Environmental Science and Pollution Research (2022) 29:47233–47241
https://doi.org/10.1007/s11356-022-19265-0

RESEARCH ARTICLE

# Comparative evaluation of natural water conditioners for their potential use in freshwater aquaculture

**Dilek Şahin**[1]

Received: 14 September 2021 / Accepted: 13 February 2022 / Published online: 18 February 2022



## Abstract

In this study, the use of natural adsorbents, such as zeolite (clinoptilolite), leonardite, and duckweed (*Lemna minor*, L. 1753) was investigated for the regulation of optimum water qualities in freshwater aquaculture. The study was carried out in 3 experiments in triplicate. In the first experiment, aquarium fish feed (35% protein) was used as the ammonia source at 3 different rates (0.2, 0.4, and 0.6 g feed per 500 mL of tap water). In the second experiment, clinoptilolite (C) and leonardite (L) mixture (C:L = 1:2) were added to balance excessive ammonia. In the third experiment, duckweed (1.5 g/500 mL) was added to aquaria (10 cm in diameter) in a way to cover the surface area, and the ammonium adsorption of duckweed at low $NH_4^+$-N concentrations was determined with 9 measurements. In this study, $NH_3$ values reached their peaks (0.19 mg/L) at the end of 1st experiment, in which ammonia values originating from the unconsumed feed were determined. In the 2nd experiment, $NH_3$ values began to decline (0.06 mg/L) with the addition of natural adsorbents (zeolite + leonardite) and were decreased to 0.003 mg/L with the addition of duckweed in experiment III, where natural adsorbents started to reach saturation. When the data obtained at the end of this study were evaluated, it was determined that all 3 natural materials had a positive effect on water parameters in aquaculture systems. As a result, it was determined that in high concentrations of zeolite + leonardite mixture and in low concentration of duckweed there had been a good removal efficiency.


**Keywords** Clinoptilolite · Leonardite · *Lemna minor* · Ammonium · Aquaculture

## Introduction

Water quality is a critical factor when culturing any aquatic organism. Optimal water quality varies by species and must be monitored to ensure growth and survival. Water quality parameters that are commonly monitored in the aquaculture industry include temperature, dissolved oxygen, pH, ammonium as 18–28 °C, 5–8 mg/L, 6.5–8.5 and 1–5 mg/L, respectively (Jorgensen 2002; Iskander et al. 2014; Ismadji et al. 2016). Removal of excessive quantities of nitrogenous compounds in aquaculture systems is an obligatory process. There are physical, chemical, and biological treatments employed to achieve this. For this purpose, adsorbent substances, such as bentonite, diatomite, zeolite, etc., as well as aquatic plants, such as water lettuce and duckweed are used. While natural adsorbents, such as zeolite are effective at high ammonium concentrations (Ergün et al. 2008; Öz et al. 2016, 2017; Tekeşoğlu and Ergün 2020), plants such as water lettuce and duckweed are effective in the removal of low ammonium concentrations of ammonia (Şahin et al. 2009).

Zeolites are hydrated alumina silicates of alkali and alkaline earth metals with a crystal structure and are in the framework silicates group. Natural zeolites are inexpensive materials that can be found widely in nature and have high cation exchange capability, molecular sieve properties, and special design for adsorption and catalysis (Mazeikiene et al. 2008).

Leonardite is the highly oxidized form of lignite during coalification and contains humic acid ranging from 35 to 85%. Leonardite is also defined as a complete organic matter that has not reached the phase of coal and contains carbon, macro- and micronutrients apart from high levels of humic acids. It has important economic value due to its high humic acid content. It is black-brown in color with the appearance of consolidated soil and is soft enough to

Responsible Editor: Xianliang Yi

✉ Dilek Şahin
dsahin@sinop.edu.tr

[1] Sinop University Vocational School, 57000 Sinop, Turkey

be crumbled easily by hand. The pH value of leonardite varies between 3 and 5, and its solubility in water is low (Ratanaprommanee et al. 2016). Due to the plant nutrients, low toxic element, and high humic acid contents of leonardite, most previous works investigated its use as a fertilizer, effect on plant yield, fertilizer value, organic matter content, and humic substance content. As a result of its use in conventional and organic agriculture, beneficial results have been obtained in terms of improving soil and roots, and supplementation of nutritional elements to plants (Engin and Cöcen 2012).

The use of aquatic macrophytes, such as water hyacinth, duckweed, water lettuce, etc., in wastewater treatment has attracted global attention in recent years. These plants can be applied on the surface of stabilization ponds, and may contribute to nutrient recovery from wastewater (Caicedo et al. 2000). Duckweed has the great capacity in absorbing the nutrients and their high nutrient removal efficiency can be used to clean wastewater in an effective, cheap, and simple way (Gürtekin and Güneşdağ 2008).

Duckweeds are small, vascular floating macrophytes that grow rapidly and reproduce vegetatively. The ease of their culture and convenience of manipulation under aseptic laboratory conditions make them suitable experimental species for toxicity trials. The use of aquatic plants as in situ bio-monitors for water quality assessment has been a common practice for many years. Aquatic plants have also been frequently used to remove suspended solids, nutrients, heavy metals, toxic organic substances, and bacteria from acid mine drainage as well as waters in urban rain runoff, landfill, and agricultural activities (Caicedo et al. 2000). On the contrary, they have not been widely used as the test species in toxicity trials designed to assess the hazard of potential contaminants (Caicedo et al. 2000; Lewis 1995). Ammonia is known to be toxic to all higher life forms, but when absorbed at a slow rate, it is well tolerated by most organisms due to their efficient detoxifying mechanisms (Goopy et al. 2004). Decreasing the proportion of free ammonia in the solution may improve the survival of plants grown on eutrophic media. High concentrations of $NH_4^+$-N inhibit the growth of duckweed, negatively affecting the biomass accumulation and the wastewater purification by duckweeds (Caicedo et al. 2000; Wang et al. 2014). Among all the species in the Lemnaceae family, *Lemna minor* is the most commonly used for toxicity testing (Selvarani et al. 2015).

This study aims to investigate the comparative efficacy of the natural adsorbents such as zeolite (clinoptilolite), leonardite, and duckweed (*Lemna minor*, L. 1753) for the maintenance of optimum water conditions (ammonium) in freshwater aquaculture.

## Materials and methods

### Experimental design

The study was carried out in 3 separate experiments in triplicate. In the first experiment, aquarium fish feed (35% protein) was used as the ammonia source at 3 different rates (0.2, 0.4, and 0.6 g feed per 500 mL of tap water) according to Kibria et al. (1997). The amount of ammonia resulting from the unconsumed feed in the aquaria was determined at the end of the first experiment which lasted for 7 days. In the second experiment, clinoptilolite (C) and leonardite (L) mixture (C:L = 1:2) was added to balance excessive ammonia. The characteristics of clinoptilolite and leonardite used in the study are provided in Table 1. These substances were analyzed by SEM/XRF/BFT (Fig. 1) at Kastamonu University Central Research Laboratory. The pH values were computed as per the method described by Güneş (2017) and Tokat (2019).

In the second experiment, certain water parameters were assessed by making 6 separate measurements at regular intervals after the addition of clinoptilolite and leonardite (C:L = 1:2). The third experiment was conducted after completion of the second experiment when the saturation amount was recorded in natural adsorbents. In this experiment, duckweed (1.5 g/500 mL) was added to aquaria (10 cm in diameter) in a way to cover the surface area, and the ammonium

**Table 1** Chemical composition of tested water conditioners clinoptilolite and leonardite

| | | | |
|---|---|---|---|
| Clinoptilolite[a] | % | | |
| $SiO_2$ | 78.41 | $SiO_2/Al_2O_3$ | 5.67 |
| $Al_2O_3$ | 13.83 | BET surface area | 34.316 $m^2/g$ |
| MgO | 1.646 | pH | 8.31 |
| $K_2O$ | 2.372 | | |
| CaO | 3.885 | | |
| $Na_2O$ | 1.042 | | |
| $Fe_2O_3$ | 1.414 | | |
| $P_2O_5$ | 0.058 | | |
| Leonardite[b] | % | | |
| $SiO_2$ | 13.68 | $SiO_2/Al_2O_3$ | 1.93 |
| $Al_2O_3$ | 7.07 | BET surface area | 12.253 $m^2/g$ |
| MgO | 0.11 | pH | 3.23 |
| $K_2O$ | 0.454 | | |
| CaO | 0.323 | | |
| $Na_2O$ | $<0.014$ | | |
| $Fe_2O_3$ | 1.238 | | |
| $P_2O_5$ | 0.055 | | |

[a,b] Clinoptilolite and leonardite samples were provided by Rota Mining Corporation (Manisa, Turkey) and Kütahya Chemistry (Kütahya, Turkey), respectively

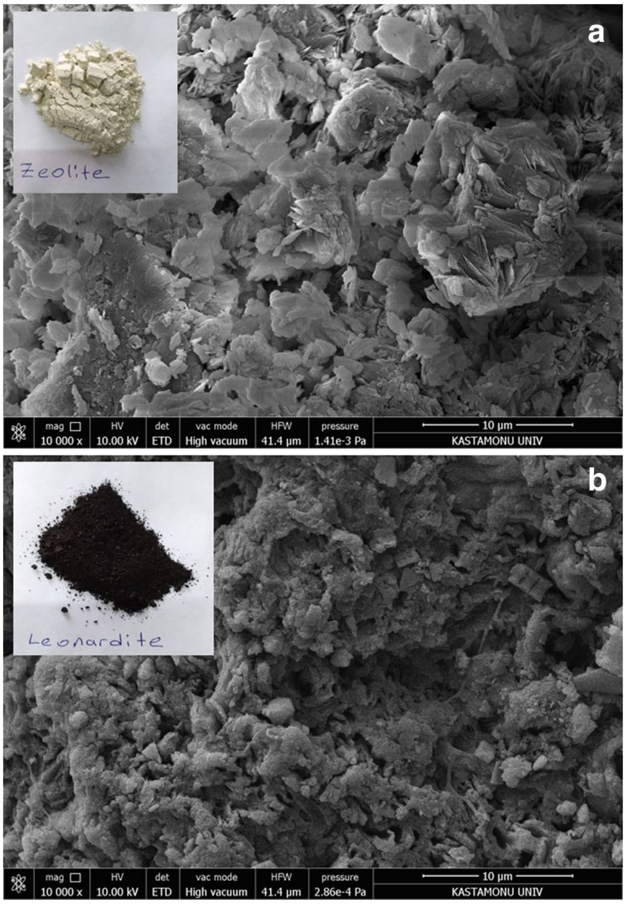



**Fig. 1** SEM analysis of clinoptilolite (**a**) and leonardite (**b**)

adsorption of duckweed at low $NH_4^+$-N concentrations was determined with 9 measurements. Duckweed was visualized with NİKON SMZ 745 T microscope (Fig. 2).

In addition, the adaptation of duckweed to the environment was evaluated. In the experiment, aquaria (containing 500-mL water) were used and no ventilation or heating mechanism was employed. The photoperiod was maintained as 12 h light and 12 h dark.

Water parameters (temperature, dissolved oxygen, pH, and $NH_4^+$) were measured with YSI Professional Plus Series instrument. In each replication, a total of 3 g natural water-regulating materials (1 g of clinoptilolite and 2 g of leonardite) was used per 500 mL of water.

The duckweed used in the experiment was collected from a natural water body with a scoop net and washed thoroughly and gently using tap water to remove plant and insect remains. Before starting the experiment, the duckweed was acclimatized for a week by keeping in an environment with conditions (T: 17.2 °C, DO: 0.43 mg/L, pH: 7.75, $NH_4^+$: 0.3 ± 0.01 mg/L) close to its natural requirements. All experimental plans of the study are demonstrated in Fig. 3.

## Data evaluation

The levels of $NH_3$ and TAN were calculated using $NH_4^+$, water temperature, and pH data (EPA 1999; Emerson et al. 1975; Chow et al. 1997). The ammonium concentration was calculated as given below:

The dissociation constant of ammonium ion (Ka) was expressed as:

$$Ka = \left[\mathrm{NH_3}\right]\left[H^+\right]\left[\mathrm{NH_4}^+\right] \tag{1}$$

Equation (1) can be further arranged as

$$\left[\mathrm{NH_3}\right]\left[\mathrm{NH_4}^+\right] = \left[H^+\right] \tag{2}$$

Thus, the relationship between ammonia and ammonium concentrations is described by:

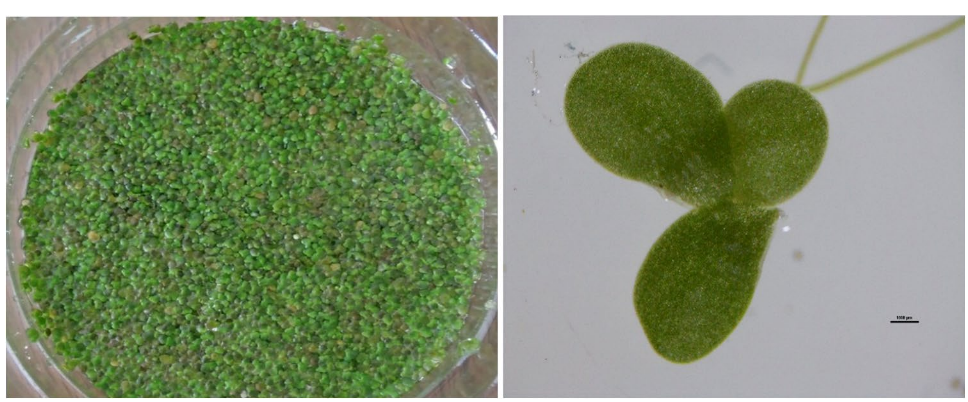
$$log10\left[\mathrm{NH_3}\right]\left[\mathrm{NH_4}^+\right] = pH - pKa \tag{3}$$

pKa varies according to solution temperature. This temperature dependence is given by Emerson et al. (1975) as follows:

$$pKa = 0.09018 + 2729.92(273.2 + T) \tag{4}$$

where, $T$ is the solution temperature in °C. Also:

**Fig. 2** *Lemna minor* (duckweed) used for the study



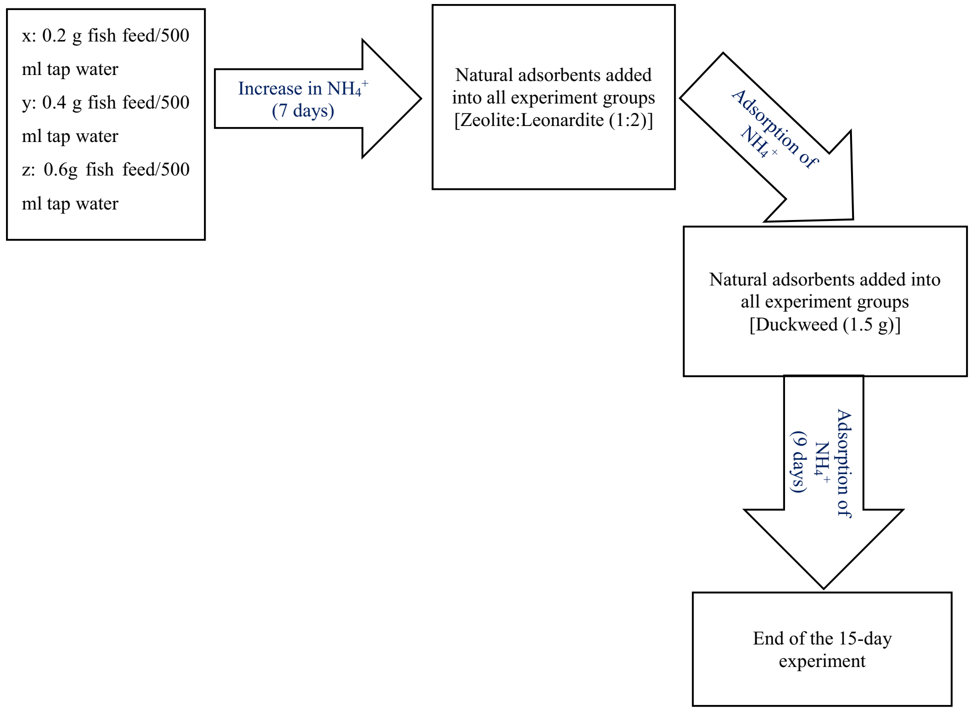



**Fig. 3** Experimental design

$$[NH_4^+] = [NH_3]T - [NH_3] \tag{5}$$

$[NH_3]T$ is the total concentration of ammonia forms. Rearrangement of this equation yields:

$$log10[NH_3][NH_3]T - [NH_3] = pH - [0.09018 + 2729.92(273.2 + T)] \tag{6}$$

The removal efficiency (%) for the three trial groups was calculated using the following equation (Yunnen et al. 2016; Tang et al. 2020):

$$\text{Removal efficiency}(\%) = \frac{C_{0-C_t}}{C_0} * 100 \tag{7}$$

where, $C_0$ is the initial ammonium concentration (mg/l) and $C_t$ is $NH_4^+$ concentrations after time t (mg/L), and t is time of process (mg/L).

## Statistical analyses

The statistical analyses were conducted using Minitab Release software (version 17) for Windows. All data were expressed as mean ± standard error (SE). Data belonging to different experimental groups for each sampling period were compared by one-way analysis of variance (ANOVA) followed by Tukey's HSD post-hoc test for multiple comparisons with the level of significance at $P < 0.05$.

# Results

## Results of experiment I

At the beginning of the study, water temperature, dissolved oxygen, pH, and ammonium values were determined as 19.3 ± 0.03 °C, 0.45 ± 0.01 mg/L, 8.62 ± 0.01, 0.1 ± 0.01 mg/L, respectively, and the difference between groups was statistically insignificant ($p > 0.05$). In the experiment, the control blank created at the beginning was used as the control group. Water temperature, dissolved oxygen, pH, and ammonium values were determined as 20.1 ± 0.02 °C, 0.49 ± 0.01 mg/ L, 8.51 ± 0.01, 0.1 ± 0.01 mg/L, respectively in the control blank.

Three different concentrations [x (0.2 g), y (0.4 g), and z (0.6 g)] of aquarium fish feed, containing 35% protein, were added into water. At the end of the 1st experiment, the mean water temperature was determined as 20.57, 20.97, and 20.46 °C, pH was determined as 7.51, 7.47, and 7.48, and dissolved oxygen was determined as 0.32, 0.31, and 0.28 mg/L for the groups of x, y, and z, respectively ($P > 0.05$). Furthermore, the increase in $NH_4^+$ level caused by three different concentrations of the feed is shown in Fig. 4.

## Results of experiment II

The water parameter values obtained in the 2nd experiment as a result of six measurements taken at regular intervals

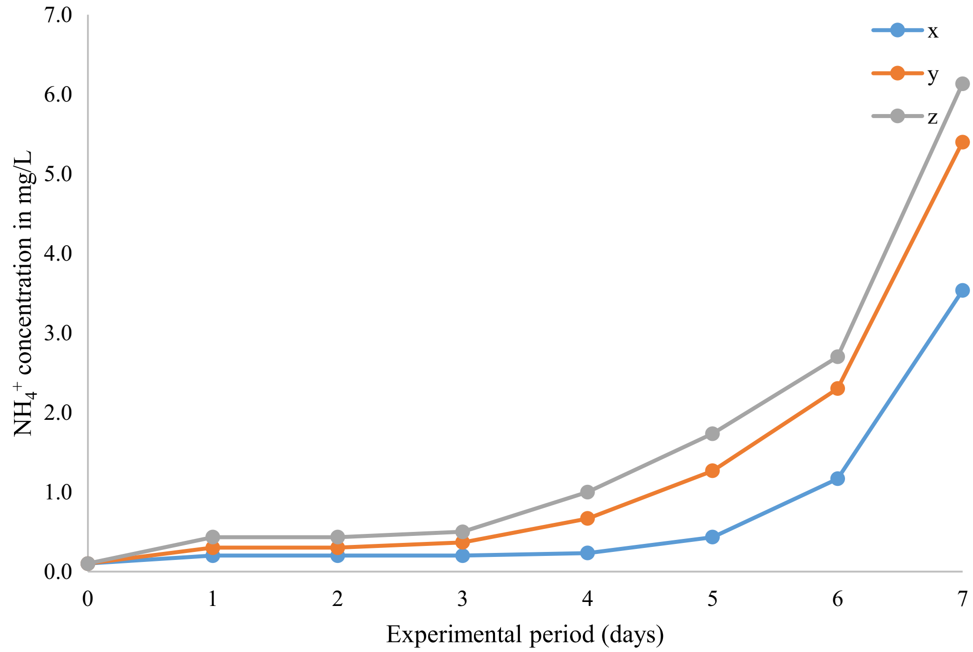



**Fig. 4** Temporal changes in Ammonium ion ($NH4^+$) concentration (mg/L) during experiment I

are presented in Table 2. At the end of the 2nd experiment, it was observed that $NH_4^+$, TAN, dissolved oxygen, and pH values differed between groups ($P < 0.05$) but no statistical significance was determined in case of temperature ($P > 0.05$). It was observed that TAN removal efficiency (Fig. 5) was significantly different in group z ($P < 0.05$).

The experiment demonstrated that natural zeolite and leonardite positively influenced the water quality parameters by reducing the increased TAN and $NH_3$ levels. The removal efficiency of the adsorbents increased as the feed and the amount of TAN originated from feed increased.

## Results of experiment III

At the end of the 2nd experiment, 1.5 g of duckweed per 500 mL was added onto the water in a way to cover the surface of water. In the 3rd phase, the effects of duckweed on ammonia removal and other water parameters were determined. The data obtained are presented in Table 3. The TAN removal efficiency (Fig. 6) was significantly higher in group z ($P < 0.05$) than in the other groups.

Fishes produce nitrogenous wastes as a consequence of the catabolism of amino acids. The assimilation of nitrogen is important for both fish health and profitability of the production (Oluwaseyi 2016). Ammonia exists in water in two different forms, (i) unionized ammonia ($NH_3$) and (ii) ionized ammonium ($NH_4^+$). It is well known that ammonia ($NH_3$) is highly toxic to fish (Prema Latha and Lipton 2007). For many fish species, it has been reported that the toxicity of unionized ammonia begins at 0.05 mg/L, and it causes death at 2 mg/L (Floyd et al. 2015). In the present study, $NH_3$ values reached their peaks at the end of the 1st experiment, in which the ammonia values originating from the unconsumed feed were determined. In the 2nd experiment, $NH_3$ values began to decline with the addition of natural adsorbents (zeolite + leonardite) and were decreased to 0.003 mg/L (Fig. 7) with the addition of duckweed in experiment III, where natural adsorbents started to reach saturation.

**Table 2** Values of selected water quality parameters (Temperature, TAN, $NH_4^+$, pH, and DO (dissolved $O_2$)) in treatment groups of experiment II (mean ± SE)

| Experimental groups* | Water parameters | | | | |
|---|---|---|---|---|---|
| | Temperature (°C) | TAN (mg/L) | $NH_4^+$ (mg/L) | pH | DO (mg/L) |
| x | 19.71 ± 0.22 | 2.61 ± 0.12$^a$ | 2.58 ± 0.12$^a$ | 7.51 ± 0.03$^a$ | 0.35 ± 0.01$^a$ |
| y | 19.86 ± 0.22 | 3.84 ± 0.11$^a$ | 3.81 ± 0.10$^a$ | 7.44 ± 0.03$^{ab}$ | 0.29 ± 0.01$^b$ |
| z | 20.22 ± 0.22 | 4.46 ± 0.41$^b$ | 4.42 ± 0.41$^b$ | 7.39 ± 0.02$^b$ | 0.26 ± 0.02$^b$ |

*x: 0.2 g fish feed, y: 0.4 g fish feed, z: 0.6 g fish feed. Different superscript letters in a column indicate significant differences between groups ($P < 0.05$)

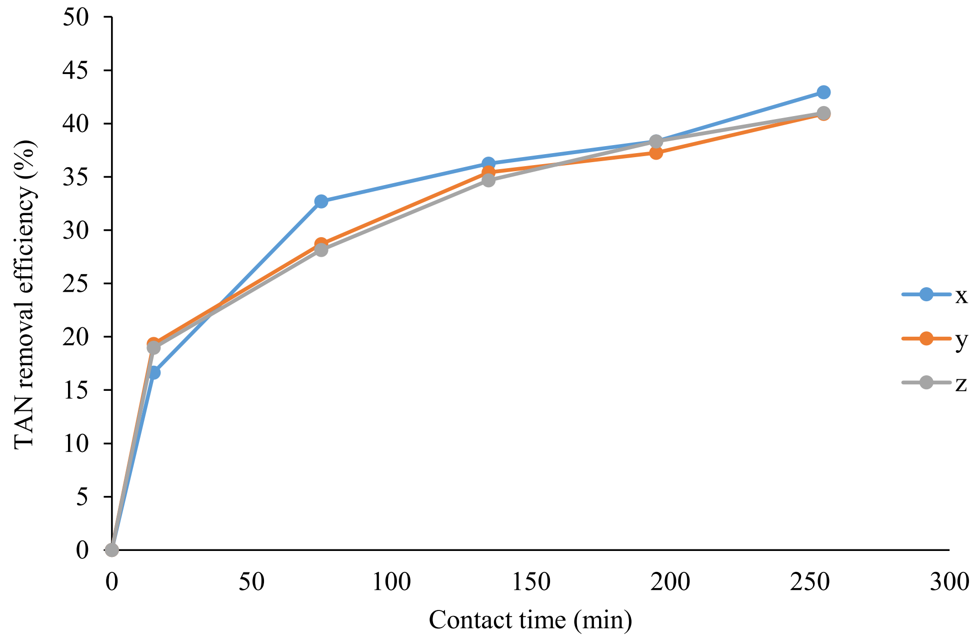



**Fig. 5** Temporal changes in TAN removal efficiency (%) between treatment groups x, y, and z according to 6 different measurements

**Table 3** Values of selected water quality parameters (Temperature, TAN, $NH_4^+$, pH, and DO (dissolved $O_2$)) in treatment groups of experiment III (mean ± SE)

| Experimental groups* | Water parameters | | | | |
|---|---|---|---|---|---|
| | Temperature (°C) | TAN (mg/L) | $NH_4^+$ (mg/L) | pH | DO (mg/L) |
| x | 19.73 ± 0.19 | 1.37 ± 0.20[a] | 1.04 ± 0.19[a] | 7.59 ± 0.02[a] | 0.38 ± 0.01 |
| y | 19.88 ± 0.21 | 1.90 ± 0.24[a] | 1.50 ± 0.23[a] | 7.53 ± 0.02[ab] | 0.37 ± 0.01 |
| z | 20.21 ± 0.25 | 2.97 ± 0.38[b] | 2.48 ± 0.39[b] | 7.51 ± 0.02[b] | 0.36 ± 0.01 |

*x: 0.2 g fish feed, y: 0.4 g fish feed, z: 0.6 g fish feed, Different superscript letters in a column indicate significant differences between groups (P < 0.05)

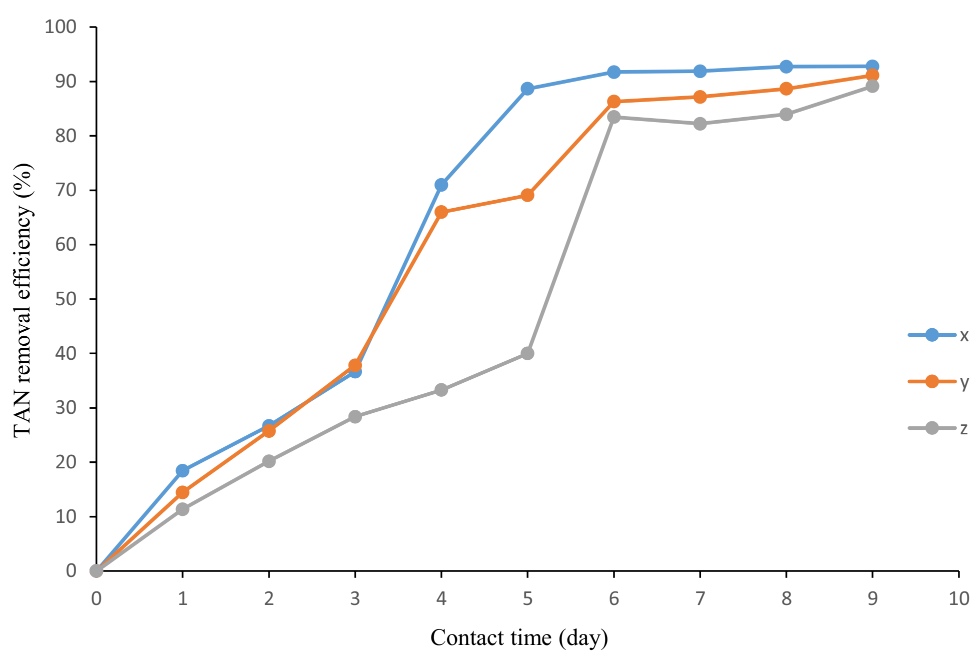



**Fig. 6** Temporal changes in TAN removal efficiency (%) between treatment groups x, y, and z according to 9 different measurements

## Discussion

In fish culture systems, it is known that the main wastes are excessive fish feed and feces. It has been reported by various studies that amount of wastes resulting from feces and unconsumed feed in intensive culture is about 10–30% (Daudaa et al. 2019; Kibria et al. 1997). In this study, zeolite and leonardite at high ammonium concentrations as well as duckweed at low ammonium concentrations were used to balance high ammonium levels in the water. At the end of the 1st experiment, $NH_4^+$ values which resulted from the feed containing 35% protein for 7 days at mean temperature of 20.3 ± 0.22 °C and pH of 7.95 ± 0.03 reached 3.53, 5.40, and 6.13 mg/L in the experimental groups x, y, and z, respectively. Similarly, Kibria et al. (1997) determined that the amount of $NH_4^+$ was approximately over 20 mg/L at 20 °C and 7.0 pH when a feed containing 45% protein was used for 7 days.

The majority of nitrogen in anaerobic wastewater exists in the form of ammonium ($NH_4^+$). This is an advantage because duckweed has a preferential ammonium uptake over other nitrogen forms (Porath and Pollock 1982). The same phenomenon is also true for natural adsorbent such as zeolite. The clinoptilolite type zeolite used in the present study can also effectively adsorb the $NH_4^+$ in water. The clinoptilolite type zeolite used in this study can also adsorb NH4 + in water effectively, and this study was conducted by Öz et al. (2016), and Şahin et al. (2019) show similarities with their studies. In their studies, Chammui et al. (2014) and Terdputtakun et al. (2017) determined that leonardite is an advantageous substance in the removal of undesired compounds (Ammonia, Cd, Zn) in aquatic environments. Moreover, a similar study conducted by Zengin (2013) reported that the use of mixture of clinoptilolite and leonardite is effective on removal zinc.

The response of duckweed to ammonium and ammonia levels has been extensively reported (Selvarani et al. 2015; Zhang et al. 2014; Arias et al. 2016). In the present study, in line with the existing evidence, it was found that *Lemna minor* is effective in the removal of excessive ammonium in water.

Nitrogenous compounds are essential for the continuity of living organisms because nitrogen is one of the fundamental building blocks of life (Şahin et al. 2019). Among the two forms of ammonia in water ($NH_3$ and $NH_4^+$), $NH_3$ displays high toxicity. Common concentrations of $NH_4^+$ in aquaculture systems range 1–5 mg/L. In the present study, it was observed that the highest ammonia value originating from the feed reached 0.19 mg/L at the end of the 1st experiment in group z, which received the highest feed amount for 7 days. This value decreased below the critical limit for aquaculture with the addition of adsorbents in the 2nd experiment and was determined to be 0.05, 0.06, and 0.06 mg/L for the groups x, y, and z, respectively. At the end of the 3rd experiment, $NH_3$ values went down to 0.00 mg/L.

While there was a decrease in the oxygen concentration in group z, which received the highest amount of feed, from the beginning of the experiment to the end of the 2nd experiment, it was determined that the oxygen concentration in this group increased in the 3rd experiment after duckweed addition. Sengupta et al. (2010) also stated that there was an increase in oxygen in the *Lemna* group. Aquatic plants contribute positively to oxygen levels through photosynthesis.

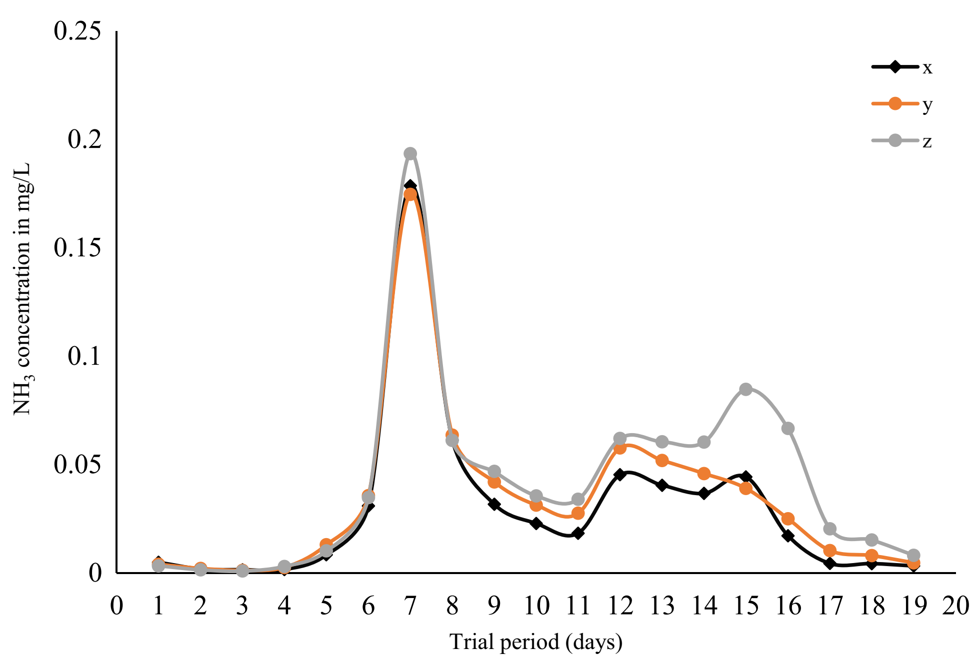



**Fig. 7** Temporal changes in ammonia (NH3) concentration (mg/L) during experiment III

Similarly, Shin et al. (2011) determined that aquatic plants contributed positively to oxygen levels in the aquarium.

Kibria et al. (1997) detailed the fractional composition of nutrients as well as the factors associated with the release of nutrients from fish feed and feces. This information is highly important for the planning of nutrient management and controlling pollution. In the present study, zeolite, leonardite, and duckweed, which have the potential to be used as both filtration materials (Zengin 2013; Öz et al. 2021, Şahin et al. 2018; Selvarani et al. 2015) and feed additives (Kanyılmaz et al. 2015; Şahin et al. 2010; Turan and Turgut 2020), were used. Zengin (2013) found that leonardite and clinoptilolite mixture has a positive effect on reducing the amount of Zn from an aqueous solution, Öz et al. (2021) and Şahin et al. (2018) determined that clinoptilolite is a good filtration material in aquariums. Selvarani et al. (2015) also found that duckweed was effective in removing nitrogen compounds in the environment. Kanyılmaz et al. (2015) added zeolite, Şahin et al. (2010) added duckweed, and Turan and Turgut (2020) added leonardite in aquarium fish feed. The potential use of a low-cost, natural adsorbent mixture composed of Turkish leonardite and clinoptilolite as well as duckweed was investigated for the removal of $NH_4^+$ and demonstrated under different experimental conditions for aquaculture such as different concentrations of fish feed, mixing ratio (C:L, 1:2), contact time, pH (7.4–7.6), and adsorbent amount (1 g C, 2 g L, 1.5 g Duckweed).

## Conclusion

In this study, it was determined that in high concentrations of zeolite + leonardite mixture and in low concentration of duckweed there had been a good removal efficiency. As a result of the present study, it was determined that remediation of nitrogenous wastes is possible using natural materials such as zeolite, leonardite, and duckweed in aquaculture. In general, when the effects of the combined use of natural adsorbents were evaluated at the end of the research, it was determined that the use of these materials has no harmful effect and the water parameters are within the optimum limits for aquaculture practices. This study will contribute to the removal of undesirable nutrient compounds with natural materials in both closed-circuit systems and other aquaculture systems.

**Acknowledgements** The author expresses gratitude toward Rota Mining Corporation (Manisa, Turkey) and Kütahya Chemistry (Kütahya, Turkey) for providing the trial materials, zeolite and leonardite. Assistance received from Dr. Meryem Öz, is also acknowledged herewith.

**Author contribution** Dilek Şahin designed, performed the experiment and data analysis, data collection and wrote the work.

**Data availability** All data generated or analyzed during this study are included in this published article.

## Declarations

**Ethics approval and consent to participate** Not applicable.

**Consent for publication** Not applicable.

**Competing interests** The author declares no competing interests.

## References

Arias A, Ramirez A, Fernandez V, Sanchez NE (2016) The use of common duckweed (*Lemna minor*) in the treatment of wastewater from the washing of sisal fiber (*Furcraea bedinghausii*). Ingeniería Y Comp 18(2):25–34

Caicedo JR, Van der Steen NP, Arce O, Gijzen HJ (2000) Effect of total ammonia nitrogen concentration and pH on growth rates of duckweed (*Spirodela plyrrhiza*). Wat Res 34(15):3829–3835

Chammui Y, Sooksamiti P, Arqueropanyo O (2014) Kinetic and mechanism of arsenic ions removal by adsorption on leonardite char as low cost adsorbent material. J Chil Chem Soc 59(1):2378–2381

Chow CWK, Davey DE, Mulcahy DE (1997) An intelligent sensor system for the determination of ammonia using flow injection analysis. Lab Auto and Inf Manag 33:17–27

Daudaa AB, Ajadib A, Tola-Fabunmic AS, Akinwoled AO (2019) Waste production in aquaculture: sources, components and managements in different culture systems. Aqua and Fish 4(3):81–88. https://doi.org/10.1016/j.aaf.2018.10.002

Emerson K, Russo RC, Lund RE, Thurston RV (1975) Aqueous re. J of the Fish Res Board of Canada 32:2379–2383

Engin VT, Cöcen Eİ (2012) Leonardite and humic matters. J of Underground Res 1(2):1–8

EPA (1999). Ambient water quality criteria for ammonia. United States Environmental Protection Agency, EPA-822-R: 99–104.

Ergün S, Tekeşoğlu H, Yiğit M (2008) Effects of dietary natural zeolite levels on ammonia excretion rates in young rainbow trouts (*Oncorhychus mykiss*). Fres Env Bulletin 17(2):245–248

Floyd RF, Watson C, Denise P, Deborah BP (2015) Ammonia in aquatic systems, IFAS FA-16, http://edis.ifas.ufl.edu/fa004_ (Available date: 20/01/2015).

Goopy JP, Murray PJ, Lisle AT, Al Jassim RAM (2004) Use of duckweed, bentonite and acid to ımprove water quality of effluent discharge from abattoirs. Asian Australasian J of Ani Sci 17(8):1168–1176. https://doi.org/10.5713/ajas.2004.1168

Güneş Ö (2017) Isparta-keçiborlu amorf silis yataklarının tarım teknolojileri alanında kullanım özelliklerinin belirlenmesi. Süleyman Demirel Üniversitesi Fen Bilimleri Enstitüsü Yüksek Lisans Tezi, 69p. (in Turkish).

Gürtekin E, Güneşdağ N (2008) The role of Duckweed (*Lemna minor* L.) in secondary clarifier tanks. SAÜ. Fen Bilimleri Dergisi, 12(1): 28–31.

Iskander AL, Khald EM, Sheta AS (2014) Zinc and manganese sorption behavior by natural zeolite and bentonite. Annals of Agric Sci 56:43–48

Ismadji S, Shentong D, Soetaredj FE, Ayucıtra A, Yu WH, Zhou CH (2016) Bentonite hydrochar composite for removal of ammonium from Koi fish tank. App Clay Sci 119:146–154

Jorgensen TC (2002) Removal of ammonia from wastewater by ıon exchange ın the presence of organic compounds [Master Thesıs]. University of Canterbury Christchurch, New Zealand, p 174

Kanyılmaz M, Tekelioğlu N, Sevgili H, Uysal R, Aksoy A (2015) Effects of dietary zeolite (clinoptilolite) levels on growthperformance, feed utilization and waste excretions by gilthead sea bream juveniles (*Sparus aurata*). Ani Feed Sci and Tech 200:66–75. https://doi.org/10.1016/j.anifeedsci.2014.09.023

Kibria G, Nugegoda D, Fairclough R, Lam P (1997) The nutrient content and the release of nutrients from fish food and faeces. Hydrobiologia 357:165–171

Lewis MA (1995) Use of freshwater plants for phytotoxıcıty testıng: a review. Env Poll 87:319–336

Mazeikiene A, Valentukevicien M, Rimeik M, Matuzevicius AB, Dauknys R (2008) Removal of nitrates and ammonium ions from water using natural sorbent:zeolites (clinoptilolite). J of Env Eng and Landsapace Man 16(2008):38–44

Oluwaseyi AM (2016) Application of dietary bentonite clay as feed additive on feed quality, water quality and production performance of African catfish (*Clarias gariepinus*). Stellenbosch University, Faculty of AgriSciences, Doctor of Philosophy, p 193

Öz M, Sahin D, Aral O (2016) The effect of naturale zeolite clinoptilolite on aquarium water contitions. Hacettepe J Biol Chem 44(2):203–206

Öz M, Şahin D, Öz Ü, Karsli Z, Aral O (2017) Investigation of ammonium saturation and desorption conditions of clinoptilolite type zeolite in aquarium conditions. Tur J of Agri-Food Sci and Tech 5(12): 1590–1594. https://doi.org/10.24925/turjaf.v5i12.1590-1594.1670.

Öz M, Şahin D, Karslı Z, Aral O, Bahtiyar M (2021) Investigation of the use of zeolite (clinoptilolite) as aquarium filtration material for electric blue hap (*Sciaenochromis ahli*). Marine Sci and Tech Bulletin 10 (2): 207–212. https://doi.org/10.33714/masteb.895198.

Porath D, Pollock J (1982) Ammonia stripping by duckweed and its feasibility in circulating aquaculture. Aquat Bot 13:125–131

Prema Latha Y, Lipton AP (2007) Water quality management in goldfish (*Carassius auratus*) rearing tanks using different filter materials. Indian Hydrobiology 10(2):301–302

Ratanaprommanee C, Chinachanta K, Chaiwan F, Shutsrirung A (2016) Chemical characterization of leonardite and its potential use as soil conditioner and plant growth enhancement. Asia-Pacific J of Sci and Tech 22(04):1–11

Şahin D, Öz M, Karslı Z, Aral O (2009) Su mercimeğinin *Lemna minor* L 1753 amonyum tutumuna etkisi. XV. Ulusal Su Ürünleri Sempozyumu “Ekosistem Yaklaşımlı Su Ürünleri Üretimi”, 1–4 Temmuz 2009, Rize, Turkey, (in Turkish).

Şahin D, Aral O, Öz M (2010) Su mercimeğinin (*Lemna minor*) komet balığı (*Carassius auratus* L., 1758) yavrularının beslenmesinde alternatif protein kaynağı olarak kullanımı. Sümder (Su Ürünleri Mühendisleri Derneği Dergisi) 35(42): 24–30 (in Turkish).

Şahin D, Öz M, Sertaşı E, Öz Ü, Karslı Z, Aral O (2018) Evaluation of natural minerals (zeolite and bentonite) for nitrogen compounds adsorption in different water temperatures suitable for aquaculture. Int Lett Nat Sci 71: 34–42. https://doi.org/10.18052/www.scipress.com/ILNS.71.34

Şahin D, Öz M, Sertaşı E, Öz Ü, Karslı Z, Aral O (2019). Adsorption process of ammonium by natural zeolite (clinoptilolite) from aqueous solution for aquaculture application. LIMNOFISH-Journal of Limnology and Freshwater Fisheries Research 5(2): 136–141. https://doi.org/10.17216/LimnoFish.420380.

Selvarani AJ, Padmavathy P, Srinivasan A, Jawahar P (2015) Performance of duckweed (*Lemna minor*) on different types of wastewater treatment. Int J Fish Aquat Stud 2(4):208–212

Sengupta S, Medda C, Dewanji A (2010) The impact of duckweed growth on water quality in sub-tropicalponds. Environmentalist 30:353–360. https://doi.org/10.1007/s10669-010-9293-6

Shin S, Song M, Thompson C (2011) Turn that light up: examining the effect of light ıntensity on photosynthesis as measured by oxygen production in *Elodea canadensis*. The Expedition 1:1–22

Tang H, Xu X, Wang B, Lv C, Shi D (2020) Removal of ammonium from swine wastewater using synthesized zeolite from fly ash. Sustainability 12:3423. https://doi.org/10.3390/su12083423

Tekeşoğlu H, Ergün S (2020) Effects of dietary natural zeolite (clinoptilolite) on growth and some blood parameters of rainbow trout (*Onchorynchus mykiss*, Walbaum 1792). Acta Aquatica Turcica 17(1):119–128

Terdputtakun A, Arqueropanyo O, Janhom S, Sooksamiti P, Naksata W (2017) Adsorption characteristics of leonardite for removal of Cd(II) and Zn(II) from aqueous solutions. International Journal of Environmental Science and Development 8(6): 1–6. https://doi.org/10.18178/ijesd.2017.8.6.984.

Tokat S (2019) Gördes (Manisa) zeolit ocaklarının kimyasal bileşenlerinin xrf spektrometrik yöntem ile belirlenmesi. Kastamonu Üniversitesi Fen Bilimleri Enstitüsü, 88 p. (in Turkish).

Turan F, Turgut, M. (2020) The effect of leonardite as feed additive on growth of goldfish (*Carassius auratus* L.). Natural and Engineering Sciences 5 (3): 184–191. https://doi.org/10.28978/nesciences.832994.

Wang W, Yang C, Tang X, Gu X, Zhu Q, Pan K, Hu Q, Ma D (2014) Effects of high ammonium level on biomass accumulation of common duckweed *Lemna minor* L. Environ Sci Pollut Res 21:14202–14210. https://doi.org/10.1007/s11356-014-3353-2

Yunnen C, Changshi X, Jinxia N (2016) Removal of ammonia nitrogen from wastewater using modified activated sludge. Pol J Environ Stud 25 (1): 419–425. https://doi.org/10.15244/pjoes/60859

Zengin G (2013) Effective removal of zinc from an aqueous solution using Turkish leonardite–clinoptilolite mixture as a sorbent. Environ Earth Sci 70(7):3031–3041. https://doi.org/10.1007/s12665-013-2364-5

Zhang K, You-Peng Chen Y, Zhang T, Zhao Y, Shen Y, Huang L, Gao X, Guo J (2014) The logistic growth of duckweed (*Lemna minor*) and kinetics of ammonium uptake. Environ Technol 35(5):562–567. https://doi.org/10.1080/09593330.2013.837937