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Environmental Assessment of Two White-Leg Shrimp (*Penaeus Vannamei*) Farming Systems; Round Tank System and Earthen Pond System

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Abstract

Shrimp farming plays an important role in providing nutritious food and generating livelihoods for many millions of people worldwide. Asia is the biggest producer of shrimp contributing nearly 80% of the global shrimp aquaculture production. The round tank system is round-shaped and is a type of lined pond that uses an impermeable geomembrane for the retention of water. The earthen pond is a water body that is basically enclosed by the earth. White-leg Shrimp (Penaeus vannamei) is native to the Pacific coast of Central and South America and it is the leading farm-raised species in the western hemisphere. Shrimp farming is responsible for a range of environmental impacts such as the destruction of the mangrove ecosystem, pollution of waterbodies, and salinization of soil and water. The objective of this study was to assess the environmental sustainability of two P. vannamei production systems using environmental indicators. The round tank system is located in the Erukkalampiddy area in the Mannar district, Sri Lanka. The earthen pond system is located in the Maikkulama area in the Puttalam district, Sri Lanka. Data on water usage, electricity usage, land area usage, and weight of harvested shrimp were collected during two cycles of production to calculate the water footprint, energy footprint, land footprint, and productivity. According to the results, the water footprint and land footprint values of the round tank system are significantly lower than the earthen pond system, while the electricity footprint is significantly higher. The round tank system showed significantly higher productivity than the earthen pond system. Although establishing a round tank system will need more capital, compared to that of an earthen pond system, it is evident that the round tank system is more environmentally sustainable.

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Round Tank System and Earthen Pond System

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Introduction

Aquaculture plays an important role in providing nutritious food and generating livelihoods for many millions of people worldwide. (Villasante et al., 2015). Asia is the biggest producer of shrimp contributing nearly 80% of the global shrimp aquaculture production. (Biao and Kaijin, 2007). There are shrimp farms in over fifty countries at the present. In 2018, 6 million tons of shrimp were produced worldwide. (FAO, 2020). China is currently the largest producer of farmed shrimp. India and Indonesia dramatically increased their share in the global shrimp market by producing large volumes at low prices. (RUBEL et al., 2019). Asian tiger shrimp (*Penaeus monodon*) is native to the Indian Ocean and the Southwestern Pacific Ocean from Japan to Australia. (Madrigal et al., 2017) (Farmed Species, n.d.). White leg shrimp (*Penaeus vannamei*) is native to the Pacific coast of Central and South America and it is the leading farm-raised species in the Western Hemisphere. (Briggs et al,2004). White leg shrimp was introduced into Sri Lanka in 2018. High growth rate, resistance to a variety of diseases, production cost less than Penaeus monodon, high productivity, tolerance for high salinity range (between 0 to 50ppt), and requirement for low protein food compared to *Penaeus monodon* are some reasons to introduce *P.vannamei* to the Sri Lankan aquaculture industry. (www.naqda.gov, n.d.)

Shrimp farming is responsible for a range of environmental impacts such as the destruction of the mangrove ecosystem, pollution of waterbodies, and salinization of soil and water. The mangrove ecosystem is the most valuable ecosystem in the coastal area since it provides protection for shorelines by preventing coastal erosion, serves as a breeding nursery and foraging ground for many species of fish, animals, and shellfish, and provides a habitat for a large number of migratory and endemic species. (Macusi et al., 2022). The majority of shrimp farms are developed along the mangrove forest areas. Shrimp farms can affect mangroves through the construction of ponds, buildings, and other facilities which directly displace mangroves. (Dewalt et al., 1996). Shrimp farming cause to damage other ecosystems in the area due to changes in the entire micro and macroclimate of the region. During the past few decades, the environmental impacts of shrimp farming have decreased significantly, as shrimp farming countries have improved their environmental management policies and regulatory frameworks. (Subasinghe, pers.com.). The effluent water of shrimp farms can consist of organic waste, chemicals, and antibiotics that can pollute groundwater as well as lagoon areas. Some farmers discharge wastewater and contaminated sediment from shrimp ponds into receiving rivers and streams that become the source of water for other shrimp ponds. (Nguyen et al., 2020). Due to the release of wastewater without proper treatment, the pathogens from infected ponds are spread to other ponds. (Nguyen et al., 2020). Water pollution causes eutrophication of water sources and which affects native species in the lagoon depleting their growth.

(Hossain et al,2013). Agriculture land in some countries has become salinized as a result of the outflow of salt water from shrimp ponds, negatively impacting land-based agriculture productivity. This phenomenon has therefore become an important environmental concern resulting in a strong public cry for better managing shrimp farm effluent and their discharge (Subasinghe pers. com.)

Shrimp farming systems are classified into several categories; extensive, semi-intensive, intensive, and super-intensive based on the intensity of management practices such as stocking density, supply of feed and fertilizer, and management of water qualities. (Sohel & Ullah, 2012). (Paul & Vogl, 2013). In extensive farming, shallow ponds of varying sizes are generally used for stocking. According to the extent of the land, the shape of the ponds might be varied. Water exchange is less frequent. Most rely on tidal flow with a single inflow or outflow point. Stocking is commonly dependent on what is bought in with the tide, based on the location of the farm and source of water. In large ponds, usually, there is no aeration. Supplementary feeding is minimal and shrimp use natural feed in ponds. Crop cycles take more time compared to intensive systems. Between crop cycles, ponds are not dried or disinfected. (Dieu et.al,2011) (Thornber et al., 2019). Semi-intensive and intensive farms are characterized by deep ponds, high stocking densities (around 15 post-larva/m2), high productivity, and the use of an artificial diet. But it covers a smaller area compared to extensive farms. Ponds are closely monitored, with a high frequency of water exchange. Ponds are continuously aerated and there is close control of stock management. The crop cycle is shorter. Between crop cycles, ponds are drained and disinfected. (Dieu et.al,2011) (Thornber et al., 2019). Super-intensive farming technologies are currently being implemented in some farms in some countries. (Global Seafood Alliance, 2017). These systems operate to maintain the balance of high shrimp productivity, water quality parameters, reduced water exchange, and greater biosecurity. Ponds use square or rectangular areas between 2,500 and 4,000 square meters. The depths are varied between 1.8 and 3.0 meters, with bottoms lined with high-density polyethylene (HDPE) geomembranes and equipped with central drains. There may be basins for water reuse, with greenhouse cover, PVC structure, wood, or galvanized metal, covered in semi-transparent or opaque film. Shrimp are fed several times a day by manual broadcasting or using feeding trays. There is a high mechanical aeration rate (20 to 30 hp/ha). This type of system has high stocking densities that range from 120 and 300 shrimp per square meter, and yields can reach up to 25,000 kg/ha/crop. (Global Seafood Alliance, 2017)

The round tank system is a type of super-intensive farming system that is round-shaped and it is a type of lined pond that use an impermeable geomembrane for the purpose of the retention of water. This tank is implemented above the ground. It has a flat bottom that is covered by High-Density Polyethylene (HDPE). (Kawahigashi, 2019). There is a drainage system for water supply and distribution of water. Water is usually pumped from pond inlet canals using an electrical pump. When doing lining, a few tubes are set up from the bottom to the top of the tank to facilitate gas movement that arises from the bottom of the tank. The aeration and water movement are provided by diffuser tubes powered by a blower. Manual feeding or automatic feeding could be used. (Kawahigashi, 2021). The earthen pond water body that is basically enclosed by the earth. It is a type of semi-intensive farming system. This pond doesn't have an exact shape. Based on the area where it is going to be implemented, its shape is different. The pond has an inlet and outlet for water supply. The aeration and water movement are provided by paddlewheels. Normally manual feeding is used to feed shrimp.

Figure 1.1: Round tank production system

Source: *Taprobane Seafood Group*

Figure 1.2: Earthen Pond production system

Methodology

This study was carried out to assess the environmental sustainability of a round tank system and an earthen pond system using different indicators which are water footprint, energy footprint, land footprint, and productivity. The round tank system is located in the Erukkalampiddy area in the Mannar district, Sri Lanka. The earthen pond system is located in the Maikkulama area in the Puttalam district, Sri Lanka. Monthly electricity usage, water usage, land area usage, and production data were collected from both production systems. Data were recorded for two production cycles from August 2021 to May 2022.

The water footprint is the volume of water used to produce the product or service along a value chain. (Ahmed et al., 2017). The water footprint has 3 components green water footprint, blue water footprint, and grey water footprint. The blue water footprint is surface or groundwater consumed in producing goods and services. (Chapagain, 2017). Due to the usage of lagoon water for both systems and water added due to rainfalls, blue and green water contribute to the water footprint of these two production systems. But lagoon water usage is only considered for the calculations due to the inability to measure added rainfall water.

Water footprint=Consumptive water (m3)/Amount of shrimp harvested (t)

(Mohanty et al., 2018)

Energy footprint is the summation of direct and indirect energy required along a production chain of a product or service. (Guzmán-Luna et al., 2021). The main energy source of both production systems is electricity provided by Ceylon Electricity Board (CEB). Electricity is used for water circulation, aeration, water pumping, and lighting. Due to the inability to measure electricity categorize-wise, total electricity usage month-wise is used as data.

Energy footprint = Energy usage (kwh) / Crop harvested (t) (Boyd & McNevin, 2020)

The land footprint is the total amount of land used to produce a product or service. (Valenti et al., 2018)

Land footprint = the area used (m2) / amount of harvested crop (Alatorre-J et al., 2012)

Productivity = total production of production system / (total production area * time spent for cycle)

(Chowdhury et al., 2015)

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Result

Table 3.1: Water Footprint of the Round Tank and Earthen Pond

	The volume of water used (m^3)	Harvested shrimp (t)		Water footprint (m^3/t)	
		Cycle 1	Cycle 2	Cycle 1	Cycle 2
Round tank	1240	6.5	8.9	190.77	139.33
Earthen pond	11400	12	9	950.00	1266.67

Water footprint values are analyzed using a non-parametric test (Mann-Whitney U test) at a 0.05 significance level. The P-value is 0.028. P-value is less than 0.05 ($P<0.05$). therefore, there is a significant difference in the water footprint of the two systems.

Table 3. 2: Energy Footprint of the Round Tank and Earthen Pond

	Round Tank System		**Earthen Pond System**	
	Cycle 1	Cycle 2	Cycle 1	Cycle 2
Electricity usage (kwh)	3080	5264	1439	1393
Crop harvested (t)	6.5	8.9	12	9
Electricity footprint (kWh/mt)	473.84	591.46	119.91	154.78

Energy footprint values are analyzed using a non-parametric test (Mann-Whitney U test) at a 0.05 significance level. The P-value is 0.023. P-value is less than 0.05 ($P<0.05$). therefore, there is a significant difference in the energy footprint of the two systems.

Table 3.3: The Land Footprint of the Round Tank and Earthen Pond

	The area used (m^2)	Harvested shrimp (t)		Land footprint (m^2/t)	
		Cycle 1	Cycle 2	Cycle 1	Cycle 2
Round tank	1240	6.5	8.9	190.77	139.33
Earthen pond	11400	12	9	950.00	1266.67

Land footprint values are analyzed using a non-parametric test (Mann-Whitney U test) at a 0.05 significance level. The P-value is 0.028. P-value is less than 0.05 ($P<0.05$). therefore, there is a significant difference in the land footprint of the two systems.

Table 3.4: Farm Productivity of the Round Tank and the Earthen Pond

	Round tank system		Earthen pond system	
	Cycle 1	Cycle 2	Cycle 1	Cycle 2
Total production of the production system (t)	6.5	8.9	12	9
Total production Area (ha)	0.124	0.124	1.140	1.140
Time spent for the cycle (days)	100	130	138	140
Productivity (t/m^2*days)	0.524	0.552	0.076	0.056

Farm productivity values are analyzed using a non-parametric test (Mann-Whitney U test) at a 0.05 significance level. The P-value is 0.001. P-value is less than 0.05 ($P<0.05$). therefore, there is a significant difference in the productivity of the two systems.

Discussion

Only the consumed water should be considered in water footprint calculations. It is not considered as consumed water, when water returns to the environment in the same state in which it was withdrawn. But if it returns polluted, it should be considered consumed. (Valenti et al,2018). According to the result in table 3.1 water footprint of the round tank for cycle 1 and cycle 2 is 190.77 m3/t and 139.33 m3/t respectively. The Water footprint of the earthen pond for cycle 1 and cycle 2 is 950.00 m3/t and 1266.67 m3/t respectively. The water footprint is normally estimated considering water loss such as evaporation or evapotranspiration. For this calculation, it is considered as equally impacted on both systems. The p-value (0.028) is less than the significant level ($p<0.05$). That means, there is a significant difference between the water footprint values of the round tank and the earthen pond. Therefore, the water footprint is significantly high in the earthen pond compared to the round tank. It means earthen pond production consumes water more than the round tank. Therefore, the round tank system supports achieving the 2nd target of SDG 12 which is achieving efficient and sustainable use of natural resources.

For both production systems, the energy requirement is fulfilled by the electricity that is supplied by the CEB. Electricity is required for water circulation and aeration, water pumping, and lighting. Electricity usage wasn’t recorded usage-wise. The p-value (0.023) is less than the significant level ($p<0.05$). That means, there is a significant difference between the energy footprint values of the round tank and the earthen pond. According to table 3.2, the electricity footprint of the round tank is significantly high compared to the earthen pond. That means the round tank system consumes more electricity to produce the unit weight of shrimps. In energy-wise, the earthen pond is more favorable and it supports achieving target 7.3 of SDG 7 which is focused to improve energy efficiency. In Sri Lanka, electricity is mainly generated using coal, fuel oil, and hydropower. Hence, the earthen pond that has low energy footprint help to achieve target 12.2 (achieve the sustainable management and efficient use of natural resources) of SDG 12.

Normally shrimp farms are located near sea areas or lagoon areas. There are many ecosystems in those areas. Clearing land areas to implement farms might create a lot of impacts on those ecosystems. It is sustainable if the farm can produce more shrimp in a small area without clearing or using a large area of an ecosystem. According to table 3.3, the round tank required 190.77 m2 area to produce 1 ton of shrimp in cycle 1, and 139.99 m2 area is required in cycle 2. The earthen pond required 950.00 m2 and 1266.67 m2 area to produce 1 ton of shrimp. When statistically analyzing these results, the received p-value is 0.028. The p-value is less than the significant level ($p<0.05$). That means, there is a significant difference between the land footprint values of the round tank and the earthen pond. Therefore, the round tank is more favorable to achieving target 12.2 (achieve the sustainable management and efficient use of natural resources) of 12.

According to table 3.4, the farm productivity of cycles 1 and 2 of the round tank is 0.524 t/m2*days and 0.552 t/m2*days respectively. The farm productivity of cycles 1 and 2 of the round tank is 0.076 t/m2*days and 0.056 t/m2*days respectively. When statistically analyzing these results, the received p-value is 0.001. The p-value is less than the significant level ($p<0.05$). That means, there is a significant difference between the farm productivity values of the round tank and the earthen pond. Therefore, the round tank system has significantly high productivity than the earthen pond. When comparing productivity values with footprint values, the round tank system is the most suitable system that helps to achieve goal 12 compare to the earthen pond system. Not only that it is evident that the round tank system is more environmentally sustainable than the earthen pond system.

Shrimp is a nutritious food. Shrimp farming has contributed to the provision of high-quality protein to many people all over the world. Therefore, it contributes to achieving SDG 2, End hunger, achieving food security and improved nutrition, and promoting sustainable agriculture. Aquatic foods including farmed species are unique sources of essential fatty acids, proteins that easily can be digested and taken up by humans, essential micronutrients including vitamins A, B12, and D, and minerals such as calcium, phosphorus, iodine, zinc, iron, and selenium. (Bennet et al. 2020). The growth, development, and well-being of hundreds of millions of people are affected by the deficiencies of these vital nutrients. (Golden et al 2021).

In addition to the direct production of food and income, employment is also created by shrimp farming, either directly or indirectly. As a result, doing a decent job and getting decent pay helps to raise standards of living and lessen poverty. There are a few job roles such as feeding, monitoring, and harvesting in Shrimp farming. There are job opportunities for those job roles. It provides income for a lot of people while reducing their poverty

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