EVALUATION OF AQUACULTURE EFFLUENTS AND MANAGEMENT PRACTICES: A CASE STUDY FOR JAMAICA

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ABSTRACT

Aquaculture effluents contain inorganic and organic particles from fish waste, residual feed, and fertilisers, which can result in eutrophication and changes to natural ecosystems if not managed properly or treated before release. Sustainable aquaculture is on the agenda worldwide, and as the aquaculture industry continues to grow, the increase in aquaculture effluents has been gaining traction with increased criticism from the environmental community regarding effluent composition and release in receiving ecosystems. As Jamaica seeks to increase food security for its population, where current production has reached 954.23 metric tons and is expected to reach 3,400 metric tons in 2028, the demand for aquaculture products continues to grow, increasing production and effluent volume. This paper provides a review of the various methodologies utilised in Jamaica to dispose of aquaculture effluents from commercial *Tilapia spp.* fish farms and an evaluation of the effluent composition on selected farms. The results from the analysis of the effluent composition indicated that the majority of the parameters tested were within the standard effluent limits set by the environmental agency. The physiochemical characteristics tested resulted in these values (TL1,TL2 (NEPA limit)): total phosphorous (0.93 mg/l, 1.04 mg/l (5 mg/l)), nitrate (0.9 mg/l, 0.9 mg/l (10 mg/l)), nitrite (102 mg/l, 87 mg/l (10 mg/l)), ammonia (0.05 mg/l, 1.12 mg/l (1.0 mg/l, TL2)), pH (8.3, 7.5 6-9)), total suspended solids (44.7 mg/l, 60 mg/l (150 mg/l)) and total dissolved solids (1060 mg/l, 544 mg/l (1000 mg/l)). Although no aquaculture effluent management plan exists for the current production systems, the best aquaculture practices, such as good water source, low feed conversion ratio, and use of settlement canals employed by fish farmers in semi-intensive production systems in Jamaica, have aided in the management of nutrient load in aquaculture effluents before release. Continuance of these practices integrated with the postulated guidelines in the implementation plan will maintain the productivity of the sector and current ecological health.

Keywords: Jamaica, aquaculture, effluent management, tilapia farming, water quality, discharge.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ASC	Aquaculture Stewardship Council
CRFM	Caribbean Regional Fisheries Mechanism
EIA	Environment Impact Assessment
FAO	Food and Agriculture Organization
FCR	Feed Conversion Ratio
FOS	Friend of the Sea
GAA	Global Aquaculture Alliance
IMTA	Integrated Multi-trophic Aquaculture
IUU	Illegal, Unreported, Unregulated
JSIF	Jamaica Social Investment Fund
MOAFM	Ministry of Agriculture Fisheries and Mining
MoHW	Ministry of Health and Wellness
NEPA	National Environmental and Planning Agency
NFA	National Fisheries Authority
NIC	National Irrigation Commission
RADA	Rural Agricultural Development Authority
SRC	Scientific Research Council
STATIN	Statistical Institute of Jamaica
USAID	United States Agency for International Development
WRA	Water Resources Authority

1 INTRODUCTION

1.1 Global Aquaculture Production

The farming of aquatic organisms for food has tremendously increased over the last four decades (Figure *1*), as governments aim to increase food security for their citizens by ensuring a safe and sustainable source of fish and fish products. In 2020, the total world aquaculture production (for food and including animal skin for the fashion industry) was 122.6 million tonnes in live weight, whereas in 2000, the world aquaculture production was 43 million tons, representing a 184% increase (FAO, 2022). Aquaculture activities typically include finfish farming in a somewhat controlled environment but also include activities such as the cultivation of molluscs, crustaceans, algae, cyanobacteria, marine invertebrates, frogs, and aquatic turtles (FAO, 2020). In 2020, world aquaculture production of inland farmed finfish was 49.1 million tonnes, accounting for 40% of total aquaculture production for the year (FAO,2022). The growth of aquaculture is not restricted to one geographic region but ranges from large producers in Asia to small producers in Oceania, Europe, and the Americas, with Latin America and the Caribbean contributing 51.71% of the total production (FAO, 2022).

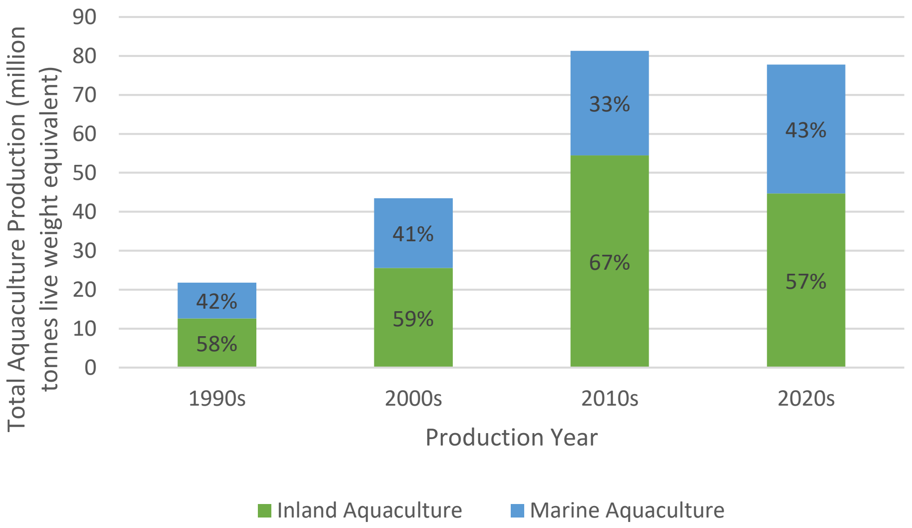


Figure 1. World Aquaculture Production 1990s - 2020 modified from FAO (2022), excluding aquatic mammals, crocodiles, alligators, caimans, and algae.

1.2 Aquaculture in Jamaica

Jamaica is located in the Caribbean region (Figure *2*) and is the third largest aquaculture producer in the Caribbean subregion (Wurmann, Soto, & Norambuena, 2022). It is the third largest West Indian Island State in the Greater Antilles after Cuba and Hispaniola, spanning 234.96 kilometres in length, and approximately 35.41 to 82.08 kilometres in width, and has a population of approximately 3 million people (Buisseret, Bryan, Black, & Ferguson, 2023; STATIN, 2019). Jamaica has an Exclusive Economic Zone of 274,000 km^2 (Marine Regions, 2019), governed by the Exclusive Economic Act (Ministry of Agriculture, Fisheries and Mining, 1991), and has an abundant fish stock which has significantly decreased over the past few years due to overfishing and the prevalence of Illegal, Unreported and Unregulated (IUU) fishing. As a result of the challenges faced by capture fisheries, the government, through international partnerships, began further development of the aquaculture sector in 1976 through a project funded by the United States Agency for International Development (USAID), which introduced the production of *Tilapia spp*. and oysters.

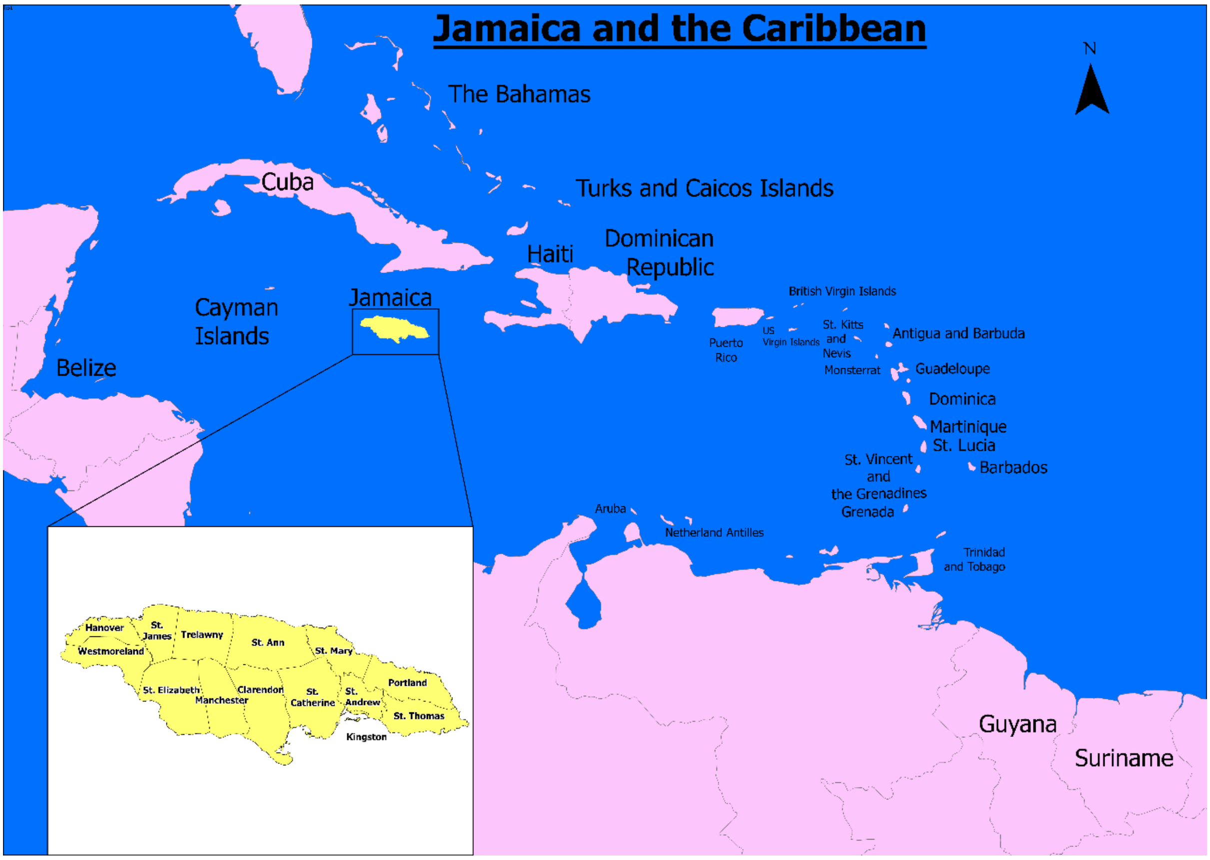


Figure 2. Jamaica´s location in the Caribbean

Jamaica's aquaculture sector is currently divided into two key areas of interest: food security and ornamental fish. Food security in aquaculture includes the production of fish for consumption, oysters, and seaweed (National Fisheries Authority, 2022). Food fish aquaculture in Jamaica includes several tilapia species:

- Jamaica Red, a mix of *Oreochromis spp.*
- Rocky Mountain White, which is an interbreed of *Oreochromis niloticus* and *Oreochromis aurea*
- Taiwanese Red, which is an interbreed between the orange female *Oreochromis mossambicus* and male *Oreochromis niloticus*
- Nile Tilapia, scientifically known as *Oreochromis niloticus*
- Sterling Red, an interbreed between the Jamaica Red and Rocky Mountain White breeds.

Other aquaculture species used to enhance food security include the local oysters *Crassostrea rhizophorae* and *Isognomon alatus* (Brown, 2010), seaweeds such as *Chondrus crispus*, *Gracilaria sp.*, and *Furcellarias sp.,* and freshwater shrimp *Macrobrachium rosenbergii.* Ornamental fish aquaculture includes goldfish and koi in local markets. Aquaculture in Jamaica is predominantly semi-intensive inland farming of tilapia in earthen ponds which has been steadily increasing over the past several years, except for 2020 and 2021 due to COVID-19 pandemic (Figure *3*).

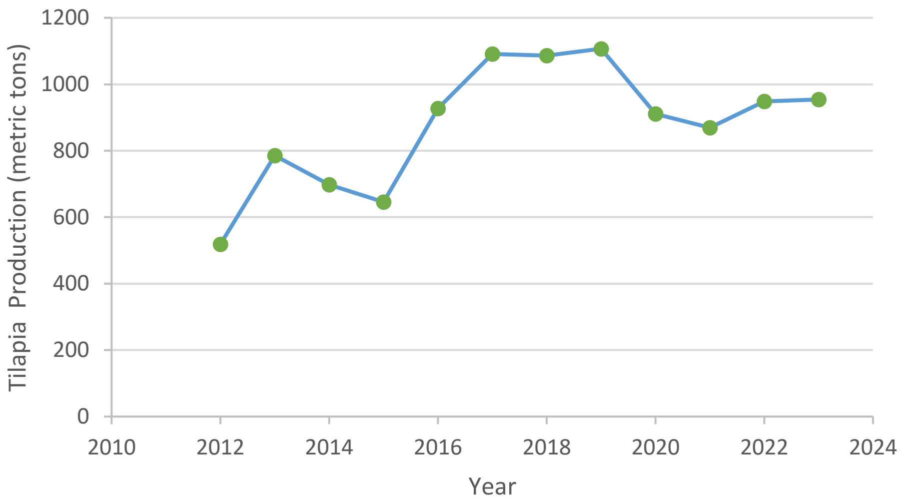


Figure 3. Jamaica´s tilapia spp. production values (metric tons) from 2012 to 2022, modified from the National Fisheries Authority (2023b).

Jamaica has formulated an aquaculture development plan and has undertaken several aquaculture projects supported by foreign aid which should lead to an increase in production (Wurmann, 2022; Fisheries, 2014). Under the Promoting Community-Based Climate Resilience in the Fisheries Sector Project, aided by The World Bank, and financed in part by the Jamaica Social Investment Fund (JSIF), there is an aquaculture project which facilitates the construction of a modern, bio-secure, climate resilient tilapia hatchery that is expected to produce over five million fry per annum once fully operational and will positively impact all aquaculture stakeholders (Ministry of Agriculture, Fisheries and Mining, 2023). The aim of this new modern hatchery is to ensure full market coverage, moving from 35% supply (500,000 fry) to 100% supply, a 300% (5 million fry) increase in seed stock production (Bennett, 2024). Not only will there be a boost in production but there will also be an increase in the environmental stewardship in the production of quality seedstock with the incorporation of a solar system, a rainwater harvesting and storage system as well as the production facility being a recirculating aquaculture system (Palmer, 2024).

1.3 Rationale

With the expansion of any industry comes an increase in pollution. Though pollution from the most polluting industries (fossil fuel industry, the agricultural industry and fashion industry) is a critical issue (Climate Trade, 2023), much attention is not given to the possibility of effluents and pollutants discharged from fishponds into the natural environment, rivers, streams, wetlands, and agricultural lands (Raczyńska, Machula, Choiński, & Sobkowiak, 2012). Jamaica is one of the largest consumers of seafood in Latin America and the Caribbean, with the main source of the product coming from imports (Brown, 2010) due to the steady decline in the local supply of wild-caught fish. Although there has been a decline, there is still a high demand for fish; as such, aquaculture, particularly tilapia production, is increasingly becoming an alternative source for fish production. Due to this, there has been an increase in aquaculture activities, especially tilapia farming in earthen ponds.

Fish farming in Jamaica has two main inputs for the production cycle: fertilisers and feed. In feed-based aquaculture, only 20–40% of the nitrogen and phosphorous applied to the feed is recovered from the harvested biomass, and the remaining 60–80% remains in the water (Lucas, Southgate, & Tucker, 2019). Residual feed, coupled with pond fertilisation, can lead to nutrient pollution in the natural environment, causing eutrophication, which ultimately leads to the depletion of oxygen in the natural biota. In Jamaica, no study has been conducted regarding the composition and release of effluent from commercial aquaculture fish farms, and there are no laws, regulations, or policies within The Fishing Industry Act of 2018 regarding the effluent release limits from these fish farms. The National Environment and Planning Agency (NEPA) is the leading government agency with a mandate for environmental protection, natural resource management, land use, and spatial planning in Jamaica. It is important to note that NEPA has general legislation regarding the release of trade effluents and requires individuals to obtain an environmental licence and permit for the construction and operation of aquaculture facilities and ponds for intensive fish farming where fish are stocked at a high density (National Environmental and Planning Agency, 2015). At the time of this study, no farm in Jamaica has an intensive fish farming production system, and neither do they have an environmental permit from NEPA. It must also be noted that Jamaica's aquaculture production system is primarily semi-intensive and partly extensive, with most of the farms concentrated in St. Catherine and Clarendon along the southern plains (Figure 4, Figure 5).

1.4 Objectives

The objective of this study is to evaluate the composition of discharge effluents of *Tilapia spp.* fishponds in Jamaica as the Ministry of Agriculture, Fisheries and Mining (MOAFM) seeks to improve food security while ensuring sustainability and conservation for the future. The supporting objectives are as follows:

1. Determine the methodologies used to dispose of effluent water from fish farms in Jamaica.
2. Analyse the levels of biological and chemical agents in aquaculture effluents.
3. Initiate guidelines for the release of aquaculture effluents to ensure a sustainable future for stakeholders.

As the aquaculture sector develops further, the data generated from this research will aid the National Fisheries Authority in granting licences to prospective aquaculture farmers based on location and production systems. This study will also aid in the development of Green Policies for fish farms, harvest rules, effluent release rules, and aquaculture fish farm spatial planning.

2 SIGNIFICANCE OF TILAPIA PRODUCTION

According to Miao et al. (2020), tilapia is the most popular cultured aquatic animal species, with approximately 145 countries reporting production values to the Food and Agriculture Organization (FAO) in 2018. In 2022, farmed tilapia production industries exceeded 6.8 million metric tons while the catfish and salmon industries recorded 1 and 2.86 million metric tonnes respectively (FAO, 2023; GLOBEFISH, 2023; Fitzsimmons K, 2023). Culturing tilapia is of global importance in ensuring food security, as *Tilapia spp*. can grow rapidly and adapt to various environments, making its growth effortless in different aquaculture systems. The farming of tilapia for human consumption has been increasing for the past few years in tropical climatic regions, where there is an exponential rise in global consumption, which the expansion of production is unable to accommodate (Fitzsimmons K, 2011). The commonly farmed tilapia species are as follows:

- *Oreochromis niloticus* (Nile Tilapia), which is widely farmed due to its ability to adapt to various environments
- *Oreochromis mossambicus* (Mossambique Tilapia), which can tolerate brackish water
- *Oreochromis aureus* (Blue Tilapia) which has a high growth rate and suited for warmer climates but can tolerate high salinity and cold waters
- Hybrid *Tilapia spp.* which are created through selective breeding (Tao et al., 2021).

These species are produced in various aquaculture systems, such as ponds, cages, tanks, and raceways, or in integrated systems employing extensive, semi-intensive, or intensive production methods.

Aquaculture in Jamaica plays a significant role in enhancing the food security of the country, as it aids in reducing the demand for imported seafood and provides a trusted source of local fish protein (National Fisheries Authority, 2023a). Jamaica was the pioneer of Tilapia production in Latin America and the Caribbean in the early 2000s where most of the product was exported to Europe and North America (Aiken, Morris, Hanley, & Manning, 2002). Prior to this, fish farmers sold their live fish to vendors from the pond embankment, where they were kept in cages when they attained market size, for ease of retrieval. This increase in production led to the establishment of a rudimentary market in Twickenham Park Spanish Town by the Inland Fisheries Unit (Chakalall & Noriega-Curtis, 1992), which still exists today. Currently, all the tilapia produced in Jamaica is absorbed by the local market. The production system which exists today is semi-intensive, with 291.13 hectares of tilapia ponds distributed between 137 fish farmers across Jamaica (National Fisheries Authority, 2023c) (Figure 5). The production cycle typically lasts six months, after which the farmers typically dispose of the aquaculture effluent as they deem most suitable for them, and then disinfect the pond bottom by adding calcium hydroxide in preparation for the next production cycle.

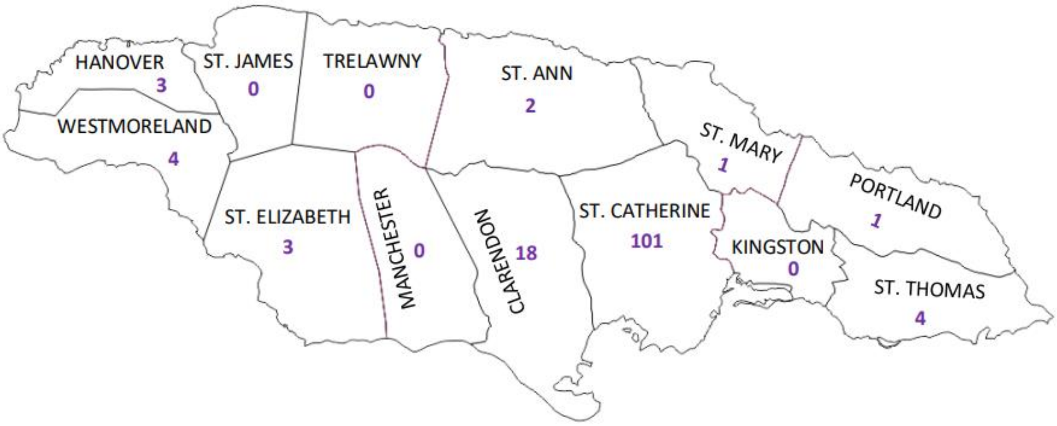


Figure 4. Distribution of the 137 aquaculture fish farmers across the 14 Parishes of Jamaica (National Fisheries Authority, 2023c)

3 AQUACULTURE EFFLUENT MANAGEMENT: ENVIRONMENTAL CONSIDERATIONS

3.1.1 Aquaculture Effluent Composition

Aquacultural effluents are known as waste materials in the water produced from aquaculture operations, which in recent years has become a concern because the amount of water used produces a large amount of wastewater (Kurniawan et al., 2021). Effluents from aquaculture ponds typically consist of a mixture of organic and inorganic particles which can be in solid or dissolved forms, comprising fish waste, residual feed, fertiliser, and metabolic by-products (Ahmad, Abdullah, Hasan, Othman, & Ismail, 2021). Organic compounds typically found in aquaculture effluents include proteins, lipids, carbohydrates, vitamins, and minerals, while inorganic compounds are mainly nitrates, nitrites, and phosphates which contain trace amounts of bicarbonate (Chiquito-Contreras et al., 2022). Additionally, effluents may contain antibiotics, immunity and growth supplements, hormone treatments and other residual chemicals, which in recent times have been reduced due to restrictions placed on these chemicals (Ahmad, Abdullah, Hasan, Othman, & Ismail, 2021 ; Huang, o.fl., 2019). Globally, most aquaculture operations are small-to medium scale enterprises which are mainly for household consumption (subsistence) (Institute International Food Policy Research, 2015) which requires minimum input, due to this knowledge, it can be argued that the average aquaculture effluent main components are residual feed, fish waste and metabolic by-products. The use of antibiotic compounds occurs on larger farms which are considerably fewer and employ an intensive production system which makes the stock more susceptible to bacterial diseases. In intensive aquaculture production systems, antibiotics are utilized to kill or inhibit the growth of microorganisms (Carvalho, David, & Silva, 2012). Although antibiotics, growth supplements and immunity boosters aid in ensuring fast and efficient production, they create a nuisance to the ecological space post-harvest, especially when the farms are larger and utilises a higher concentration of these productivity enhancers (Dauda, Ajadi, Tola-Fabunmi, & Akinwole, 2019). Another component of aquaculture effluents is the presence of bacteria and viruses, which can naturally occur in the production system or as a result of immunocompromised fish which have been innundated with viruses or bacteria (Ozbay & Gulnihal, 2006). There is no fixed aquaculture effluent standard due to the independent operations of aquaculture facilities, which are impacted by the production system utilised, species culture, management practices, and feed input (Table *1*).

Over the last two decades, studies have sought to investigate the composition of aquaculture effluents, with many studies having one consensus which identifies residual feed as the main ingredient contributing to effluent characteristics. According to Yeo, Morris, and Binkowski (2004), the principal source of aquaculture waste in the effluent composition was uneaten fish feed, closely followed by excretory wastes that were consumed but unassimilated by the fish. Despite this, waste from fish feed can be reduced through proper feeding mechanisms, as traces of residual commercial feed are inevitable as the pellets sometimes break down into particles that are too small for the fish to consume, thus leaving remnants in the water (Yeo, Morris, & Binkowski, 2004). Boyd and Tucker (2012) shared the same conclusion in their study which identified the presence of nitrogen and phosphorus compounds in uneaten feed and metabolic waste from fish. The presence of abundant residual feed and excretory wastes often affects the normal acceptable ranges of several water quality parameters owing to the effects of dissolved organic matter. High nutrient loads increase the pH, ammonia, total nitrogen, and total phosphorous, and decrease the available dissolved oxygen (Kurniawan et al., 2021). If water quality parameters are not monitored and regulated during the production cycle, they may have detrimental effects on the stock as well as on the general environment post-harvest during the release of discharge effluents.

Table 1. Characteristics of aquaculture effluents

REFERENCE	Halfhide, Åkerstrøm, Lekang, Gislerød, & Ergas (2014)	Guldhe, Ansari, Singh, & Bux (2017)	Coldebella, o.fl. (2017)	Coldebella, o.fl. (2017)	Coldebella, o.fl. (2017)	Frimpong, o.fl. (2014)	Frimpong, o.fl. (2014)	Frimpong, o.fl. (2014)
CULTURE SYSTEM	RAS	Not specified	Small Intensive System (.3ha)	Medium Intensive System (0.3001 to 0.7 ha)	Large Intensive System (>0.7ha)	Low intensity	Semi-intensive	Intensive
COUNTRY	Norway	Durban (South Africa)	Brazil	Brazil	Brazil	Ghana	Ghana	Ghana
PARAMETER								
Temperature	-	-	15.5	14.5	26.75	-	-	-
Total Dissolved Solids	-	-	46.25	58.75	45	-	-	-
Dissolved Oxygen	-	-	5.4	2.99	1.97	-	-	-
Nitrite (mg/L)	-	-	0.21	0.43	0.2	-	-	-
Nitrate (mg/L)	18.1	40.67	0.4	0.79	0.47	0.01 – 0.1	0.1 – 0.2	0.2 – 0.3
Phosphate (mg/L)	-	-	0.02	0.01	0.02	-	-	-
Ammonia (mg/L)	-	5.32	0.82	2.49	1.78	0.1 – 0.5	0.5 – 2.0	2.0 – 5.0
Total Nitrogen (mg/L)	18.5	90.31	2.48	9.08	6.25	-	-	-
Total phosphorus (mg/L)	~2.5	8.82	0.39	2.2	1.3	0.05 – 0.1	0.1 – 0.3	0.3 – 0.7
BOD (mg/L)	-	-	7.48	49.2	27.75	2.0 – 5.0	5.0 – 20.0	20.0 – 40.0
COD (mg/L)	253	96	23.75	85.25	80	-	-	-
pH	6.97	-	6.81	6.63	6.34	-	-	-

3.1.2 Impacts of Aquaculture Effluents on the Environment

Like all industries, the waste generated will have some impact on socio-ecological standards. According to Cossio (2020), 95% of the global wastewater produced in low- and lower-middle-income countries is discharged into the environment without treatment (Kurniawan et al., 2021). Land-based aquaculture facilities generate effluents that can have a significant environmental impact if not properly managed. Effluents from land-based aquaculture facilities can have various effects on the ecology of the discharge area, such as water pollution, habitat degradation, and nutrient overload which may cause algal blooms and oxygen depletion, often resulting in fish deaths. The level of impact that aquaculture effluents have on the environment depends on the nutrient load which is directly related to the production system, the species being cultured, and the management practices along with environmental conditions (Ahmad, Abdullah, Hasan, Othman, & Ismail, 2021).

When nutrient rich aquaculture effluents are released in receiving water bodies such as rivers, streams, and oceans, the impact it has can result in eutrophication, water quality degradation, alteration of aquatic communities and benthic habitats (Emara, Farfour, & Mousa, 2016). Suspended solids and other physicochemical parameters increase the sedimentation of the receiving water body and the turbidity in the water column. This often results in the suffocation of organisms inhabiting the benthic space and reduces the photosynthetic process in this space. The impact of this often results in changes, such as species composition in aquatic communities, due to new ecological conditions. The components of aquaculture effluents pose an ecological risk at the site of discharge, where residual antibiotics, coupled with traces of diseases and parasites introduced into natural water bodies are often times harmful to wild fish stock, changing their behaviour, displacing native communities and in extreme cases results in fish kills (Ahmad, Abdullah, Hasan, Othman, & Ismail, 2021). Nutrient overload in aquaculture effluent often results in eutrophication caused by high nitrogen and phosphorus components, thus stimulating algal growth, resulting in oxygen-free dead zones in the discharge area. However, researchers have suggested that reducing the nutrient input in the production cycle will help handle the eutrophication problem, while others have argued that this approach will affect production yield and cost (Pihlainen et al., 2020). A study done by Raczyńska, Machula, Choiński, & Sobkowiak (2012) concluded that aquacultural effluent discharge has significant impact on the physio-chemical water quality parameters in rivers where they were discharged. The concentration of nitrogen, and partially phosphorus content and water hardness, increased when the nutrient load from the ponds was released into the river, with a notable continuous increase over several days of sampling. The successive increase may be attributable to the deposition of physiochemical parameters in the bottom sediment and their subsequent slow release. In addition to nitrogen and phosphorus, aquaculture effluents contain a high level of biological oxygen demand, chemical oxygen demand, turbidity, and suspended and dissolved solids which increase their ecotoxicity (Igwegbe et al., 2022).

When nutrient-rich aquaculture effluents are released on land, they have varying effects on the space which one may deem beneficial or disadvantageous. Because of the volume of aquaculture effluents which are normally released, it can reach surface waters depending on the trajectory or it can simply leach, percolate the soil, and contaminate ground water. This ultimately leads to potable water pollution and can affect human and animal health. According to Avnimelech (2009), inland aquaculture has been linked to the pollution of water bodies used for everyday consumption by humans, where it has been estimated that one aquaculture facility can generate waste equivalent to 240 people from just three tonnes of freshwater fish. When such effluents enter the soil, they can lead to soil acidification based on their composition and affect the fertility of the soil and overall agronomy production. It must be noted that aquaculture farmers often utilise the effluent at the end of their production cycle for other farming activities, as the nutrients typically found in aquaculture wastewater are required for plant development (Chiquito-Contreras et al., 2022). A study in an aquaponics system utilising Nile tilapia and tomato concluded that the observed production was similar to that of a conventional hydroponic system (Kloas et al., 2015). Another study, with Nile Tilapia and lettuce, revealed that the aquaponic solution increased plant growth by 39% (Delaide et al., 2016).

3.1.3 Management Strategies

Effluent management is crucial for safeguarding the ecosystem for future generations while maintaining the sustainability of the aquaculture sector. The components in aquaculture effluents generally occur in low concentrations, but because of the quantity of water used in the production system, they may be considered high when compared to other industrial and domestic effluents (Ozbay & Gulnihal, 2006). Understanding the effects of aquaculture effluents on the environment has enabled the development of current global aquaculture management practices and policies. Boyd (2004), Carvalho, David, and Silva (2012), Ozbay and Gulnihal (2006), and Ahmad, Abdullah, Hasan, Othman, & Ismail (2021) have reached a consensus on management strategies used to control the potential impact of aquaculture effluent on the environment. These include effluent treatment systems, recirculation aquaculture systems, and employing the best aquaculture practices during the production cycle.

Maintaining moderate stocking densities and good water quality is the first aquaculture best practice which is a vital management strategy for producing environmentally tolerable effluents. Production systems with good water quality tend to assimilate waste better than ponds with diminished water quality (Boyd, 2004). Monitoring the water quality throughout the production cycle will enable the necessary corrective actions to be undertaken to not only maintain fish health but also the overall health of the ecological space post-harvest. Once anomalies are identified through regular monitoring, water exchange can be applied as a management strategy along with pond draining. Nitrogenous compounds and phosphates are often the most important constituents of aquaculture effluents, as they can cause eutrophication and affect ecology within the environment. Feed management can reduce the nutrient loads of these compounds (Ozbay & Gulnihal, 2006). It has been observed that phosphorous levels in the effluents reached a peak immediately after feeding and returned to the appropriate baseline between feeding times (Coloso et al., 2001). Having efficient FCR, coupled with distributing the feed in smaller quantities several times a day, will lower the concentrations of residual feed and, by extension, nutrient levels in aquaculture effluents. Converting aquaculture ponds to retention ponds after the production cycle is another management strategy and treatment method for aquaculture effluent. Retention ponds allow nutrients to be assimilated by the natural biological processes of the pond and solids to settle at the bottom of the pond (Ozbay & Gulnihal, 2006).

Ahmad, Abdullah, Hasan, Othman, & Ismail (2021) suggests that in improving effluent quality from aquaculture ponds, countries with regulations and policies should implement guidelines and permits for effluents standards while those who lack regulations should encourage better management practices to minimize environmental impacts.

3.1.4 Effluent Treatment Strategies in Aquaculture

Aquaculture farms release effluents based on their management practices and local environmental regulations. Two types of aquaculture effluents are released, treated, or untreated. Untreated effluents are released into the environment, whereas treated effluents are cleaned prior to release. Cleaning includes being transferred to wastewater treatment ponds, biofiltration systems, or vegetative buffers before being released into the environment. In some instances, aquacultural effluents may be discharged into agricultural lands in the form of irrigation as they are able to provide crops with nutrients (Kimera, Sewilam, Fouad, & Suloma, 2021; Al Juboury, Abdulredha, & Nile, 2022). Recently, small-scale and subsistence aquaculture farmers have used aquaponics as a management and effluent treatment method, while large-scale farmers have incorporated integrated multitrophic aquaculture systems (IMTAs) which increases the sustainability of aquaculture practices during the current environmental climate.

The treatment system used in many aquaculture production facilities utilises the natural biological processes of the pond to assimilate waste (Boyd, 2004), where organic matter is converted into carbon dioxide, water, ammonia, phosphate, and other inorganic matter (Gross, Boyd, & Wood., 2000). The most common and simple way of treating aquaculture effluent is desilting, which involves the removal of solid waste from pond culture after two or three production cycles (Ahmad, Abdullah, Hasan, Othman, & Ismail, 2021). This process allows for the accumulation and settling of solid waste at the bottom of the pond which is then removed manually after harvest (Dauda, Ajadi, Tola-Fabunmi, & Akinwole, 2019).

In addition, the development of treatment technology is actively progressing, and woodchip bioreactors, biofiltration, bioremediation, and biofloc usage are still in the research stages (Ahmad, Abdullah, Hasan, Othman, & Ismail, 2021). Biofiltration utilises artificial systems consisting of plants and other substrates to reduce nutrient content by absorption (Chiquito-Contreras et al., 2022). Bioremediation utilises microorganisms to disintegrate organic contents, which in recent times have been integrated into IMTA, where organisms such as sea cucumbers are incorporated because of their detritivorous nature, assimilating particulate organic matter (Chiquito-Contreras, et al., 2022).

Several studies have been conducted to determine the best treatment method for aquaculture effluent. A recent study by Igwegbe et al. (2022) utilised a ´green´ coagulant to treat aquaculture effluents, which generated 74% optimal turbidity removal. The green coagulant was synthesised from the local *Garcinia kola* seed by extraction and placed in a test environment with aquacultural effluent from a nearby fishpond (Igwegbe et al., 2022). Another study utilised electrocoagulation technology using iron-aluminum in the treatment of wastewater from aquaculture ponds, which generated 92% turbidity removal (Igwegbe, Onukwuli, & Onyechi, 2019). A set of 16 experiments were conducted using the Box–Behnken design with independent variables of charge time, current, and settling time to determine the most ideal procedures to remove pollutants in aquaculture effluents (Igwegbe, Onukwuli, & Onyechi, 2019).

The use of recirculating aquaculture system (RAS) not only helps in treating effluent but also reduces the need for fresh water as the water is reusable. 85-98% of the organic matter and suspended solids are removed while 65-96% of the phosphorous is removed (Dauda, Ajadi, Tola-Fabunmi, & Akinwole, 2019). Residual nutrients from a RAS with 3.4 tons of fish can aid in the production of 35 t of tomatoes when utilised as a fertiliser (Yogev, Barnes, & Gross, 2016). The increase in water reuse systems in aquaculture is another method of treating aquaculture effluents (Verdegem, 2013). Although the initial cost and space requirement may be high, compensation is inevitable, as there will be no cost to treat the waste, as it will be mechanically removed from the system compared to treating effluents discharged from ponds or flow-through systems. RAS saves water and allows the waste to be repurposed into compost or undergo further treatment and used on land (Turcios & Papenbrock, 2014).

Another economical treatment method involves the use of reed beds. In one study, water from a fishpond was channelled from fishponds to reed beds (macrophyte pond), where there was a notable removal of all nutrients (approximately 90 %), except for phosphorous which was 80% (Kerepeczki et al., 2011). Reed beds, also known as constructed wetlands, are becoming more important as they are a more cost-effective method for treating aquaculture effluents (Turcios & Papenbrock, 2014).

3.2 Guidelines on effluent management

3.2.1 Guidelines for Aquaculture Effluent Management

Understanding the composition of effluents from aquaculture ponds, specifically tilapia fish farms, is essential for assessing the environmental sustainability of operations for all stakeholders. Incorporating aquaculture effluent management strategies into the tenets of good aquaculture practices for tilapia farming operations aids in mitigating potential environmental issues. Regular monitoring and analysis of effluent parameters are crucial for ensuring compliance with environmental regulations, according to each country´s specifications. Based on the literature reviewed, guidelines on effluent management vary depending on the country´s environmental regulations, the production system utilised, and the location of aquaculture activities.

Pouil et al. (2019) stated that the culture systems of earthen ponds result in a higher nutrient load along with plankton growth, suspended solids, and higher oxygen demands, necessitating the implementation of policies and regulations. Several countries such as the United States of America, Thailand, Taiwan, and Hawaii have established water quality standards for aquaculture effluents in their regulations, while countries such as Malaysia have not yet enforced regulations regarding aquaculture effluents but have instead relied on guidelines from Environmental Quality (Industrial Effluent) Regulation 2009 (Ahmad, Abdullah, Hasan, Othman, & Ismail, 2021).

Utilising the best management practices in aquaculture can significantly impact the water quality in tilapia production systems. In a recent study, it was concluded that floating feed is associated with higher water quality, especially dissolved oxygen concentration.
Yeo, Morris, & Binkowski (2004), Tucker, (1998) and Tucker, Boyd, & Hargreaves (2002) made several recommendations to reduce the impact of effluents from aquaculture ponds. It can be deduced from the guidelines reviewed that the general recommendations for managing aquaculture effluents from tilapia earthen ponds are:

1. Effluent monitoring: Key effluent parameters should be monitored regularly, such as dissolved oxygen, ammonia, biological oxygen demand, chemical oxygen demand, nitrate, nitrite, and phosphates. Monitoring should be conducted prior to release and at the effluent release point.

2. Efficient feeding strategies: Commercial pellets used to feed tilapia are often loaded with nutrients, which, when remaining in the water, lead to eutrophication and water quality degradation. An optimised feed conversion ratio aids in reducing residual feed (Tucker, Boyd, & Hargreaves, 2002).

3. Waste management strategies throughout production: Ensure that uneaten feed is removed along with any other visible organic or inorganic matter.

4. Effluent treatment and recycling: Using settlement tanks to remove suspended solids, nutrients, and contaminants; reed beds to remove nutrient loads; and biofilters to extract organic matter which can be used for fertilisers. When treated, effluent water can be recycled and used in the next production cycle or for irrigation purposes for agricultural lands (Yeo et al., 2004; Tucker, 1998).

From the general guidelines, it is concluded that effluent management must be performed during the production cycle and before release to the environment, with post monitoring testing at the discharge site on an ad-hoc basis.

3.2.2 Regional Guidelines for Aquaculture Effluent Management

In Latin America and the Caribbean region, there is a country-specific regulatory framework governing aquaculture discharge guided by international organisations such as the FAO and the Network of Aquaculture Centres in Latin America and the Caribbean. Regulatory compliance and certification of aquaculture activities are important for *Tilapia spp.* farming operations as they ensure the success of the business while ensuring that the practices are in alignment with aquaculture best practices for environmental conservation (Ahmad, Chin, Harun, & Low, 2022). Having good water quality standards during production ensures a safe and healthy environment for fish stock and minimises any environmental impact during discharge. This measure protects biodiversity in the local ecosystem at discharge locations. Three well-known global aquaculture certification programs are Global Aquaculture Alliance (GAA), Aquaculture Stewardship Council (ASC) and Friend of the Sea (FOS), which all promote responsible aquaculture practices geared towards environmental responsibility.

It is important to incorporate environmental impact assessments (EIAs) into the granting of aquaculture licences and permits, as this is an effective way to protect the environment, and identification of potential consequences in the planning process will allow for proper management. According to Van Wyk and Davis (2006), governments often exempt small-scale aquaculture developments from EIA requirements; however, many small-scale aquaculture farms, concentrated in the same area, can have a potential cumulative effect on the environment.

4 METHODOLOGY

4.1 Study Area

The study area encompasses the tilapia fish-farming industry in Jamaica (Figure 4 Figure 5). The major target group for this study was commercial aquaculture farmers, who were active all year and were selected from the Aquaculture Division's internal database. Due to the number of farms located across Jamaica, only a few were randomly sampled and used in the questionnaire aspect of the study. It was ensured that the selected farms production area spanned at least 0.04 hectares, with at least one pond in operation on the property.

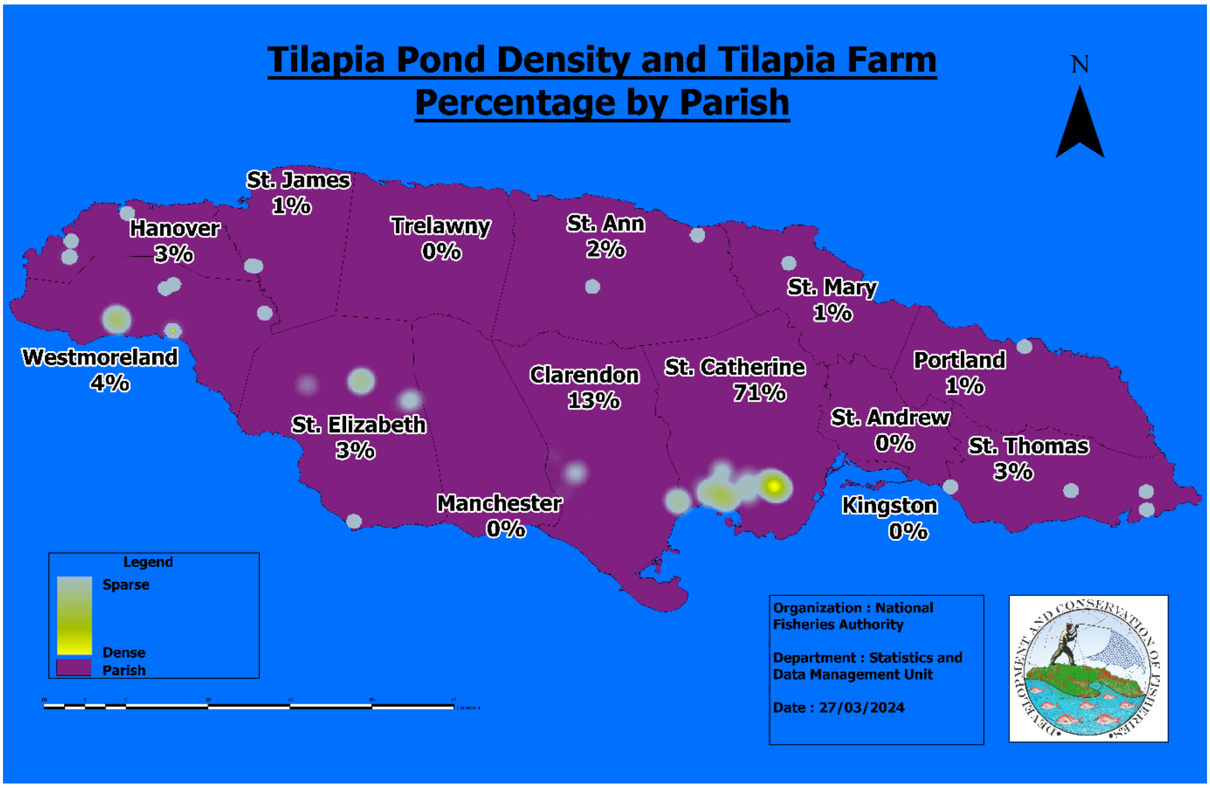


Figure 5. Spatial distribution map for aquaculture tilapia fish farms in Jamaica

4.2 Questionnaire Implementation

The questionnaire (Appendix I) was distributed to 50 active commercial *tilapia spp.* fish farmers in Jamaica. The fish farmers selected were located throughout the 14 parishes of Jamaica, with most questionnaires answered by respondents in the main aquaculture area in the parish of St. Catherine (Figure 5). The responses were manually recorded and transferred to a Microsoft Excel spreadsheet for ease of reference.

4.3 Aquaculture Effluent Composition Analysis

The second phase of the research was a laboratory analysis of aquaculture effluents from two tilapia fish farms in Jamaica, hereafter known as testing location 1 (TL1) and testing location 2 (TL2). This study initially aimed to comprehensively analyse the effluents from seven (7) aquaculture fish farms in Jamaica. However, because of the time constraints of the GRÓ Fisheries Training Programme, the harvesting periods of the additional farms did not align; therefore, laboratory analysis was not performed during this period. The additional farms, however, will be sampled at a later date and samples will continue to be taken over a period of one year for all farms to determine trends to facilitate the sustainable development of the sector.

Samples from both the water source (inlet) and effluent (outlet) were collected from the farms by an Aquaculture Research Officer from the National Fisheries Authority according to directives provided by the Scientific Research Council (SRC). After collection, the samples were transported to the laboratory in a sterile igloo with ice within 24 hours. The SRC engineering team then analysed the samples using the Hach and Standard Methods for the Examination of Water and Wastewater (SMEWW) testing methods for 13 parameters: ammonia, nitrate, nitrite, total coliform, faecal coliform, total suspended solids, total dissolved solids, pH, biological oxygen demand, chemical oxygen demand, fat oil and grease, total phosphorous, and detergents. The results were then cross-referenced against established standard effluent limits for intensive aquaculture effluents from NEPA (Table *2*).

Table 2. Aquaculture effluent limits for intensive fish farming in Jamaica (modified from NEPA)

Parameter	**Effluent Limit**
Ammonia	1.0 mg/L
Detergents	15 mg/L or <0.015 kg / 1000 kg product
Nitrate (as nitrate and nitrite)	10 mg/L
Oil and Grease	10 mg/L or <0.01 kg / 1000 kg product
pH	6.5 - 8.5
Phosphate	5.0 mg/L
Total Dissolved Solids	1000 mg/L
Temperature	2°C < OR > Average Ambient Temperature
Total Suspended Solids	Max. Day <150 mg/L Monthly Average 50mg/L
Biological Oxygen Demand (BOD)	<30 mg/L
Chemical Oxygen Demand (COD)	<0.1 kg / 1000 kg product or <100mg/L
Dissolved Oxygen (DO)	>4 mg/L

4.4 Results Analysis

4.4.1 Questionnaire

The collected data were first cleaned and then analysed using a comprehensive approach using Microsoft Excel. This allowed for easy inference to determine the existence of a correlation between qualitative and quantitative variables.

4.4.2 Laboratory Analysis

The data received from the laboratory analysis of the water source and effluent samples were first organised in Excel to generate the statistical analysis presented in graphs.

5 RESULTS

5.1 Status of Effluent Management in Jamaica

The first step in the evaluation of discharge effluents from commercial aquaculture fish farms is identifying and recognising the current status of management practices, the source of water, and disposal methodologies. At the time of this study, 50 farmers were interviewed (70% of St. Catherine, 22% Clarendon and 8% other) while effluents from two farms were collected for laboratory analysis.

5.1.1 Water Source

Aquaculture fish farms in Jamaica obtained water from several sources (Figure 6). The survey concluded that 74% of the water sources for commercial aquaculture fish farmers came from The National Irrigation Commission. The remaining water sources for aquaculture production are rivers, springs, and wells which supply 12%, 10%, and 4% of the aquaculture fish farmers, respectively.

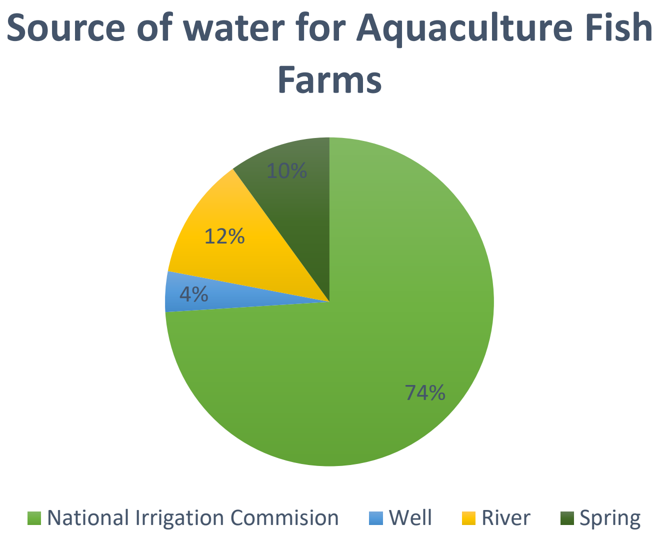


Figure 6.Source of water for aquaculture fish farms

5.1.2 Water Quality Management During Production Cycle

The results from the study showed that 84% of the commercial tilapia fish farmers interviewed did not conduct a water quality analysis during the production cycle. Further investigation of the reason for the lack of testing concluded that the lack of training, lack of equipment coupled with its cost, and accessibility resulted in no water quality analysis being conducted.

For 16% of farms that performed water quality analysis during the production cycle, the questionnaire showed that the quality analysis was carried out mainly by employees (50%), both employees and government agencies (17%), both employees and external laboratories (17%), or just a government agency (16%) (Figure 7). The commonly tested parameters were temperature, Dissolved Oxygen (DO), and pH. Of note is that one correspondent conducts a monthly analysis performed by an external laboratory which includes the assessment of other water quality parameters such as ammonia, nitrates, nitrites, phosphate, hardness, fat oil and grease, detergents, total dissolved solids (TDS), total suspended solids (TSS), biological oxygen demand (BOD), chemical oxygen demand (COD), total coliform, and faecal coliform.

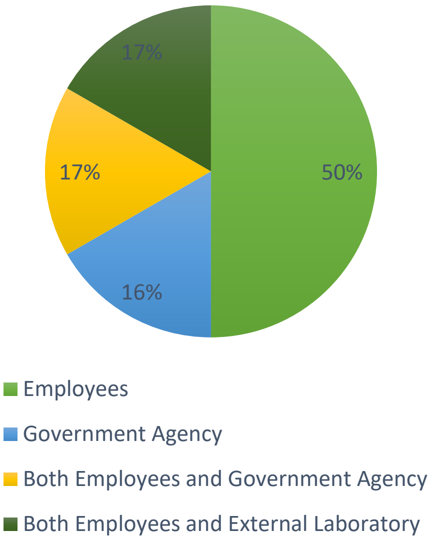


Figure 7. Administration of water quality analysis

33% of the respondents who performed water quality analysis revealed that they experienced deviations in their testing, but initiated the necessary corrective measures as soon as it was seen. These deviations were:

- Low DO levels which often occurred in the mornings at the time of testing.
- High levels of total coliforms during the rainy season which occurred due to agricultural activities occurring in the vicinity of the river (water source). This has been resolved over the past two years, as agricultural farmers have removed their animals from close proximity to the river.
- High pH levels were detected, and the ponds were immediately flushed upon notice.

5.1.3 Effluent Management Plan

The results showed that the majority (86%) of commercial tilapia fish farmers in Jamaica did not use an effluent management plan in their operations (Figure *8*). The consensus from the respondents regarding the lack of an effluent management plan was that their operations were considerably small, and the expense that would be associated with installing the structures and the space required made it not feasible.

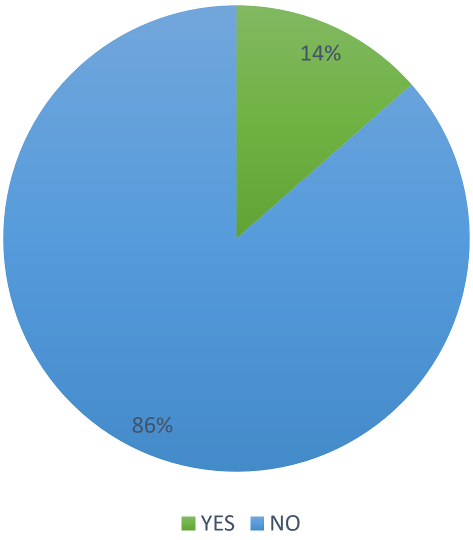


Figure 8. Percentage of farmers that utilise an effluent management plan

Effluents from aquaculture operations were released at various locations (Figure 9). However, most commercial aquaculture fish farmers in Jamaica operate agricultural land, and several respondents (21%) stated that they utilise the effluent from their farms for irrigation purposes. Some respondents (19%) also utilize the canal system which may be considered as an improvised settlement tank where suspended solids and silt sink to the bottom during transport to the final release point.

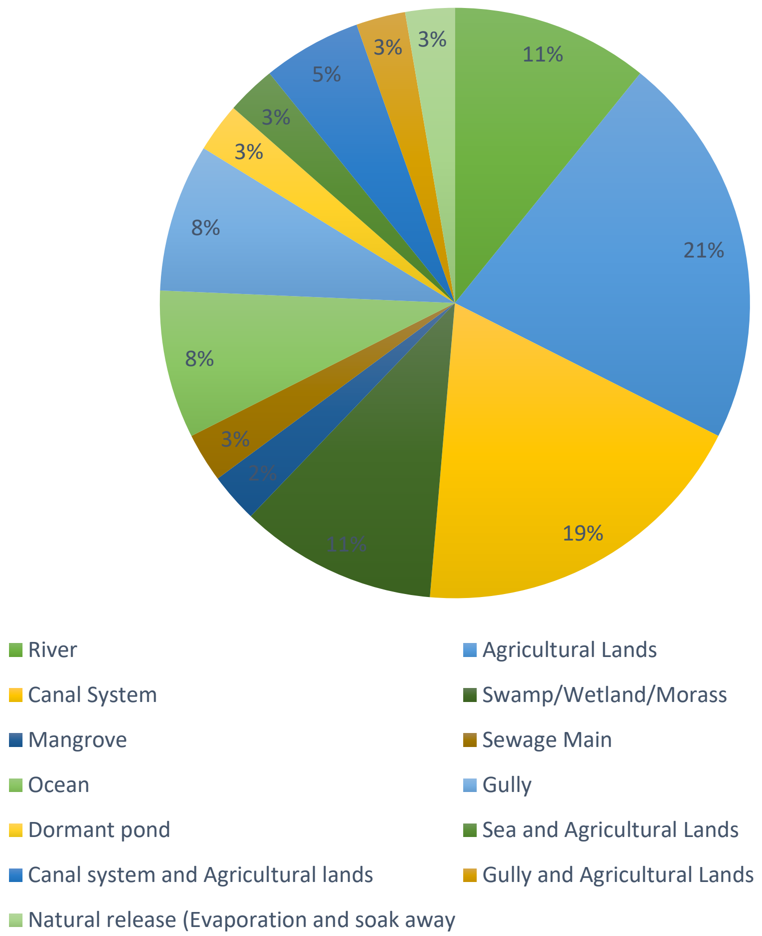


Figure 9.Site of release of aquaculture effluents in Jamaica

Before releasing the effluent at the final site, 20% of commercial aquaculture fish farmers inadvertently employ treatment methods where excessive nutrient extraction is performed. From the survey conducted, farmers who utilised an effluent treatment method employed a settlement tank (80%), whereas others utilised a reed-bed (10%) or a sinkhole (10%) (Figure *10*).

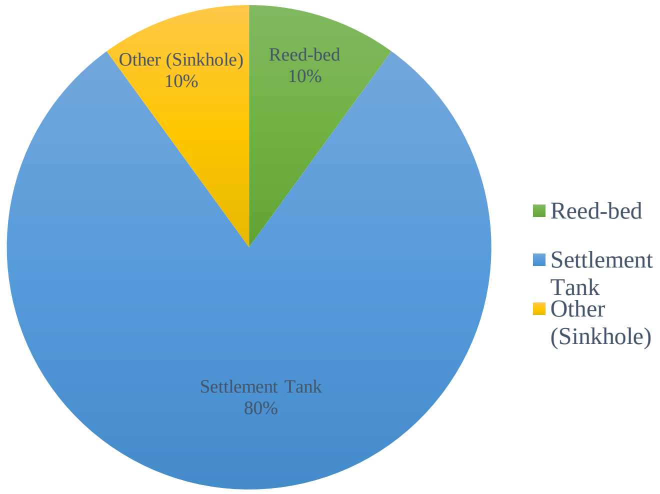


Figure 10. Treatment methods used for aquaculture effluents

5.2 Effluent Composition from Fish Farms in Jamaica

5.2.1 Nitrates and nitrite levels

The level of nitrate at both TL1 and TL2 from the inlet (0.9 mg/L and 5.06 mg/L respectively) and outlet pipe (0.9 mg/L and 0.9 mg/L respectively) are well below the standard effluent limit (10 mg/L) set by NEPA (Figure *11*). In contrast, the nitrite levels were significantly higher than the standard effluent limits (10 mg/L) set by NEPA. The outlet pipe in TL1 recorded nitrite levels of 102 mg/L, whereas the outlet pipe in TL2 recorded 87 mg/L. Decomposition of ammonia from aquaculture feed or algae results in high nitrite levels.

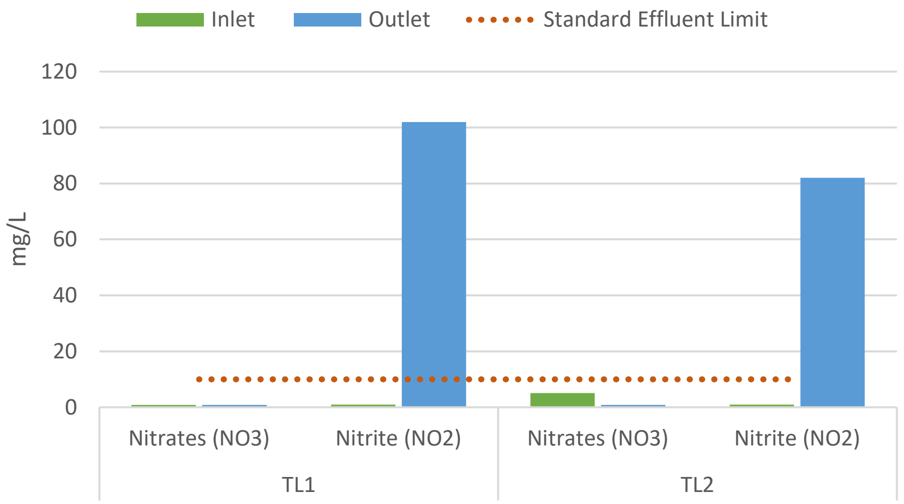


Figure 11. Nitrate and nitrite levels from the inlet pipe (water source) and the outlet pipe (aquaculture effluent) in TL1 and TL2

5.2.2 Phosphorous levels

From the analysis, it was observed that the total phosphorous levels for both TL1 and TL2 at the inlet (TL1- 0.28 mg/L), TL2- 0.88 mg/L and outlet pipes (TL1- 0.93 mg/L, TL2 – 1.04 mg/L) were well below the standard effluent limit (5 mg/L) set by NEPA (Figure *12*). It must be noted that there was a slight elevation in the total phosphorus level at the outlet pipes, although it remained within the limits in both locations.

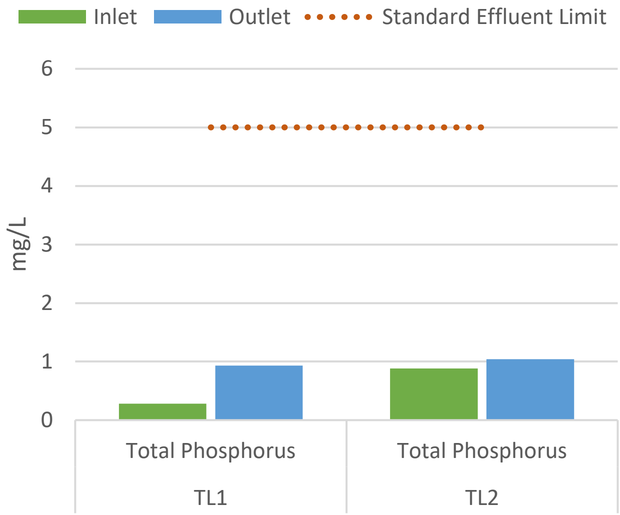


Figure 12. Total phosphorous levels from inlet pipe (water source) and the outlet pipe (aquaculture effluent)

5.2.3 *Faecal and total coliform levels*

It was observed from the sample analysis (Figure *13* and Figure *14*) that the total coliform levels were elevated in both the inlet and outlet pipes for TL1 and only the outlet pipe for TL2 (920 MPN/100 mL, 540MPN/100mL, and 1600 MPN/100 mL, respectively). The level of faecal coliform was high in the inlet pipe for test location one (240 MPN/100 mL) and outlet pipe for TL2 (920MPN/100mL).

The source of water is from NIC which provides non-potable water (untreated) for irrigation purposes in farming communities. Some animals forage in the vicinity of the system which explains the elevated coliform levels in samples from both the inlet and outlet pipes.

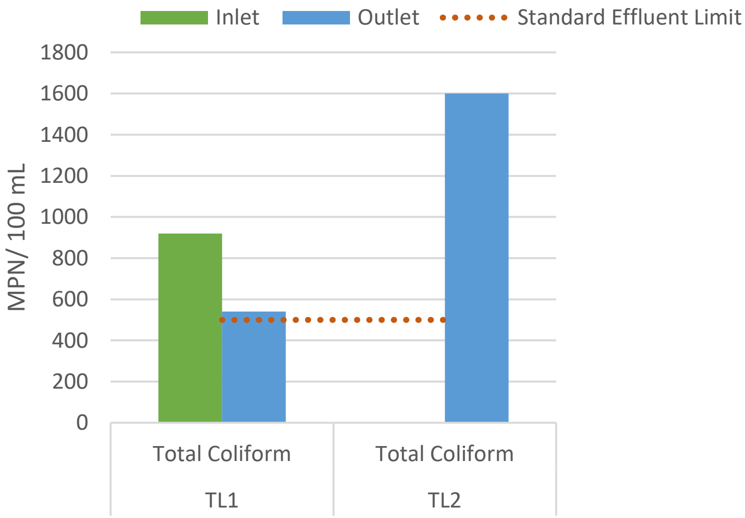


Figure 13. Level of total coliform from the inlet pipe (water source) and the outlet pipe (aquaculture effluent)

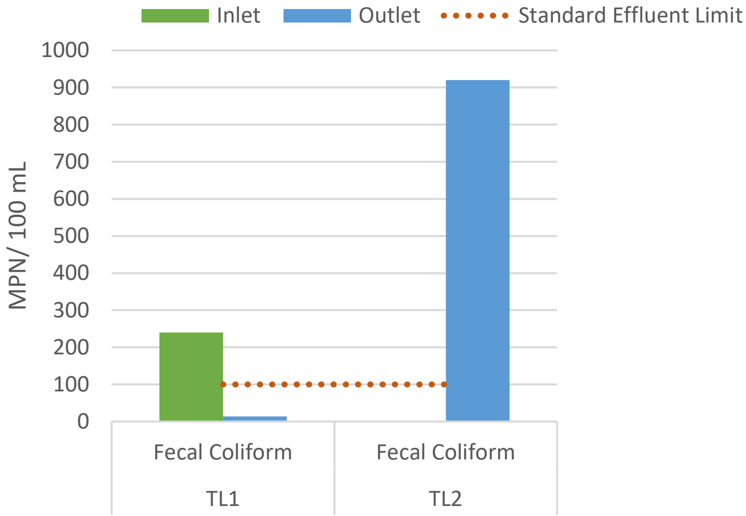


Figure 14. Level of faecal coliform from the inlet pipe (water source) and the outlet pipe (aquaculture effluent)

6 DISCUSSION

Sustainability of aquaculture in Jamaica is of great importance to the fisheries sector. Evaluation of effluents from commercial aquaculture fish farms in Jamaica is required to determine the ecological standpoint for all stakeholders. This study was conducted to examine the current management practices for aquaculture effluents and the composition of these discharge from the commercial aquaculture *Tilapia spp.* sub-sector in Jamaica and is the first assessment of this magnitude. Innumerable findings were obtained from questionnaires distributed to fish farmers throughout Jamaica, as well as from the analysis of effluent discharge from two randomly selected farms.

6.1 Evaluation of Effluent Analysis in Jamaica

The results of the analysis from the inlet and outlet pipes at aquaculture tilapia production facilities in Jamaica showed that overall, the effluent composition was within the standard limits established by NEPA (Appendix II). Apart from nitrite and coliform levels which were elevated above the limit, the phosphorous and nitrate levels were within the pre-established limit. The diverse levels of aquaculture management practices across fish farms in Jamaica, such as stocking density, feeding regime, and water quality monitoring, may result in differing effluent limits. Regardless of the different management strategies utilised during the production cycle, it was observed from the analysis at TL1 and TL2 that there were no significant differences in the levels of the physiochemical parameters tested.

The observed phosphorous levels from the farms sampled denoted that the phosphorous levels are well below the standard limits set up by the NEPA. It was observed that the total phosphorous levels (Figure *12*) in the aquaculture effluent were 0.93 mg/L and 1.04 mg/L, for TL1 and TL2 respectively which is below the standard effluent limit of 5.0 mg/L. Nitrates were also below the standard effluent limit of 10 mg/L, with TL1 and TL2 indicating the same value of 0.9 mg/L in the effluent. In contrast, the nitrite levels (Figure *11*) were significantly higher than the standard effluent limit of 10 mg/L at both locations, where TL1 recorded a value of 102 mg/L and TL2 recorded a value of 87 mg/L. Although no further investigation was done at the site of release regarding the impact on the environment, it has been shown that nitrogen and phosphorous are often cause for concern, as they can lead to eutrophication and environmentally deleterious events (Ahmad et al., 2021; 2022; Raczyńska, 2012). The data are synonymous with declarations made by Lucas (2019), which predict that 60–80% of nitrogen and phosphorous will remain in aquaculture effluents derived from feed. Based on the duration of the study, further analysis is needed to determine the percentage of nitrogen and phosphorous remaining in the water as a result of the feed.

Concerning the total coliform levels (Figure 13)Figure *13*, the observed results in the effluents discharged from both locations were above the standard effluent limit set up by the NEPA. However, it must be noted that at TL1, the total and faecal coliform levels (Figure *14*) at the water source were noticeably higher than the standard limits set up by NEPA, 920MPN/100mL and 240 MPN/100 mL, respectively). These results could be related to the location of the production facility, as aquaculture areas within farming communities are more likely to have increased coliform due to the foraging of animals near the source of water. During the effluent analysis stage, the levels were reduced to 540 MPN/100 mL and 14 MPN/100 mL respectively. It would be expected that these levels should be higher in other effluent water but not in fish ponds, and once aquaculture best practices are employed in the production cycle, it is expected that waste would be assimilated through natural biological processes (Boyd, 2004; Gross, 2000), which is reflected in the data obtained. In contrast, at TL2, the total and faecal coliform levels at the water source were below the standard limits set by NEPA, as expected. On the other hand, the aquaculture effluents for total and faecal coliform were well above the standard effluent limit, recording values of 1600MPN/100mL and 920MPN/100mL respectively. It may be inferred that the natural biological processes of the pond at TL2 are sub-standard, resulting in a lack of microbial action to assimilate the waste (Boyd C. E., 2004; Gross, 2000).

Concerning ammonia, the levels were below the standard limits of 1.0 mg/L for both the inlet and outlet pipes at TL1, recording values of 0.05 mg/L for both. However, at TL2, the level at the inlet pipe was 0.02 mg/L but the outlet level was slightly elevated at 1.12 mg/L. This elevated level could be attributed to the use of nitrogen based agricultural fertilizers (Emara, Farfour, & Mousa, 2016).Although feed and fertiliser inputs are the main contributors to the effluent composition, the exact nutrient input rate needs to be further studied to create linkages, as it is not possible to determine a general pond production system as different farms utilise different inputs.

Although the effluent results obtained from TL1 and TL2 were similar in value, it must be noted that the values of a few physiochemical parameters for effluent analysis for TL2 were outside the pre-established standard effluent limits (Appendix II). No consensus could be reached during this study because more investigation is required regarding the general production cycle processes, such as water source, feeding regime, fertiliser input, water quality monitoring during the production cycle, and aquaculture best practices.

6.2 Aquaculture Effluent Management Practices in Jamaica

The results obtained from the questionnaire concluded that no fish farm owner or operator in Jamaica has an established aquaculture effluent management plan in their production system. Nevertheless, although there is a lack of a documented management plan, it has been deduced that the practices employed by fish farmers throughout Jamaica are identical to those which lay the foundation for aquaculture effluent management policies and guidelines. Such practices include having a good source of water, moderate stocking densities, efficient FCR, monitoring water quality during the production cycle, and even effluent treatment systems (Boyd, 2004; Ozbay & Gulnihal, 2006; Carvalho, David, & Silva, 2012; Ahmad, Abdullah, Hasan, Othman, & Ismail, 2021). Fish farms throughout Jamaica employ a semi-intensive production system that is sparsely distributed across the island. Although the major aquaculture farming communities at St. Catherine and Clarendon (Figure 5) have a high density of aquaculture farms, they are widely distributed throughout the Parish, which should indicate that during the release of effluents from these facilities, there would be no nutrient load expected in the immediate environment. The farms within the remaining Parishes are few and far between each other and often have lower production.

To understand aquaculture effluents, their composition must first be understood. In the survey conducted, the majority of respondents (79%) indicated that the source of their water came from NIC. NIC is a governmental institution which manages and operates irrigation systems in farming communities in Jamaica. Their mandate prioritises the welfare of their clients and, as such, enables the provision of secure and reliable irrigation services through a series of canal systems in these communities. This implies that the water supplied to most fish farms is of high standard, thus contributing to good effluent standards once best aquaculture practices are maintained. During the production cycle, 84% of respondents noted that they did not monitor water quality during the production cycle or conduct testing for several reasons. One is that the NIC carries out its own quality checks and standards on the product being distributed to clients. Coupled with this rationalisation, *Tilapia spp.* are considered hardy species that are adaptable to various conditions. Therefore, substandard water quality does not affect metabolic processes or their ability to grow. Further investigation also revealed that reasons why the majority of the respondents who do not conduct water quality checks during the production cycle is due to a lack of access to the required equipment and lack of training. Increasing the availability of equipment and training sessions for water quality monitoring during the production cycle will enable traceability of physiochemical parameters for optimal production. For 16% of respondents who perform water quality monitoring during the production cycle, the services are administered by employees, personnel from government agencies, external laboratories, or a combination, which mainly tested the pH, temperature, and dissolved oxygen levels. Further investigation revealed that 67% of the farms which conducted water quality monitoring tests during the production cycle experienced deviations in at least one parameter, with the necessary corrective measures undertaken to restore normality.

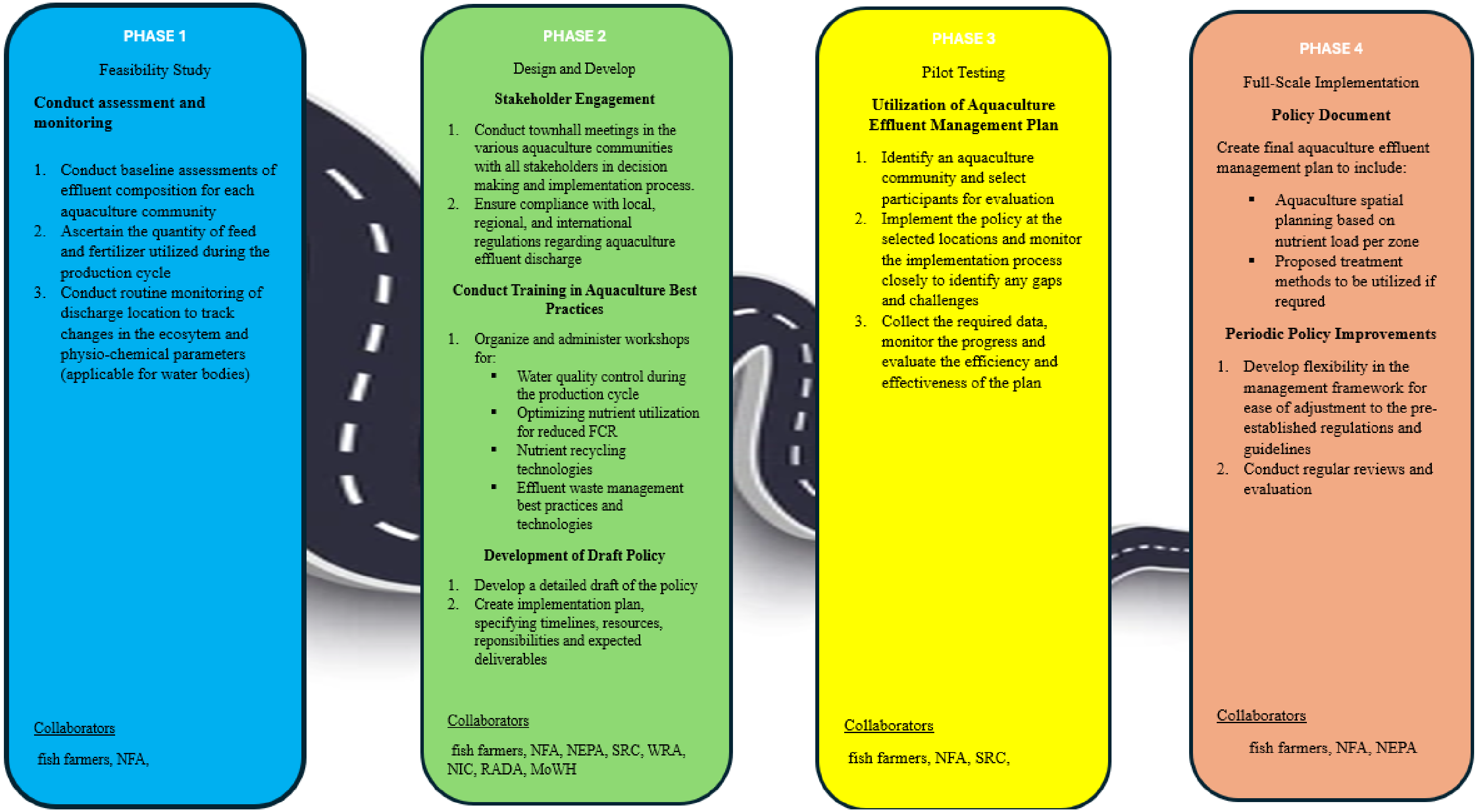
Currently, there are no guidelines, regulations, or policies regarding the release of aquaculture effluent. The questionnaire revealed that there are four main sites for the release of aquaculture effluents: agricultural land (21%), canal systems (19%), rivers (11%), and swamps, wetlands, and morasses (11%). The minor sites (38%) of release are gullies, dormant ponds on property, the ocean, mangroves, sewage main, or soak away pits. The canal systems which most aquaculture farmers utilise during effluent discharge serve as makeshift settlement tanks, as when the effluents are released, they remain in the canal for a period of time. This allows suspended solids to settle to the bottom of the canal as the water flows through. Although there is an absence of an effluent management system, several post-harvest practices suggest that effluents are being released in an environmentally safe manner. One such measure is the utilisation of effluent treatment areas. From the questionnaire, it was inferred that 27% of the respondents who stored their effluents before release utilised a settlement tank (80%), reed-bed (10%), and sinkholes (10%).

The surveyed fish farmers deduced that no negative environmental impact was visible in the vicinity of their site of effluent release. It must be noted that some respondents stated that they utilised their effluents for irrigation purposes on their agricultural crops, as most are in farming communities. This allows for better management of resources, especially during periods of drought where water scarcity is of utmost importance, and they have both natural fertiliser and access to water.

6.3 Implementation Plan for Aquaculture Effluent Management in Jamaica

The development of an aquaculture effluent management policy is important, as the sector continues to expand. For the policy to be implemented in an effective manner, there needs to be a sequence of activities to ensure proper execution, and that the protocols within the policy are practical and understood by all stakeholders. The implementation plan (Figure 15) provides action to be taken for this purpose. The first phase of the implementation plan is to conduct a feasibility study of the effluent composition for all fish farms across the island to create a baseline assessment of the current levels of the different effluent parameters. During this phase, the linkage between the production system inputs, such as feed and fertilisers, should be determined, as well as the routine monitoring of the discharge location. The information gathered by the research department of the aquaculture division during this phase will guide the development of a draft policy for the second phase. During this phase, there must be a stakeholder engagement session with the owners and operators of fish farmers, along with members of the community in which the farms are located, and various government entities whose policies and regulations coincide with the implementation plan. After these consultations, it is essential that training sessions are held to educate personnel on effluent waste management and water quality testing during the production cycle to promote best aquaculture practices.

After the successful completion of phase one and two, the draft policy should be tested in a small pilot study to determine the actual practicality of the protocols to be implemented. This will be done in phase three which will involve a small aquaculture community with select participants. The policy will be put into action, where data will be collected over the period, so that any gaps or challenges identified can be addressed. This will lead to phase four which will be a gradual introduction of the policy throughout all aquaculture communities in Jamaica. After full implementation, there will be periodic reviews to ensure that sustainable aquaculture remains a priority.



PHASE 1

Feasibility Study

Conduct assessment and monitoring

1. Conduct baseline assessments of effluent composition for each aquaculture community
2. Ascertain the quantity of feed and fertilizer utilized during the production cycle
3. Conduct routine monitoring of discharge location to track changes in the ecosytem and physio-chemical parameters (applicable for water bodies)

Collaborators

fish farmers, NFA,

PHASE 2

Design and Develop

Stakeholder Engagement

1. Conduct townhall meetings in the various aquaculture communities with all stakeholders in decision making and implementation process.
2. Ensure compliance with local, regional, and international regulations regarding aquaculture effluent discharge

Conduct Training in Aquaculture Best Practices

1. Organize and administer workshops for:
    - Water quality control during the production cycle
    - Optimizing nutrient utilization for reduced FCR
    - Nutrient recycling technologies
    - Effluent waste management best practices and technologies

Development of Draft Policy

1. Develop a detailed draft of the policy
2. Create implementation plan, specifying timelines, resources, reponsibilities and expected deliverables

Collaborators

fish farmers, NFA, NEPA, SRC, WRA, NIC, RADA, MoWH

PHASE 3

Pilot Testing

Utilization of Aquaculture Effluent Management Plan

1. Identify an aquaculture community and select participants for evaluation
2. Implement the policy at the selected locations and monitor the implementation process closely to identify any gaps and challenges
3. Collect the required data, monitor the progress and evaluate the efficiency and effectiveness of the plan

Collaborators

fish farmers, NFA, SRC,

PHASE 4

Full-Scale Implementation

Policy Document

Create final aquaculture effluent management plan to include:

- Aquaculture spatial planning based on nutrient load per zone
- Proposed treatment methods to be utilized if requred

Periodic Policy Improvements

1. Develop flexibility in the management framework for ease of adjustment to the pre-established regulations and guidelines
2. Conduct regular reviews and evaluation

Collaborators

fish farmers, NFA, NEPA

Figure 15. Implementation plan for developing a policy framework for the management of aquaculture effluents in Jamaica

7 CONCLUSION AND FUTURE POLICY RECOMMENDATIONS

7.1 Conclusion

As the aquaculture industry seeks to achieve sustainability in all aspects of operations, aquaculture effluent should be prioritised. Pollutants in aquaculture systems are unavoidable, but management practices and treatment methodologies, where necessary, must be employed to ensure that the values of the pollutants are within the standard effluent limits, according to pre-established guidelines from national, regional, and international organisations. Although the study period was short which affected the sample size for effluent analysis, the results generated from this study will assist in future investigations as the aquaculture sector continues to grow.

The outcomes of the study were as follows:

1. Effluents from *Tilapia spp.* farms in Jamaica are within the standard effluent limits set by the NEPA. The outliers of the effluent limits for particular parameters are due to external factors which can be better controlled.

2. Although no aquaculture effluent management plan exists, fish farmers are cognizant of the environmental impacts which aquaculture effluents may have at discharge locations, and have practices in their operations to delimit any negative environmental impact.

This study has provided significant insight into the current management of effluents from aquaculture fish farms in Jamaica. It is important to note that there is currently no major significant environmental harm to aquaculture effluents; however, it is critical to implement guidelines and policies with a view towards environmental sustainability as the further development of tilapia fish farming occurs.

7.2 Recommendations

The following recommendations are proposed:

- Further investigations must be conducted by increasing the number of test sites to increase the perception of aquaculture effluents in Jamaica.

- Annual training of aquaculture fish farmers in effluent management and water quality analysis

- Development of a green license for aquaculture producers

- Testing of aquaculture effluents to be conducted by the Aquaculture Division

- Create a database for results from effluent analysis to establish trends and any possible changes

- Implementation of a reuse cycle for farmers who perform mixed farming or transport to nearby agricultural counterparts after testing, with favourable results to alleviate the effects of drought.

- Develop and implement a long-term aquaculture effluent management which considers:
    1. Aquaculture spatial planning at the application stage for fishpond construction
    2. Periodical testing of water source by an accredited laboratory
    3. Periodical testing of aquaculture effluents by an accredited laboratory
    4. Development of aquaculture effluent treatment plans

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APPENDICES

Appendix I

Thank you for participating in this study. The information you provide will help The National Fisheries Authority to assess the water quality of effluent from fishponds and its potential environmental impact in Jamaica. The information provided will be kept confidential and presented as collated data for all fish farms assessed at the end of the study.

GENERAL INFORMATION

Date:--

Name of Fish Farmer (owner): --

Name of Fish Farm: --

Location of Farm (GPS coordinates, if available): ---

Contact Information (phone number / email address): ---

Total area of fishponds (acres): ---

Total number of ponds: --

Total number of ponds in production: --

Tilapia Fish Species Cultivated: --

Average pond depth (feet): ---

WATER SOURCE ON FISH FARM

1. Location of water entry point on property (G.P.S coordinates and description):

2. Source of water entry point:

NIC ☐ Well ☐ River ☐ Other ---------------------------

3. Type of system at entry point:

Pressurized ☐ Gravity fed ☐ Both ☐

WATER QUALITY TESTING DURING PRODUCTION

1. Do you collect water samples for testing?

   Yes ☐ No ☐

2. If ‘yes’, what water quality parameters do you routinely test for during production?

   pH ☐ Dissolved Oxygen (DO)☐ Ammonia ☐ Nitrate ☐

   Total Suspended Solids ☐ Temperature ☐ Other---------------------------------

3. Who conducts the water testing?

   In-house personnel☐ External laboratory ☐ Government agency ☐

   Other: --------------------------

4. Have you encountered any water quality issues or deviations from acceptable levels in your testing?

   Yes ☐ No ☐

5. If ‘yes’, please describe the issues encountered and any corrective actions taken.

FISHPOND WATER EFFLUENT MANAGEMENT PLAN

1. Do you have a water effluent management system in place?

   Yes ☐ No ☐

2. If 'yes', describe your effluent management system.

   ----

3. If 'no', why do you not have a water effluent management system in place?

   ----

4. Location of water exit point (G.P.S coordinates and description):

   ----

5. Site of water release:

   River ☐ Agricultural Lands ☐ Canal system ☐ Other ----------------------------------

6. Is water stored before release?

   Yes ☐ No ☐

7. If 'yes', where is it stored?

   Treatment Tank ☐ Non-treatment Tank ☐

8. Is the water treated before release?

   Yes ☐ No ☐

9. If 'yes' what treatment measure is used?

   Reed-bed ☐ Hypo chlorination ☐ Other ----------------------------------

ENVIRONMENTAL IMPACT

1. Have you observed any environmental impacts in the vicinity of your fish farm related to water effluent?

   Yes ☐ No ☐

2. If ‘yes’, please describe the observed impacts and any measures taken to mitigate them.

SUGGESTIONS AND COMMENTS

1. Do you have any suggestions or comments regarding water effluent release, testing and management on fish farms?

Thank you for your participation. Your input is valuable in assessing and improving the water effluent management of fish farming in Jamaica.

Appendix II

Table 3. Results of laboratory analysis of physiochemcial parameters for TL1.

Parameter	**TL1 Inlet Pipe**	**TL1 Outlet Pipe**	**Standard Effluent Limit for Intensive Fish Farming**
Nitrate	0.9 mg/L	0.9 mg/L	10 mg/L
Nitrite	2 mg/L	102 mg/L	10 mg/L
Ammonia	0.05 mg/L	0.05 mg/L	1.0 mg/L
Total Phosphorus	0.28 mg/L	0.93 mg/L	5.0 mg/L
pH	7.3 at 21°C	8.3 at 21°C	6-9
Total Suspended Solids	12.7 mg/L	44.7 mg/L	<150 mg/L
Total Dissolved Solids	1050 mg/L	1060 mg/L	1000 mg/L
Biological Oxygen Demand	13 mg/L	20.9 mg/L	<30 mg/L
Chemical Oxygen Demand	28 mg/L	52 mg/L	<100 mg/L
Total Coliform	920 MPN/100mL	540 MPN/100mL	500 MPN/100 mL
Faecal Coliform	240 MPN/100mL	14 MPN/100mL	100 MPN/100 mL
Detergents	0.33 mg/L	0.33 mg/L	15 mg/L
Fats, Oils and Grease	0 mg/L	0.67 mg/L	10 mg/L

Table 4. Results of laboratory analysis of physiochemical parameters for TL2

Parameter	**TL2 Inlet Pipe**	**TL2 Outlet Pipe**	**Standard Effluent Limit for Intensive Fish Farming**
Nitrate	5.06 mg/L	0.9 mg/L	10 mg/L
Nitrite	5 mg/L	87 mg/L	10 mg/L
Ammonia	0.02 mg/L	1.12 mg/L	1.0 mg/L
Total Phosphorus	0.88 mg/L	1.04 mg/L	5.0 mg/L
pH	7.4 at 21°C	7.5 at 21°C	6-9
Total Suspended Solids	2.5 mg/L	60 mg/L	<150 mg/L
Total Dissolved Solids	396 mg/L	544 mg/L	1000 mg/L
Biological Oxygen Demand	0.4 mg/L	157 mg/L	<30 mg/L
Chemical Oxygen Demand	3 mg/L	206 mg/L	<100 mg/L
Total Coliform	1.8 MPN/100 mL	1600 MPN/100mL	500 MPN/100 mL
Faecal Coliform	1.8 MPN/100mL	920 MPN/100mL	100 MPN/100 mL
Detergents	0.12 mg/L	0.53 mg/L	15 mg/L
Fats, Oils and Grease	1.33 mg/L	2.33 mg/L	10 mg/L