Jurnal Pengabdian Nusantara

Vol. 4, No. 4, Agustus 2026, pp. 211~217
ISSN: 2987-2413
http://kampungjurnal.org/index.php/JPN/index

Implementation of Eco-Wetland Phytoremediation Technology to Support Cleaner Production and Waste Load Reduction in Tofu Factories

Nada Amirah *, Pitto Pratiwi Malau, Nurul Dahlia Harahap
Institut Kesehatan Deli Husada Deli Tua
Jl. Besar Delitua No.77, Deli Tua Tim., Kec. Deli Tua, 20355, Kabupaten Deli Serdang, Indonesia

Article Info

Article history:

Received July 11, 2026
Revised July 23, 2026
Accepted August 10, 2026

Keywords:

Eco-Wetland, Phytoremediation, Water Lettuce and Water Jasmine, Tofu Wastewater, Cleaner Production

ABSTRACT

The small-scale tofu industry Tahu Sumedang Putri Deli generates large volumes of wastewater that have been discharged directly into the drainage channel without treatment, causing odor, turbidity, and blockage that disturb the surrounding settlement. This community service program aims to implement an eco-wetland phytoremediation technology using water lettuce (Pistia stratiotes) and water jasmine (Echinodorus palaefolius) equipped with a coarse screen, as well as to strengthen the partner's capacity in wastewater management and cleaner production practices. The method consisted of socialization, training, technology implementation, mentoring and evaluation, and sustainability planning, supported by the environmental group Klinik Reboisasi. Results showed a 77.8% plant survival rate on day 7, with all water jasmine plants surviving while water lettuce reached 66.7%. Over six days of operation, wastewater pH increased from 4.76 to 7.3–7.4, TDS decreased by 43.3–49.9%, and dissolved oxygen increased by 29.6–48.1%. Partner knowledge scores rose from an average of 55.0 to 86.25, with 87.5% of partners able to operate the system independently. These improvements were also supported by routine cleaning of the channel and plants, as well as the selection of water jasmine seedlings with well-developed root systems. The program indicates that eco-wetland is one of the least expensive and viable solutions for small scale tofu industries, though it requires source reduction for wastewater management to remain sustainable.

Corresponding Author:

Nada Amirah
Institut Kesehatan Deli Husada Deli Tua
Email: nadaamirah96@gmail.com

INTRODUCTION

Household-based tofu production is an important small enterprise sector in many residential areas, such as the "Tahu Sumedang Putri Deli" enterprise, which began operations in 2014. This enterprise produces a white tofu with a daily capacity of around 500 kg. The tofu is sold to two major markets and processed to order to make fried tofu, fried tempeh, and pastel (savory pastries). Processing tofu generates a large volume of wastewater, estimated at 4,250 to 5,100 liters per day. This is estimated by processing 250 to 300 kg of soybeans per day and assuming a pollution ratio is around 17 liters of wastewater for one kilogram of processed soybeans. These estimates fall within the range of other studies of the characteristics of wastewater from small tofu industries, where volume of wastewater discharged is directly proportional to the volume of soybeans processed, and has the potential to exceed set standards, if not controlled at the source (1).

Business owner observations and interviews indicate that production wastewater discharges directly untreated through PVC piping in the factory ditch. The waste carries residual whey and finer soybean pulp that settles in the pipes and ditches, causing foul odors, turbid water, and potential blockages. Clustered small to medium scale tofu factories in Indonesia face the same issues, as most do not have wastewater treatment plants (WWTPs), resulting from land scarcity and high capital costs. For these reasons, many studies advise establishing common WWTPs or appropriate technologies for small and medium enterprises (SMEs) (2). Designs for small scale wastewater treatment plants for tofu or tofu-tempeh industries have been evaluated for their pollution removal efficiency and cost, as well as occupied space. Based on these, the appropriate technology for a particular business is selected (3). In terms of regulations, every wastewater generating business or activity in Indonesia is obliged to ensure the wastewater that are discharged into water bodies or environmental drainage systems meet the applicable wastewater quality standards as stipulated in Government Regulation Number 22 of 2021 on the Implementation of Environmental Protection and Management (4).

To solve the identified challenges, this community service project developed a technology with provisions for eco-wetland phytoremediation using water lettuce, (Pistia stratiotes) and Mexican sword plant (Echinodorus palaefolius) and the installation of coarse filters on discharge channels.The chosen technology is based on simplicity, low cost, and ease of operation, and requires no maintenance by our partners. The main goals of this initiative are to: (a) increase the partners' capacity in management of environmental business by enhancing their understanding of management of tofu wastewater; (b) decrease the pollution load of wastewater by showing improved values of pH, reduced values of TDS, enhanced DO, and enhanced effluent aesthetics; (c) stimulate the application of cleaner production principles in small-scale tofu business.

The significance of the cleaner production approach lies in its focus at all stages of production in preventing waste generation at a minimum cost. It is, therefore, more appropriate for small-scale tofu enterprises than many waste treatment methods that involve substantial capital investments (5). This effort also aligns with the spirit of implementing green industry concepts within small-scale industries, emphasizing waste management as an integral component of business sustainability and a demonstration of the industry's environmental responsibility toward the surrounding community (6).

METHOD

The implementation method for this community service activity is designed to support the application of phytoremediation eco-wetland technology—utilizing water lettuce (Pistia stratiotes) and Echinodorus palaefolius (often known as "water jasmine") and featuring a coarse filter at the discharge channel alongside strengthening wastewater management and implementing cleaner production practices at a small-scale tofu factory. Implementation is carried out in stages and through a participatory approach, involving the supporting partner "Klinik Reboisasi" (Reforestation Clinic), an environmental group experienced in developing eco-wetland systems and community-based environmental rehabilitation. The implementation stages comprise the following five key activities:

a. Socialization

Socialization is conducted to reach a consensus on the issues, partner needs, eco-wetland design, and the activity implementation workflow. The proposing team facilitates discussions and the mapping of wastewater issues; the partner, "Tahu Sumedang Putri Deli," provides data on production, location, and the condition of wastewater channels; while Klinik Reboisasi offers technical input regarding the eco-wetland design.

b. Training

The training phase aims to enhance the partner's capacity in wastewater management and the implementation of cleaner production; it is conducted by the proposing team with active support from Klinik Reboisasi. Training materials cover cleaner production principles in the tofu industry, the concepts and operational mechanisms of phytoremediation eco-wetlands, the function of coarse filters for solids control at the source, and the basics of water quality monitoring (TDS, pH, and DO). Proposing team members and students create and facilitate learning modules, deliver lectures, and facilitate discussions. Klinik Reboisasi provides training based on its practical field experience. Meanwhile, the tofu factory partner actively joins the discussions and simulation exercises. The end of training evaluations is based on a pre- and post-knowledge test. The indicator of success is an increase in post-knowledge test scores by 80% or more when compared to pre-knowledge test scores. This approach of an evaluation of training is similar to that of other community service programs that measure the effectiveness of training by using a pre- and post-knowledge test to assess understanding of the participants (7).

ISSN: 2654-8127

Figure 1. Technical training on Eco-Wetland implementation with partners and Klinik Reboisasi

c. Technology Implementation

The proposing team along with the tofu factory partner and the Reforestation Clinic implement the technology. The main activities include the installation of coarse filters on drainage pipes, the construction of a phytoremediation eco-wetland unit with two types of floating plants (water lettuce and water jasmine), and the integration of the waste stream from the production process into the filtration and eco-wetland system. The proposing team conducts the implementation tasks based on the design and cleaner production approach. Students support implementation tasks by measuring the quality of waste and documenting the quality of waste. The Reforestation Clinic supports the task by installation and planting. The partner is highly engaged in the construction and the initial operational stage of the system. In this phase the evaluation is of the installation of the system according to the design, the waste flow operational, the phytoremediation plants survive, and grow with a minimum level of success of 80%.

d. Mentoring and Evaluation

The Reforestation Clinic implements periodic mentoring to assist the proposing team in the operationalization of the eco-wetland system in accordance with the SOPs. Guidance is provided as needed and the partners are guided on how to monitor the quality of liquid waste (TDS, pH and DO) and the adherence to SOPs. The proposing team and student volunteers monitor system performance and evaluate the partner's waste management practices. The partner at the Reforestation Clinic develops the partner's capacity to identify and resolve issues while the factory partner runs the operations and reports any operational challenges. Evaluation involves comparing pre- and post-intervention conditions regarding technical aspects (improvement in waste quality) and managerial aspects (SOP compliance and the partner's operational independence).

e. Program Sustainability

Program sustainability is fostered through the implementation of simple SOPs, a passive and low-maintenance eco-wetland system design, and partner capacity building conducted jointly with the Reforestation Clinic. Partners are encouraged to integrate eco-wetland-based waste management into their factory's operational routines, with the Reforestation Clinic serving as a post-program support network for technical consultation as needed.

RESULTS AND DISCUSSION

Before the coarse filtration system and eco-wetland were put into operation, the proposing team, together with partners and the Reforestation Clinic, conducted a thorough cleanup of the wastewater drainage ditch. This process included removing accumulated soybean residue and old sediment the result of long-standing habits of discharging untreated waste. This initial cleanup was crucial to ensure that the flow of wastewater toward the filtration and eco-wetland units would not be obstructed by residual solids, while also establishing a cleaner environment for the phytoremediation plants to adapt.

It is important to note that cleaning the ditches will be a continuous activity, even after the construction of the eco-wetland. Lack of continuous cleaning results in the build-up of solid and liquid whey that ultimately leads to the eco-wetland media over saturation and root deterioration. This results in a lack of capacity for the eco-wetland to absorb and neutralize contaminates, resulting in rapid wilting of the plants. The effects of inadequate cleaning have been observed in the rehabilitation of community wastewater treatment plants, where the performance of the biological treatment systems deteriorated and ammonia started accumulating due to lack of cleaning of the treatment media and components (8).

Wastewater was directed to the coarse filter and the eco-wetland following the designed treatment flow when the system was ready for operation. After one week, plant growth was monitored and of the 18 planted seedlings, 14 (77.8%) had survived. In particular, all of the 6 Echinodorus palaefolius (water jasmine) had survived. seedlings (100%) survived, whereas among the 12 *Pistia stratiotes* (water lettuce) seedlings, 8 (66.7%) survived and 4 wilted.

Table 1. Survival Rate of Phytoremediation Plants on Day 7

Plant Type	Initial Quantity	Alive	Wilted	Survival Percentage
Water Jasmine	6	6	0	100%
Water Lettuce	12	8	4	66,7%
Total	18	14	4	77,8%

During the implementation period of six days, wastewater quality parameters were captured for every plant unit. In the Echinodorus palaefolius (water jasmine) unit, wastewater pH increased from 4.76 to 7.32, and TDS decreased from 383 ppm to 192 ppm (a 49.9% decrease), while DO increased from 2.7 mg/L to 3.5 mg/L (a 29.6% increase). For the Pistia stratiotes (water lettuce) unit, pH increased from 4.76 to 7.35, TDS decreased from 383 ppm to 217 ppm (a 43.3% decrease), and DO increased from 2.7 mg/L to 4.0 mg/L (a 48.1% increase).

Table 2. Changes in Wastewater Quality in the Water Jasmine Unit

Parameter	Initial Condition	Day 2	Day 4	Day 6
pH	4,76	7,24	7,45	7,32
TDS (ppm)	383	201	194	192
DO (mg/L)	2,7	3,2	3,2	3,5

Table 3. Changes in Wastewater Quality in the Water Lettuce Unit

Parameter	Initial Condition	Day 2	Day 4	Day 6
pH	4,76	7,54	7,61	7,35
TDS (ppm)	383	219	200	217
DO (mg/L)	2,7	3,2	3,8	4,0

Based on the research, the improvements in pH and DO observed in the water lettuce unit have been reported to be the results of pH increases of approximately 11.9% and TDS reductions of up to 83% in water lettuce in constructed wetlands treating domestic wastewater. Thus, the plant has the ability to neutralize acidic wastewater and increase DO in different types of liquid waste (9). For the water jasmine unit, results align with studies showing long hydraulic retention times lead to better pollutant removal and improved pH and temperature. As such, the six-day period of this field application should be considered satisfactory for achieving measurable improvements in the quality of wastewater (10).

It should be noted that the degree of TDS reduction in this field application was greater than what has been observed in laboratory studies. For example, in one laboratory study, water jasmine only achieved a 12.4% TDS removal for domestic wastewater. Variations in the degree of removal can be attributed to variations in the characteristics of wastewater, plant density, and operating conditions (11). In general, water jasmine showed better removal of TDS when compared to water lettuce. However, water lettuce had better improvements in DO over water jasmine. Both water jasmine and water lettuce showed good improvements in wastewater pH from an acidic state of 4.76 to a pH above 7.0. This is important because acidic tofu wastewater poses a negative impact on the ecosystem and drainage networks surrounding the wastewater treatment facility.

ISSN: 2654-8127

The ability of water jasmine to absorb pollutants is evidenced by studies that show it being an effective phytoremediator to extract heavy metals, such as copper (Cu), via the accumulation of the heavy metals in the root and stem tissues (12). Similar findings have been published for the treatment of landfill leachate, where water jasmine reduced various pollutant parameters in the constructed wetland systems, further showing the plant has the ability to be employed in various types of wastewater that are characterized by high loads of both organic and inorganic substance (13). The literature basically supports the notion that water jasmine is a multipurpose phytoremediation tool, capable of combining the absorption of pollutants with aesthetic value, and hence, can be employed in both the treatment of industrial wastewater and in the urban landscaping of aquatic settings (14). The higher mortality rate of water lettuce (33.3%) compared to water jasmine (0%) shows that water lettuce is more sensitive to higher initial pollutant loads. This further supports the assertion that the decomposition of tofu wastewater reaches the optimal balance of water lettuce only after a certain period of time with low initial pollutant loads and with a higher biomass density (15).

Improvements in TDS, pH and DO levels as well as the considerable reduction in TDS levels in both units cannot be attributed to the plants alone. The improvements can be attributed to the maintenance carried out in both units during the period of the study. It is common practice to clear channels during the operational phase of the eco-wetland to facilitate the flow of waste water and to prevent the deposition of raw solids on the roots of the plants. Routine maintenance on the plants (removing dead leaves and debris) also helped in maintaining optimum conditions for the uptake of pollutants. The choice of plants also contributed. The water jasmines were of mature specimens with extensive root systems, which provided an extensive area for the uptake of pollutants. This was compared to Water lettuces (Pistia stratiotes) which are difficult to obtain in older specimens with mature root systems. The water lettuces used in the study were of smaller size with fine roots compared to the water jasmine which led to faster wilting and slower uptake of pollutants.

A study by Amirah et al. Comparing the phytoremediation abilities of Limnocharis flava (genjer) and Eichhornia crassipes (water hyacinth) on tofu wastewater from the home industry illustrates the need for root density and the contact time of wastewater within the phytoremediation system (16). In these studies, the water hyacinth exhibited the highest removal at 46% for Biochemical Oxygen Demand (BOD), and 44% for Chemical Oxygen Demand (COD), in just 2 days; but its effectiveness dropped to 25–26% at 4 and 6 days. Conversely, Limnocharis flava demonstrated its best removal at 35% for BOD and 37% for COD on day 4, and at 2 and 6 days, the reductions from 17 to 31% were observed. Amirah and colleagues proposed that the decreased effectiveness of both plants after day 4 was due to the saturation of the absorption of pollutants and the initiation of the degradation of the plant biomass. In this regard, the peak removal of BOD and COD obtained by Amirah and colleagues is slightly higher than the reductions of Total Dissolved Solids (TDS) achieved presently with Echinodorus palaefolius (water jasmine) (49.9%) and Pistia stratiotes (water lettuce) (43.3%).

The choice of water lettuce and water jasmine as phytoremediators in this study is also justified since not all aquatic plants work to treat tofu wastewater. For example, for other tofu factory wastewater, research states that water spinach (Ipomoea aquatica) is not efficient to reduce COD in a short contact time, so the choice of the phytoremediator plants depends on the characteristics of wastewater and the contact time (16). On the other hand, the combination of Azolla microphylla and Eichhornia crassipes also shows that they can treat tofu wastewater, and this provides the partner the opportunity to develop other species of phytoremediators for the eco-wetland, if and when local plants become available (17).

The constructed wetland technique in this activity is consistent with other studies on the treatment of soy industry wastewater. Those studies show that constructed wetland systems can remove organic pollutants at low cost (18). For partner capacity building, pre- and post-test results from eco-wetland management training showed an increase in knowledge from 55.0 to 86.25 (a 3.13 point increase on the scale used) with all eight participants (100%) showing improvements in their scores. Field observations after the training showed that seven out of eight partners (87.5%) worked independently to operate, maintain, and monitor the eco-wetland. As a result, the transfer of knowledge and skills was effective and the training supported the management of the system after the assistance period was over.

Table 4. Evaluation Results of the Eco-Wetland Management Training

Training Type	Average Pre-test	Average Post-test	Improvement	Participants Who Improved
Eco-Wetland Management	5,50	8,63	+3,13 points	8 people (100%)

In addition to reducing pollutant loads, the eco-wetland creates opportunities for partner engagement; tofu wastewater that has been treated to some extent can be used as a raw material for liquid organic fertilizer to help grow horticultural crops (19). To complement the existing phytoremediation system, partners might also consider adding a natural biocoagulant unit using locally sourced materials such as citrus peel waste as an additional pre-treatment step to further reduce the solids load before the wastewater enters the eco-wetland unit (20). Overall, these results demonstrate that the integration of coarse filtration, phytoremediation eco-wetlands, and waste management training can yield significant improvements in both the technical aspects of wastewater quality and the partners' operational capacity within a relatively short period of assistance.

CONCLUSION

This community service activity demonstrates that the implementation of a phytoremediation eco-wetland technology utilizing Pistia stratiotes (water lettuce) and Echinodorus palaefolius (water jasmine) integrated with a coarse filter in the drainage channel can significantly improve the quality of tofu factory wastewater within six days. Improvements were evidenced by a shift in pH toward neutral, a reduction in Total Dissolved Solids (TDS) of nearly 50%, and an increase in dissolved oxygen levels. A plant survival rate of 77.8% by day seven, combined with a rise in partner knowledge scores from an average of 55.0 to 86.25 and the fact that 87.5% of partners could operate the system independently indicates that this approach is feasible and applicable for low-cost implementation in small-scale tofu businesses.

It should be noted the eco-wetland will not solve tofu factory waste management. This system is a demonstration of a beginning for using ecological approaches to managing pollution loads. However, along with this system, there needs to be a priority on waste reduction. This includes using cleaner production principles, controlling solids at the source with filtration, and maintaining partners' discipline in keeping the drainage channels free of pollution. Therefore the management of tofu factory waste needs a combination of different ecological technologies, partnership operational discipline, and the application of cleaner production principles to ensure long-term sustainability.

REFERENCES

[1] [1] Pambudi YS, dkk. Analisis karakteristik air limbah industri tahu dan alternatif proses pengolahannya berdasarkan prinsip-prinsip teknologi tepat guna. Syntax Literate. 2021;6(8).

[2] [2] Nadia A, Cahyonugroho OH. Perencanaan bangunan instalasi pengolahan air limbah komunal industri tahu di Kabupaten Jombang. J Serambi Eng. 2024;9(3).

[3] [3] Siswoyo SP, Ariani IK, Basransyah, Abdallah BN, Anifah EM. Evaluasi dan pemilihan desain alternatif instalasi pengolahan limbah cair industri tahu-tempe. J Serambi Eng. 2024;9(3).

[4] [4] Pemerintah Republik Indonesia. Peraturan Pemerintah Nomor 22 Tahun 2021 tentang Penyelenggaraan Perlindungan dan Pengelolaan Lingkungan Hidup. Jakarta: Sekretariat Negara Republik Indonesia; 2021.

[5] [5] Septifani R, Suhartini S, Perdana IJ. Cleaner production analysis of tofu small scale enterprise. IOP Conf Ser Earth Environ Sci. 2021;733:012055.

[6] [6] Saskara IAN, Yoga GP. Implementasi konsep industri hijau dalam pengelolaan limbah industri kecil di Kota Denpasar. J Vastu Widya. 2022;14(2):45-58.

[7] [7] Ardyanti D, Pramono JS, Tonapa E, Andrian A. Pemberdayaan masyarakat melalui media informasi digital untuk akses layanan yang lebih efektif. Selaparang J Pengabdian Masy Berkemajuan. 2025.

[8] [8] Wahid DRG, Utami A. Rehabilitasi Instalasi Pengolahan Air Limbah (IPAL) komunal Ngudi Saras di Dusun Jetak, Kabupaten Sleman untuk mengurangi amonia total. J Sumberdaya Alam Lingkung. 2023;10(3):106-13.

[9] [9] Ali M, Aslam A, Qadeer A, Javied S, Nisar N, Hassan N, et al. Domestic wastewater treatment by Pistia stratiotes in constructed wetland. Sci Rep. 2024;14:7553.

[10] [10] Pusvitasari AB. Pengaruh waktu tinggal terhadap penurunan kadar polutan, pH, suhu limbah cair industri tahu menggunakan tanaman melati air (Echinodorus palaefolius) pada metode fitoremediasi. J Teknol Kim Unimal. 2025;14(1):136-52.

[11] [11] Fajar M, Ujung DYN, Kurnianingtyas E, Taher T. Performance of free water surface constructed wetlands (FWS-CWs) using water jasmine (Echinodorus palaefolius) in removing COD and TDS from domestic wastewater. Indones J Environ Manag Sustain. 2026;10(3):214-27.

[12] [12] Lorensia RE, Rachmadiarti F. The ability of Mexican sword plant (Echinodorus palaefolius) as copper (Cu) phytoremediator. LenteraBio. 2024;13(3):429-36.

[13] [13] Ratnawati R, Nurhayati I, Rohim IN, Andriani V. Phytoremediation of landfill leachate using Chlorophytum comosum, Echinodorus palaefolius, and Hippochaetes lymenalis. J Ecol Eng. 2024;25(12):124-35.

[14] [14] Sari MOSK. Water jasmine (Echinodorus palaefolius): a phytoremediation agent for environmental health improvement and landscape enhancement. J Biomed Sci Health. 2026;3(1):32-41.

[15] [15] Syuhada AD, Saputra AE, Gunawan T. Potensi tanaman Azolla microphylla dan Pistia stratiotes dengan metode fitoremediasi dalam pengolahan limbah tahu. Bul Keslingmas. 2025;44(2):113-8.

[16] [16] Amirah N, Munthe NT, Sitio SSP, Tanjung LF, Putri RN. Comparison of the effectiveness of phytoremediation of yellow velvetleaf (Limnocharis flava) and water hyacinth (Eichhornia crassipes) on reducing BOD and COD of liquid waste from home-made tofu industry in Namorambe District. Deli Int Conf Allied Sci. 2026;1(1):44-50.

[17] [17] Kango SF, Jusuf H, Nurfadillah AR. Uji efektivitas daya serap tanaman kangkung air dalam menurunkan kadar Chemical Oxygen Demand (COD) pada limbah cair pabrik tahu Ayula Tilango Kabupaten Bone Bolango. J Kolaboratif Sains. 2026;9(1).

[18] [18] Rahman A, Lisha SY, Fitrada W. Efektivitas Azolla microphylla dan Eichhornia crassipes dalam pengolahan limbah cair

ISSN: 2654-8127

tahu. J Eng. 2024;6(1):23-31.

[19] [19] Galuh SD, Mirzatika L, Sujarwadi R. Waste water treatment analysis of soybean industry using wetlands system. Int J Res Publ Rev. 2021;2(7):291-5.

[20] [20] Aqlys SASH, Cahyonugroho OH. Potensi dan efektivitas limbah cair industri tahu sebagai pupuk organik cair terhadap pertumbuhan cabai dan tomat. J Serambi Eng. 2024;9(3):8595-603.

[21] [21] Humairoh AA, Ramayanti C, Dewi E. Ekstraksi pektin dari limbah kulit jeruk mandarin sebagai biokoagulan pengolahan limbah cair pulp dan industri tahu. J Serambi Eng. 2026;11(2).