC}	Percent removal of metal concentration in fish
SEM-EDX	Scanning electro micrograph -
Si	Silicon
Si/Al	Siicon per aluminum
SiO^-	Silicon monoxide ion
ZES	Zeolite embedded sheet

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HOW TO CITE THIS ARTICLE

Takarina, N.D.; Matsue, N.; Johan, E.; Adiwibowo, A., (2025). Removing metals concentration in water and common carp using sheet type adsorbent reared in modified aquarium. Global J. Environ. Sci. Manage., 11(1): 93-112.

DOI: 10.22034/gjesm.2025.01.06

URL: https://www.gjesm.net/article_718114.html