ISSN: 3064-9846
Research Article

Journal of Agricultural, Earth and Environmental Sciences

Evaluation of Discharge Effluents from Commercial Aquaculture Fish Farms in Jamaica

Krystal Kimberly Peter-Gay Facey[1, 2*], Birgitta Andreasen[3], þorleifur Ágústsson[3]

[1]*Ministry of Agriculture, Fisheries and Mining, Jamaica*
[2]*Gró-Fisheries Training Program, Iceland*
[3]*Firum, Faroe Islands*

[*]**Corresponding author:** Krystal Kimberly Peter-Gay Facey, Ministry of Agriculture, Fisheries and Mining, Jamaica & Gró-Fisheries Training Program, Iceland.

Submitted: 01 November 2024 **Accepted:** 08 November 2024 **Published:** 15 November 2024

https://doi.org/10.63620/MKJAEES.2024.1061

Citation: *Facey, K. K. P. G., Andreasen, B., & Ágústsson, B. (2024). Evaluation of discharge effluents from commercial aquaculture fish farms in Jamaica. J of Agri Earth & Environmental Sciences, 3(6), 01-18.*

Abstract
As the aquaculture industry continues to grow, the increase in aquaculture effluents has been gaining traction in the environmental community with increased criticisms regarding effluent composition and release on receiving ecosystems. As Jamaica seeks to increase food security for its population, production of Tilapia fish has reached 954.23 metric tons and is expected to reach 3400 metric tons in 2028. This paper provides a review on the various methodologies utilized in Jamaica to dispose of aquaculture effluents from commercial Tilapia spp. fish farms and an evaluation of effluent composition on selected farms. Aquaculture effluents comprises of inorganic and organic particles from fish waste, residual feed and fertilizer which can result in eutrophication and changes to natural ecosystem if not managed properly or treated before release. Though the demand for aquaculture products continues to grow in Jamaica, thus increasing production and effluent volume, there has been no environmental degradation.The results from analysis of the effluent composition indicated that the majority of the parameters tested were within the standard effluent limit set by the environmental agency. The results revealed the following values for the physiochemical characteristics tested: 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)), 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)).Though 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 has aided in the reduction 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: Aquaculture Effluent, Fish Farm, Tilapia, Earthen Ponds, Jamaica, Environment

Introduction

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 (food, animal skin for the fashion industry) was 122.6 million tonnes in live weight while in 2000, the world aquaculture production was 43 million tonnes, representing a 184% increase [1]. Aquaculture activities typically includes finfish farming in a somewhat controlled environment, but also includes activities such as the cultivation of molluscs, crustaceans, algae, cyanobacteria, marine invertebrates, frogs, and aquatic turtles [2]. In 2020, world aquaculture production of inland farmed finfish was 49.1 million tonnes, accounting for 40% of total aquaculture production for the year [1]. 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, where Latin America and the Caribbean contributes 51.71% of the total production [1].

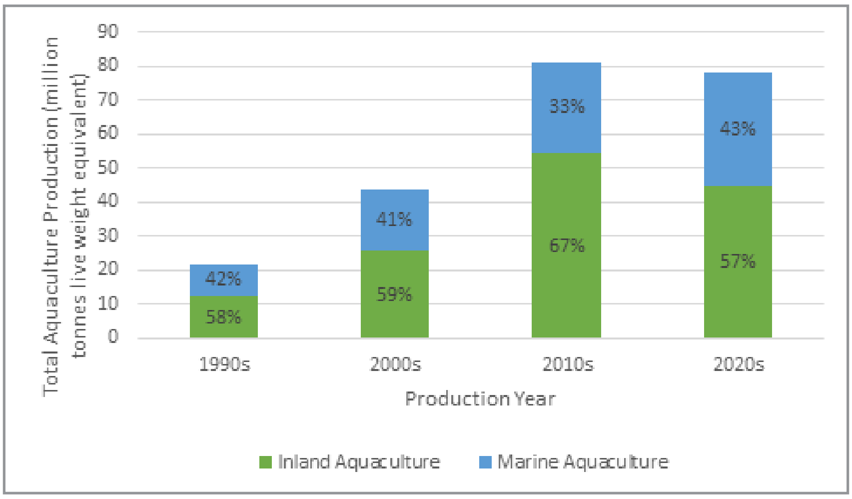

Figure 1: World Aquaculture Production from 1990s - 2020 modified from (FAO, 2022). (Excluding aquatic mammals, crocodiles, alligators and caimans and algae)

Aquaculture in Jamaica

Jamaica is in the Caribbean region (Figure 2) and is the third largest aquaculture producer in the Caribbean subregion [3]. It is the third largest West Indian Island State in the Greater Antilles after Cuba and Hispaniola, spanning 146 miles in length, and approximately 22 to 51 miles in width variation and has a population of approximately 3 million persons [4, 5]. Jamaica has an Exclusive Economic Zone of 274,000km2, governed by the Exclusive Economic Act 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 [6, 7]. As a result of the challenges faced with capture fisheries, the government, through international partnerships commenced the further development of the aquaculture sector in 1976 through a project funded by the United States Agency for International Development (USAID), which saw the production of Tilapia spp. and oysters.

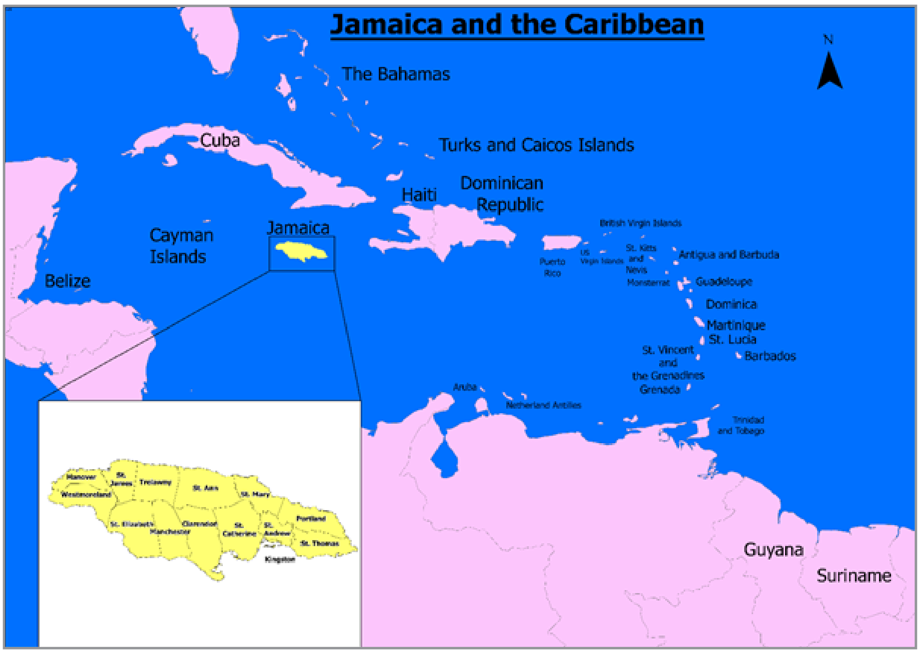

Figure 2: Jamaica´s location in the Caribbean

Currently, Jamaica´s aquaculture sector is divided into two key areas of interest, food security and ornamental fish. Food security in aquaculture includes the production of food fish, oysters, and seaweed [8]. Food fish aquaculture in Jamaica includes several Tilapia species which are:

- Jamaica Red which is 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 which is an interbreed between the Jamaica Red and Rocky Mountain White.

Other aquaculture species used to enhance food security includes the local oysters, Crassostrea rhizophorae and Isognomon alatusand seaweeds such as Chondrus crispus, Gracilaria sp., and Furcellarias sp. and more recently the freshwater shrimp, Macrobrachium rosenbergii. The ornamental fish area includes species such as goldfish and koi for the local market [9]. 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 (Figure 3) [10].

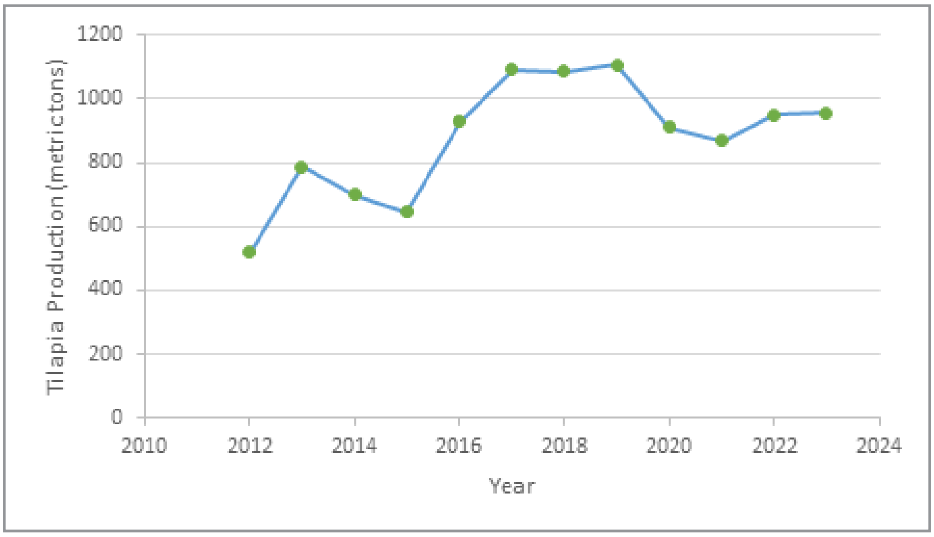

Figure 3: Jamaica´s Tilapia spp. production values (metric tons) for the period 2012 to 2022, modified from (National Fisheries Authority, 2023b)

Currently, 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 [3]. One aquaculture project is The Promoting Community-Based Climate Resilience in the Fisheries Sector Project under The World Bank, financed in part by the Jamaica Social Investment Fund (JSIF), which have invested in the construction of a modern, bio secure climate resilient tilapia hatchery, which is expected produce over five million fry per annum once fully operational and will positively impact all aquaculture stakeholders [11]. The aim of the 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 seedstock production [12]. 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 [13, 14].

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 much attention is not given to the possibility of pollutants discharge effluents from fishponds into the natural environment, rivers, streams, wetlands, and agricultural lands [15, 16]. 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, due to the steady decline in the local supply of wild caught fish [9]. Though there has been a decline, there is still a high demand for fish and as such aquaculture production, particularly Tilapia fish production, is increasingly becoming an alternative source for fish. Due to this, there has been an increase in aquaculture activities, especially the farming of fish in earthen ponds.

Fish farming in Jamaica has two main inputs for the production cycle, fertilizers, and hand feed. In feed-based aquaculture, only 20% to 40% of the nitrogen and phosphorous applied to the feed is recovered in the harvested biomass, and the remaining 60% to 80% remains in the water [17]. Residual feed, coupled with pond fertilization, can lead to nutrient pollution in the natural environment causing eutrophication, which ultimately leads to the depletion of oxygen for the natural biota. In Jamaica, no study has been conducted regarding the composition and release of effluent from commercial aquaculture fish farms and there is no law, regulations, or policy within The Fishing Industry Act of 2018 regarding effluent release limits from these fish farms. The National Environment and Planning Agency (NEPA) is the lead government agency with the 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 as well as requiring individuals to obtain an environmental license and permit for the construction and operation of aquaculture facilities and ponds for intensive fish farming where fish are stocked at a high density [18]. 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, where most of the farms are concentrated in St. Catherine and Clarendon along the southern plains (Figure 4 and Figure 5).

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 to:

- Determine the methodologies used to dispose of effluent water from fish farms in Jamaica.
- Analyze the level of biological and chemical agents in aquaculture effluents.
- Initiate guidelines for the release of aquaculture effluents to ensure a sustainable future for all stakeholders.

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

Aquaculture Effluent Management
Environmental Considerations

According to Miao, Tilapia is the most popularly cultured aquatic animal species, with approximately 145 countries reporting production values to the Food and Agriculture Organization (FAO) in 2018 [19]. 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 [20-22]. The culturing of Tilapia is of global importance in ensuring food security as Tilapia spp. can grow rapidly and can adapt to various environments which makes 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 [23]. The commonly farmed species of Tilapia are 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 has the ability to tolerate high salinity and cold waters and hybrid Tilapia spp. which are created through selective breeding [24]. These species are produced in various aquaculture systems such as ponds, cages, tanks, 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 [25]. 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 [26]. Prior to this, fish farmers sold their live fish to vendors from the pond embankment, where they were kept in cages when they had attained market size for ease of retrieval. The increase in production led to the establishment of a rudimentary market in Twickenham Park Spanish Town by the then Inland Fisheries Unit, 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 in production distributed between 137 fish farmers across Jamaica (Figure 5) [27, 28]. The production cycle typically lasts six months and once finished, the farmers typically dispose of the aquaculture effluent as they deem most suitable for them, then disinfects the pond bottom by adding calcium hydroxide in preparation for the next production cycle.

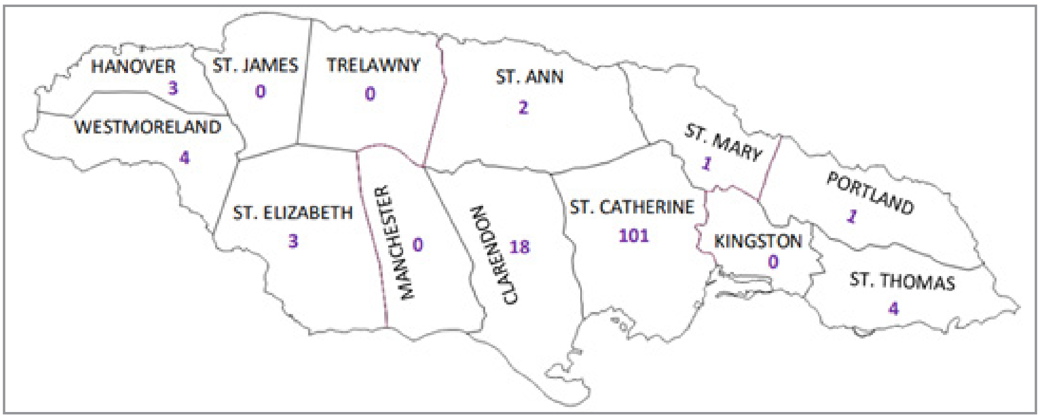

Figure 4: Distribution of the 137 aquaculture fish farmers across the 14 Parishes of Jamaica (National Fisheries Authority, 2023c)

Aquaculture Effluent Composition

Aquacultural effluents are known as the waste materials in the water produced from aquacultural operations, which in recent years has become a concern as the amount of water used produces a large amount of wastewater [29]. Effluents from aquaculture ponds typically consists of a mixture of organic and inorganic particles which can be in a solid or dissolved form, comprised of fish waste, residual feed, fertilizer, and metabolic by-products [30]. Organic compounds typically found in aquaculture effluents includes proteins, lipids, carbohydrates, vitamins, and minerals while the inorganic compounds are mainly nitrating, nitrites, and phosphates which trace amounts of bicarbonate [31]. 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 [30, 32]. Globally, most aquaculture operations are small-to medium scale enterprises which are mainly for household consumption (subsistence) 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 [33]. The use of antibiotic compounds occurs in larger farms which are considerably fewer and employs 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 [34]. 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 utilizes a higher concentration of these productivity enhancers [35]. Another component of aquaculture effluents is the presence of bacteria and viruses, which can be naturally occuring in the production system or as a result of immunocompromised fish which have be innundated with a virus or bacteria [36]. There is no fixed aquaculture effluent standard due to the independent operations of aquaculture facilities, which are impacted by the production system utilized, species cultured, management practices and feed input (Table 1).

Over the last two decades, several 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 the effluent characteristic. According to Yeo, Morris, and Binkowski the principal source of aquaculture waste in the effluent composition was uneaten fish feed, closely followed by the excretory wastes that was consumed but unassimilated by the fish [37]. Despite this, the waste from fish feed can be reduced through proper feeding mechanisms, as traces of residual commercial feed is inevitable as the pellets sometimes breakdown into particles too small for the fish to consume, thus leaving remnants in the water [37]. Boyd and Tucker shares the same conclusion in their study which identified the presence of nitrogen and phosphorus compounds in uneaten feed and metabolic waste from fish [38]. The presence of residual feed and excretory wastes in abundance often affects the normal acceptable ranges of several water quality parameters due to the effects of dissolved organic matter. High nutrient loads increase the pH, ammonia, total nitrogen, and total phosphorous and decreases the available dissolved oxygen [29]. If water quality parameters are not monitored and regulated during the production cycle, it may have detrimental effects to the stock as well as to the general environment post-harvest during the release of discharge effluents.

Table 1: Characteristics of aquaculture effluents

REFERENCE	Halfhide, Åkerstrøm, Lekang, Gislerød, & Ergas [39]	Guldhe, Ansari, Singh, & Bux [40]	Coldebella, o.fl. [41]	Coldebella, o.fl. [41]	Coldebella, o.fl. [41]	Frimpong, o.fl. [42]	Frimpong, o.fl. [42]	Frimpong, o.fl. [42]
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	-	-	-

Impacts of Aquaculture Effluents on the Environment

Like all industries, waste generated will have some form of impact on socio-ecological standards. According to Cossio, 95% of the global wastewater produced in low and lower-middle-income countries is discharged without treatment to the environment [43]. Land-based aquaculture facilities generate effluents that can have significant environmental impact if not managed properly. 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, oxygen depletion which most often results in fish deaths. The level of impact that aquaculture effluents have on the environment is dependent on the nutrient load which is directly related to the production system, the species being cultured and the management practices along with the environmental conditions [30].

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 [44]. Suspended solids and other physio-chemical parameters increases the sedimentation of the receiving water body and 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 the aquatic communities due to the 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 behavior, displacing native communities and in extreme cases results in fish kills [30]. Nutrient overload in aquaculture effluent often result in eutrophication, caused by the 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 to handle the eutrophication problem, whilst others have argued that this approach will affect the production yield and cost [45]. A study done by Raczyńska, Machula, Choiński, & Sobkowiak concluded that aquacultural effluent discharge has significant impact on the physio-chemical water quality parameters in rivers where they were discharged [16]. The concentration of nitrogen, and partially the phosphorus content and water hardness increased when the nutrient load from the ponds were released into the river, with notable continuous increase over several days of sampling. The successive increase may be attributable to the deposition of the physio-chemical parameters in the bottom sediment and their subsequent slow release. In addition to nitrogen and phosphorous, aquaculture effluents contain a high level of biological oxygen demand, chemical oxygen demand, turbidity, suspended and dissolved solids which increases its ecotoxicity [46].

When nutrient rich aquaculture effluents are released on land, it has varying influence on the space which one may deem beneficial or disadvantageous. Due to the volume of aquaculture effluents which is normally released, it can reach surface waters depending on the trajectory or it can simply leach, percolating the soil and contaminate the ground water. This ultimately leads to the pollution of potable water and can affect human and animal health. According to Avnimelech, inland aquaculture has been linked to pollution of water bodies used for everyday consumption by human, where it has been estimated that one aquaculture facility can generate waste equivalent to 240 people from just three tonnes of freshwater fish [47]. When such effluents enter the soil, they can lead to soil acidification based on the composition; and affects the fertility of the soil and overall agronomy production. It must be noted that aquaculture farmers often utilize the effluent at the end of their production cycle for their other farming activities, as the nutrients typically found in aquaculture wastewater are required for plant development [48]. A study in an aquaponics system utilizing Nile tilapia and tomato, concluded that the production seen was like that of a conventional hydroponics system [49]. Another study, with Nile Tilapia and lettuce, revealed that the aquaponics solution increased plant growth by 39% [50].

Management Strategies

Effluent management is crucial in 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 due to the quantity of water used in the production system, it may be considered high, when compared to other industrial and domestic effluents [36]. Understanding the effects which aquaculture effluents have on the environment has enabled the development of current aquaculture management practices and policies globally. Several authors have had a consensus on management strategies used to control the potential impact of aquaculture effluent on the environment [51, 36, 30, 34]. These includes effluent treatment systems, utilization of recirculation aquaculture systems and employing best aquaculture practices during the production cycle.

Maintaining moderate stocking densities and maintaining good water quality is the first aquaculture best practice which is a vital management strategy in producing environmentally tolerable effluents. Production systems which have good water quality tend to assimilate waste better than ponds with diminished water quality [51]. 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 the draining of the pond. Nitrogenous compounds and phosphates are often the most important constituents of aquaculture effluents, as they can cause eutrophication and ecological within the environment. Utilizing feed management can reduce the nutrient load from these compounds [36]. It has been observed that phosphorous levels in the effluents had reached a peak right after feeding and returns to the appropriate baseline between feeding times [52]. 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 methods for aquaculture effluents. The retention ponds allow nutrients to be assimilated by the natural biological processes of the pond and solids to settle to the bottom of the pond [36].

Ahmad, Abdullah, Hasan, Othman, & Ismail 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 [30].

Effluent Treatment Strategies in Aquaculture

Aquaculture farms release their aquaculture effluents based on their management practices and their local environmental regulations. There are two types of aquaculture effluent being released, treated or untreated. Untreated effluents are released, as is, into the environment, while treated effluents are cleaned before released. The 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 in agricultural lands as a form of irrigation as it is able to provide the crops with nutrients [53, 54]. In recent times, small scale and subsistence aquaculture farmers have used aquaponics as a management and effluent treatment method while large scale farmers incorporate the use of 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 utilizes the natural biological processes of the pond to assimilate the waste, where organic matter through microbial action, is converted into carbon dioxide, water, ammonia, phosphate, and other inorganic matter [51, 55]. The most common and simple way of treating aquaculture effluent is desilting, which is the removal of solid waste from the pond culture after two or three production cycles [31, 56]. This process allows for the accumulation and settling of solid waste at the bottom of the pond which is then removed manually after harvest [57].

Also, the development of treatment technology is actively making progress where woodchip bioreactors, biofiltration, bioremediation and bio floc usage is still in the research stages [30]. Biofiltration utilizes artificial systems consisting of plants and other substrates to reduce the content of nutrients by absorption [31]. Bioremediation utilizes microorganisms to disintegrate the organic contents, which in recent times have been integrated into IMTA, where organisms such as sea cucumbers are incorporated due to their detritivorous nature, assimilating particulate organic matter [31].

Several studies have been conducted to determine the best treatment methods for aquaculture effluents. A recent study demonstrated the utilization of a ´green´ coagulant to treat aquacultural effluents, which generated a 74% optimal turbidity removal [46]. The green coagulant was synthesized from the local Garcinia kola seed by extraction and placed in test environment with aquacultural effluent from a nearby fishpond [46]. Another study utilized the use of electrocoagulation technology using iron-aluminium in the treatment of wastewater from aquaculture ponds, which generated a 92% turbidity removal [56]. A set of 16 experiments were conducted using the Box-Benhken Design with independent variables of charge time, current and settling time to determine the most ideal procedures to remove pollutants in aquacultural effluents [56].

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 [57]. Residual nutrients from a RAS with 3.4 tonnes of fish can aid in the production of 35 tonnes of tomatoes when utilized as a fertilizer [58]. The increase in water re-use systems in aquaculture is another method for treating aquaculture effluents [59]. Though 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 for the waste to be repurposed into compost or undergo further treatment and used on land [60].

Another economical treatment method is the use of reed beds. In a study, water from a fishpond was channelled from fishponds to reed beds (macrophyte pond) where there was a notable removal of all nutrients of approximately 90%, except for the phosphorous which was 80% [61]. Reed-beds are also known as constructed wetlands which are becoming more important as it is a more cost-effective method for treating aquaculture effluents [60].

Guidelines on Effluent Management

Guidelines for Aquaculture Effluent Management

Understanding the composition of effluents from aquacultural ponds, specifically tilapia fish farms, is essential for assessing the environmental sustainability of the operations for all stakeholders. Incorporating aquaculture effluent management strategies in 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 specification. Based on the literature reviewed, guidelines on effluent management varies depending on the country´s environmental regulations, the production system utilized as well as the location of the aqua cultural activities.

Pouil et. al states that the culture systems of earthen ponds results in a higher nutrient load, along with plankton growth, suspended solids, and higher oxygen demands which has necessitated the implementation of policies and regulations [62]. Several countries such as The United State of America, Thailand, Taiwan and Hawaii have established water quality standards for aquaculture effluents in their regulations, while countries such as Malaysia has not yet enforced a regulation regarding aquaculture effluents but has instead relied on guidelines from Environmental Quality (Industrial Effluent) Regulation 2009 [30].

Utilizing 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 was associated with higher water quality, especially dissolved oxygen concentration.

Various researchers have made several recommendations to reduce the impact of effluents from aquaculture ponds [63-65]. It can be deduced from the guidelines reviewed that the general recommendations for managing aquacultural effluents from tilapia earthen ponds are:

- **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.
- **Efficient feeding strategies:** Commercial pellets used to feed Tilapia are often loaded with nutrients, which when remaining in the water leads to eutrophication and water quality degradation. Having an optimized feed conversion ratio aids in the reduction of residual feed [65].
- **Waste management strategies throughout production:** Ensure that uneaten feed is removed along with any other visible organic or inorganic matter.
- **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 fertilizers. When treated, the effluent water can be recycled and used in the next production cycle or for irrigation purposes for agricultural lands [63][64].

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

Regional Guidelines for Aquaculture Effluent Management

In the Latin America and Caribbean region, there are country specific regulatory framework governing aquaculture discharge which have been guided from international organizations such as the FAO and the Network of Aquaculture Centers in Latin America and the Caribbean. Regulatory compliance and certification of aquaculture activities is important for Tilapia spp. farming operations as it ensures success of the business while ensuring the practices are in alignment with aquaculture best practices for environmental conservation [66]. Having good water quality standards during production ensures a safe, healthy environment for the fish stock and minimizes any environmental impact during discharge. This measure protects the 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 licenses and permits as this is an effective way in protecting the environment as identification of potential consequences in the planning process will allow for proper management. However, according to Van Wyk & Davis, governments often exempt small-scale aquaculture developments from EIAs requirements, but, many small-scale aquaculture farms, concentrated in the same area, can have a potential cumulative effect on the environment [67].

Methodology

Study Area

The study area encompasses the tilapia fish farming industry in Jamaica (Figure 4). The major target group for this study was commercial aquaculture farmers, who were active all year, which were selected from the Aquaculture Division internal database. Due to the number of farms located across Jamaica, only a select 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.

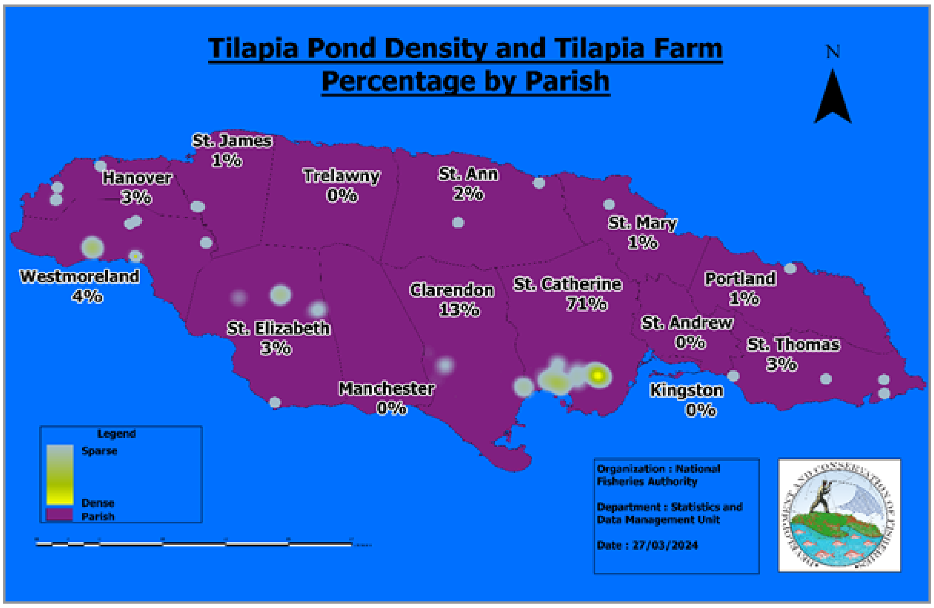

Figure 5: Spatial distribution map for aquaculture tilapia fish farms in Jamaica

Questionnaire Implementation

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

Aquaculture Effluent Composition Analysis

The second phase of the research was a laboratory analysis of the aquaculture effluents from two tilapia fish farms in Jamaica, hereafter known as testing location 1 (TL1) and testing location 2 (TL2). The study initially aimed to comprehensively analyse the effluents from seven (7) aquaculture fish farms in Jamaica. However, due to the time-constraints of the fisheries training programme, the harvesting period of the additional farms did not align, therefore laboratory analysis was not done during the 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 farm 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 the directives given by the Scientific Research Council (SRC). After collection, the samples were transported to the lab in a sterile igloo with ice within 24 hours. The SRC engineering team then analyzed the samples using Hach and Standard Methods for the Examination of Water and Wastewater (SMEWW) testing methods for thirteen parameters, which were, ammonia, nitrate, nitrite, total coliform, fecal coliform, total suspended solids, total dissolved solids, pH, Biological Oxygen Demand, Chemical Oxygen Demand, Fats Oil and Grease, total phosphorous, and detergents. The results were then cross referenced against the 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

Results Analysis

Questionnaire

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

Laboratory Analysis

The data received from the laboratory analysis of the water source and effluent samples was first organized in excel to generate statistical analysis presented in graphs.

Aquaculture Effluent Implementation Plan Development

Once the results from the two phases of the study was received, an implementation plan was developed for the management of aquaculture effluents in Jamaica.

Results

Status of Effluent Management in Jamaica

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

Water Source

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

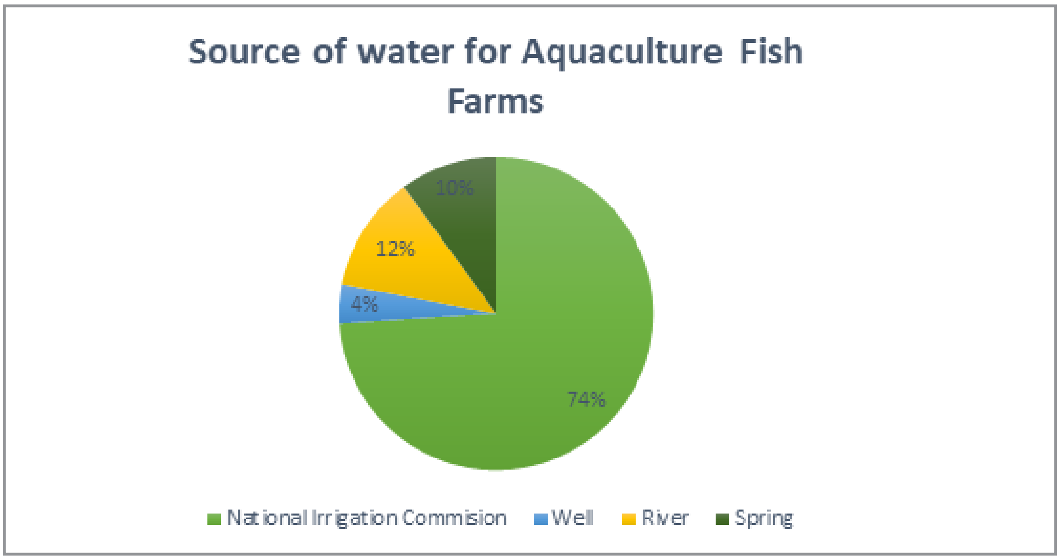

Figure 6: Source of water for aquaculture fish farms

Water Quality Management During Production Cycle

The results from the study showed that 84% of the commercial tilapia fish farmers interviewed do not conduct water quality analysis during the production cycle. Further investigation as to 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 who did perform water quality analysis during the production cycle, the questionnaire shows that the quality analysis was carried out mainly by employees (50%), both employees and government agency (17%), both employees and external laboratory (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 analysis monthly, done by an external laboratory which includes the assessment of other water quality parameters such as ammonia, nitrates, nitrites, phosphate, hardness, fats oil and grease, detergents, total dissolved solids (TDS), total suspended solids (TSS), biological oxygen demand (BOD), chemical oxygen demand (COD), total coliform and fecal coliform.

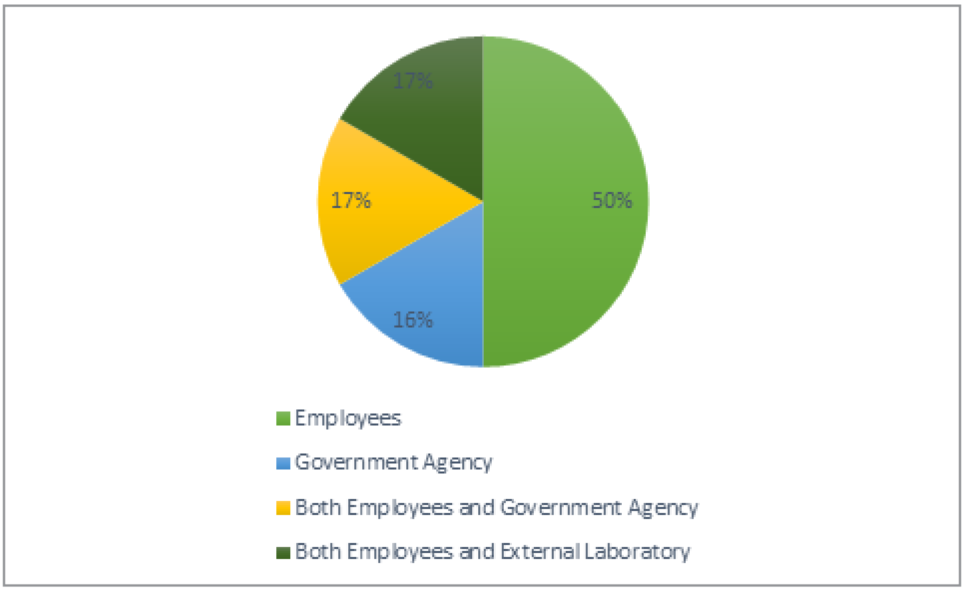

Figure 7: Administration of water quality analysis

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 coliform during the rainy season which occurred due to agricultural activities occurring in the vicinity of the river (water source). This has been resolved for the past two years as agricultural farmers have removed their animals from close proximity to the river.
- High pH levels were detected, the ponds were immediately flushed upon notice.

Effluent Management Plan

The results from the study showed that the majority (86%) of commercial tilapia fish farmers in Jamaica do not utilize an effluent management plan in their operations (Figure 8). The consensus from the respondents as to the lack of an effluent management plan was that their operations are considerably small and the expense that would be associated with installing the structures and the space required made it not feasible.

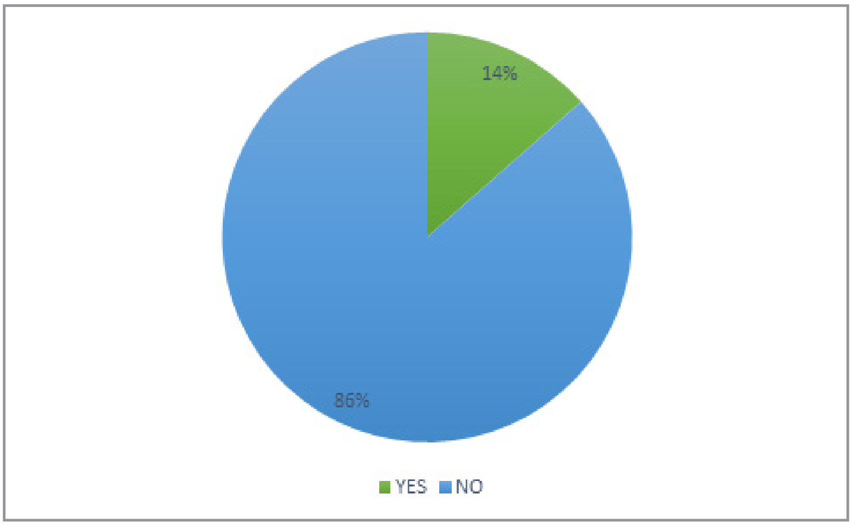

Figure 8: Percentage of farmers that utilize an effluent management plan

The effluents from aquaculture operations are released at various locations (Figure 9). However, most commercial aquaculture fish farmers in Jamaica operate agricultural land and several respondents (21%) have stated that they utilize 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.

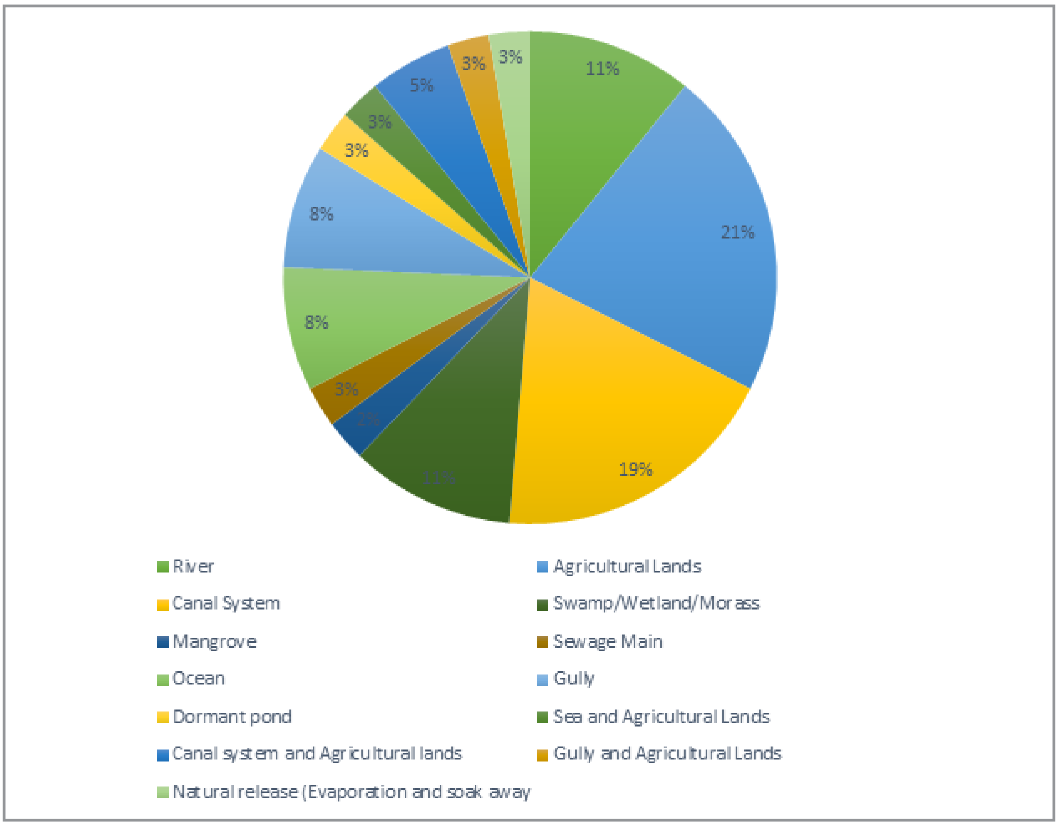

Figure 9: Site of release of aquaculture effluents in Jamaica

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

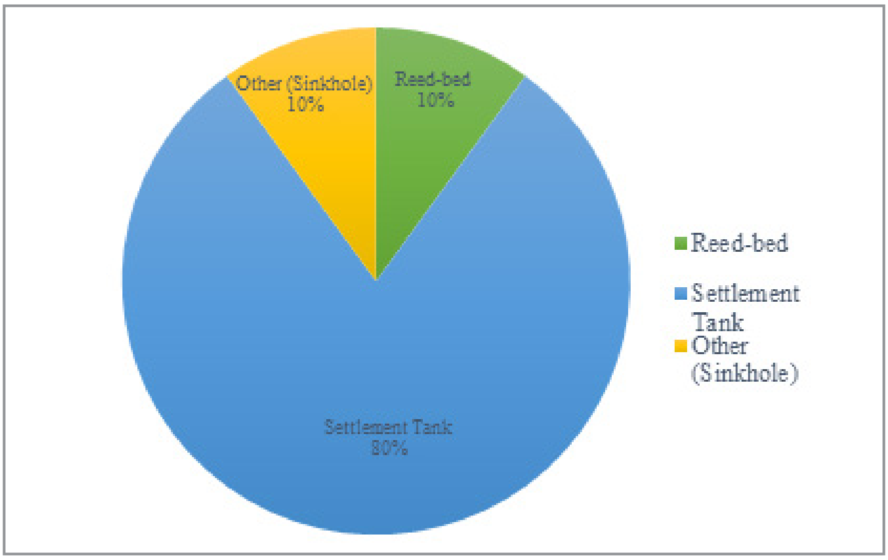

Figure 10: Treatment methods used for aquaculture effluents

Effluent Composition from Fish Farms in Jamaica

Nitrates and Nitrite Levels

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

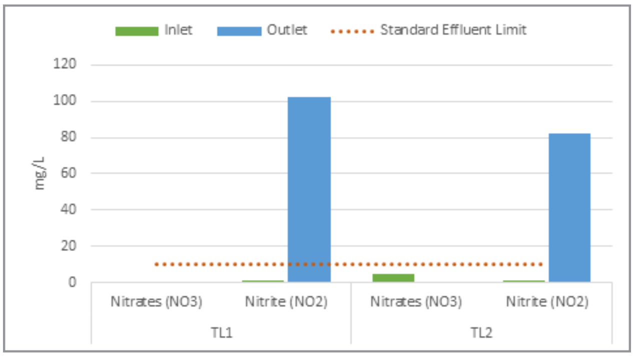

Figure 11: Nitrate and nitrite levels from the inlet pipe (water source) and the outlet pipe (aquaculture effluent) in TL1 and TL2

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 at the outlet pipes, there were a slight elevation in the total phosphorus level though it remained within the limits in both locations.

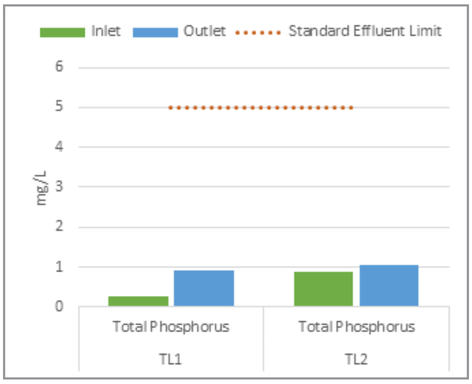

Figure 12: Total phosphorous levels from inlet pipe (water source) and the outlet pipe (aquaculture effluent)

Fecal and Total Coliform Levels

It was observed from the sample analysis (Figure 13 and Figure 14) that the total coliform levels were elevated at 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. There are animals which forage in the vicinity of the system which explains the elevated coliform levels for samples from both the inlet and outlet pipes.

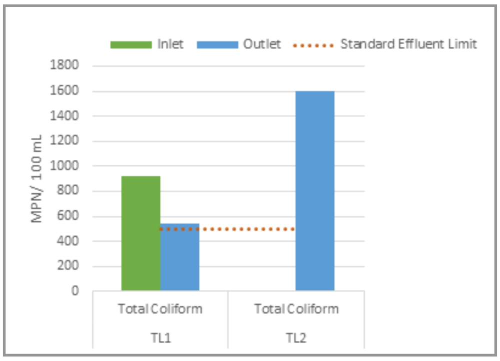

Figure 13: Level of total coliform from the inlet pipe (water source) and the outlet pipe (aquaculture effluent)

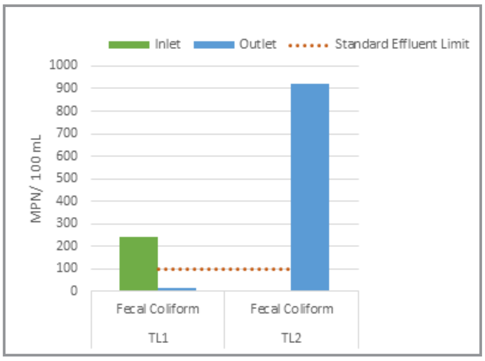

Figure 14: Level of fecal coliform from the inlet pipe(water source) and the outlet pipe (aquaculture effluent).

Discussion

The sustainability of aquaculture in Jamaica is of great importance to the fisheries sector. The evaluation of effluents from commercial aquaculture fish farms in Jamaica is required to figuring out 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 analysis of effluent discharge from two randomly selected farms.

Evaluation of Effluent Analysis in Jamaica

The results of the analysis from the inlet and outlet pipes at aquaculture tilapia production facilities in Jamaica, it was showed that overall, the effluent composition is within the established standard limits 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 diversified 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 differing management strategies utilized during the production cycle, it was observed from the analysis at TL1 and TL2, that there were no significant differences in the levels of physio-chemical 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 5.0mg/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 t levels (Figure 11) were significantly higher than the standard effluent limit of 10mg/L for both locations, where TL1 recorded a value of 102mg/L and TL2 recorded a value of 87mg/L. Though no further investigation was done at the site of release regarding the impact on the environment, it has been denoted that nitrogen and phosphorous are often cause for concerns as they can lead to eutrophication and environmentally deleterious events [16][30[66]. The data is synonymous with declarations made by Lucas, that predicts that there will be 60% - 80% of nitrogen and phosphorous remaining in aquaculture effluents derived from feed [17]. Based on the duration of the study, further analysis are needed to determine the percentage of nitrogen and phosphorous remaining in the water as a result of feed.

Concerning the total coliform levels (Figure 13), the observed results in the effluents discharged for both locations were above the standard effluent limit set up by the NEPA. However, it must be noted that at TL1, the total and fecal 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 in fish ponds, once aquaculture best practices are employed in the production cycle, it is expected that waste would be assimilated through the natural biological processes [51][55], which is what is reflected in the data obtained. Contrastingly, at TL2, the total and faecal coliform levels at the water source were below the standard limits set up 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 is sub-standard, resulting in the lack of microbial action to assimilate the waste [51, 55].

Concerning ammonia, the levels were below the standard limits of 1.0mg/L for both the inlet and outlet pipes at TL1, recording values of 0.05mg/L for both. However, at TL2 the level at the inlet pipe was 0.02mg/L but the outlet level was slightly elevated at 1.12mg/L. This elevated level could be attributed to the use of nitrogen based agricultural fertilizers [44]. Though feed and fertilizer input are the main contributors to the effluent composition, the exact nutrient input rate needs to be further studied to create linkage as it is not possible to determine a general pond production system as different farms utilizes different inputs.

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

Aquaculture Effluent Management Practices in Jamaica

The results obtained from the questionnaire, has concluded that no fish farm owner and operator in Jamaica has an established aquaculture effluent management plan in their production system. Nevertheless, though there is a lack of a documented management plan, it has been deduced that the practices employed by fish farmers through Jamaica are identical to those which lay the foundation of aquaculture effluent management policies and guidelines. Such practices include having a good source of water, moderate stocking densities, efficient FCR, monitoring the water quality during the production cycle, and even effluent treatment systems [55, 36, 34, 30]. Fish farms throughout Jamaica employ a semi-intensive production system, which are sparsely located across the island. Though the major aquaculture farming communities in 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.

In understanding aquaculture effluents, the composition must first be understood. From the survey conducted, the majority of respondents (79%) indicated that the source of their water comes from NIC. NIC is a government institution which manages and operates the irrigation systems to farming communities in Jamaica. Their mandate prioritizes 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, it was noted by 84% of respondents that they do not monitor the water quality during the production cycle or conduct testing due to several reasons. One of which is that the NIC carries out their own quality checks and standards on the product being distributed to clients. Coupled with this rationalization is the fact that Tilapia spp. are considered hardy species, adaptable to various conditions. Therefore, substandard water quality will not affect their metabolic processes and their ability to grow. Further investigation also revealed that 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 the traceability of the physiochemical parameters for optimal production. For the 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 being undertaken to restore to normality.

Currently, there are no guidelines, regulations or policies as to where aquaculture effluents should be released. From the questionnaire administered, it was revealed that there are four main sites for the release of aquaculture effluents, being agricultural land (21%), canal system (19%), rivers (11%) and swamps, wetland and morass (11%). The minor sites (38%) of release are gullies, dormant ponds on property, the ocean, mangrove, sewage main or a soak away pit. The canal systems which most aquaculture farmers utilize during effluent discharge serves as a makeshift settlement tank, as when the effluents are released, they remain in the canal for a period of time. This allows for the suspended solids to settle to the bottom of the canal as the water flows through. Though there is an absence of an effluent management system, several practices post-harvest suggests that the effluents are being released in an environmentally safe manner. One such measure is the utilization of effluent treatment areas. From the questionnaire, it was inferred that 27% of the respondents who store their effluents before release utilizes a settlement tank (80%), reed-bed (10%) and sinkhole (10%).

The fish farmers surveyed deduced that no negative environmental impact was visible in the vicinity of their site of effluent release. It must be noted that some respondents have stated that they utilize 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 a natural fertilizer and access to water.

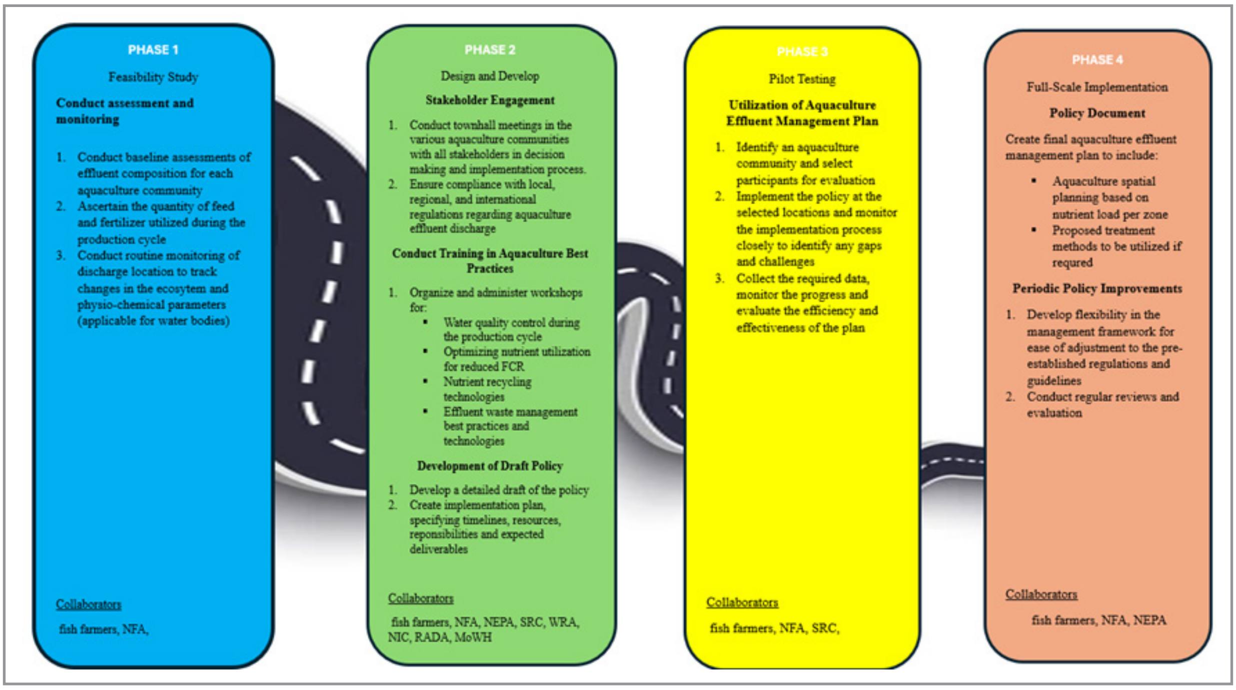

Figure 15: Implementation plan for developing a policy framework for the management of aquaculture effluents in Jamaica

Conclusion and Future Policy Recommendations

Conclusion

As the aquaculture industry seeks to achieves sustainability in all aspects of the operations, aquaculture effluent consideration must be prioritized. The 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 organizations. Though the period for the study was short which impacted the sample size for effluent analysis, the results generated from the study will assist in future investigations as the aquaculture sector continues to grow.

The outcome of the study has concluded that

1. Aquaculture effluents from Tilapia spp. 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. Though 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 of aquaculture effluents, nonetheless, it is critical to implement guidelines and policies with a view towards environmental sustainability as the further development of tilapia fish farming occurs.

Recommendations

The following recommendations are proposed

- Further investigation must be done by increasing the test sites to amass a greater 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 re-use cycle for farmers who do mix farming or transport to nearby agricultural counterparts after testing with favorable 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.

References

1. FAO. (2022). The State of World Fisheries and Aquaculture. Towards Blue Transformation. Rome: FAO.
2. The State of World Fisheries and Aquaculture. (2020). Sustainability in Action. Rome 244. https://openknowledge.fao.org/items/b752285b-b2ac-4983-92a9-fdb24e92312b.
3. Wurmann, C., Soto, D., & Norambuena, R. (2022). Regional review on status and trends in aquaculture development in Latin America and the Caribbean – 2020. Rome: FAO Fisheries and Aquaculture Circular No.1232/3.
4. Buisseret, D., Bryan, P., Black, C., & Ferguson, J. (2023). Geography and Travel - Jamaica. Britannica. https://www.britannica.com/place/Jamaica#/media/1/299716/208878.
5. STATIN. (2019). Population Statistics. Retrieved from Statistical Institute of Jamaica. https://statinja.gov.jm/Demo_SocialStats/PopulationStats.aspx.
6. Marine Regions. (2019). Marine Gazetteer Placedetails. Marineregions.org. https://www.marineregions.org/gazetteer.php?p=details&id=8459.
7. Ministry of Agriculture, Fisheries and Mining. (1991). Ministry of Agriculture, Fisheries and Mining. Retrieved from Ministry of Agriculture, Fisheries and Mining. https://www.moa.gov.jm/sites/default/files/pdfs/The_Exclusive_Economic_Zone_Act.pdf.
8. National Fisheries Authority. (2022). Jamaica Fisheries Quarterly Statistics Report 1(1). Kingston, Jamaica: Natioanl Fisheries Authority.
9. Brown, D. D. (2010). Past and current oyster culture in Jamaica. . A regional shellfish hatchery for the Wider Caribbean, 89.
10. Ministry of Agriculture, Fisheries and Mining. (2023). $445-million modern tilapia hatchery to be constructed by the National Fisheries Authority. Ministry of Agriculture, Fisheries and Mining. https://www.moa.gov.jm/content/445-million-modern-tilapia-hatchery-be-constructed-national-fisheries-authority
11. Bennett, K. (2024). Tilapia hatchery upgrade to propel Jamaica back in export business. The Jamaica Observer. https://www.jamaicaobserver.com/2024/03/06/tilapia-hatchery-upgrade-propel-jamaica-back-export-business/
12. Palmer, A. (2024). New Tilapia Hatchery to be constructed. Jamaica Information Service. https://jis.gov.jm/radio_programs/new-tilapia-hatchery-to-be-constructed/
13. Climate Trade. (2023). The world's most polluting industries. Climate Trade. https://climatetrade.com/the-worlds-most-polluting-industries/
14. Raczyńska, M., Machula, S., Choiński, A., & Sobkowiak, L. (2012). Influence of the fish pond aquaculture effluent discharge on abiotic environmental factors of selected rivers in Northwest Poland. Acta Ecologica Sinica, 32(3), 160-164.
15. Lucas, J., Southgate, P., & Tucker, C. (2019). Aquaculture: Farming Aquatic Animals and Plants, 3rd Edition. John Wiley & Sons.
16. National Environmental and Planning Agency. (2015). Legislations and Regulations. National Environmental and Planning Agency. https://www.nepa.gov.jm/sites/default/files/2021-12/NRCA-Permits-Licences-amended-2015.pdf
17. Miao, W., & Wang, W. (2020). Trends of aquaculture production and trade: Carp, tilapia, and shrimp. Asian Fisheries Science, 33(1), 1-10.

18. Fitzsimmons, K. (2023). 2022 Global Review of Tilapia Production and Markets. World Aquaculture Society. https://www.was.org/Meeting/Program/PaperDetail/160819.
19. Fitzsimmons, K., Martinez-Garcia, R., & Gonzalez-Alanis, P. (2011). Why tilapia is becoming the most important food fish on the planet. Better science, better fish, better life, 8-16.
20. Tao, W., Xu, L., Zhao, L., Zhu, Z., Wu, X., Min, Q., . . . Zhou, Q. (2021). High-quality chromosome-level genomes of two tilapia species reveal their evolution of repeat sequences and sex chromosomes. Molecular Ecology Resources, 21(2), 543-560.
21. National Fisheries Authority. (2023). Jamaica Fisheries: Quarterly Statistics Report. Kingston, Jamaica: National Fisheries Authority 1(3). https://www.moa.gov.jm/sites/default/files/pdfs/Jamaica%20Fisheries%20Quarterly%20Statistics%20Report%2C%20January%20-%20March%20 2023.pdf.
22. Aiken, K., Morris, D., Hanley, F., & Manning, R. (2002). Aquaculture in Jamaica. Naga 25(3/4), 10-15.
23. Chakalall, B., & Noriega-Curtis, P. (1992). Tilapia Farming in Jamaica. https://www.fao.org/4/x0332b/x0332b01.htm.
24. National Fisheries Authority. (2023). Jamaica Fisheries: Quarterly Statistics Report Kingston, Jamaica: National Fisheries Authority 2 (2).
25. Kurniawan, S. B., Ahmad, A., Rahim, N. F., Said, N. S., Alnawajha, M. M., Imron, M. F., & Hasan, H. A. (2021). Aquaculture in Malaysia: Water-related environmental challenges and opportunities for cleaner production. Environmental Technology & Innovation, 24, 101913.
26. Ahmad, A., Abdullah, S. R., Hasan, H. A., Othman, A. R., & Ismail, N. I. (2021). Aquaculture industry: Supply and demand, best practices, effluent and its current issues and treatment technology. Journal of Environmental Management, 287, 112271.
27. Chiquito-Contreras, R. G., Hernandez-Adame, L., Alvarado-Castillo, G., Martínez-Hernández, M. D., Sánchez-Viveros, G., Chiquito-Contreras, C. J., & Hernandez-Montiel, L. G. (2022). Aquaculture—Production System and Waste Management for Agriculture Fertilization - A Review. Sustainability, 14(12), 7257.
28. Huang, X.-f., Guang-yu Ye., Nai-kang Yi., Li-jun Lu., Lin Zhang., Liu-yan, Y., . . . Liu., J. (2019). Effect of plant physiological characteristics on the removal of conventional and emerging pollutants from aquaculture wastewater by constructed wetlands. Ecological engineering, 135, 45-53.
29. Institute International Food Policy Research. (2015). 2014-2015 Global Food Policy Report. In I. F. Institute, 2014-2015 Global Food Policy Report.
30. Carvalho, E., David, G. S., & Silva, R. J. (2012). Health and environment in aquaculture. BoD–Books on Demand.
31. Dauda, A. B., Ajadi, A., Tola-Fabunmi, A. S., & Akinwole, A. O. (2019). Waste production in aquaculture: Sources, components and managements in different culture systems. Aquaculture and Fisheries, 4(3), 81-88.
32. Ozbay, & Gulnihal. (2006). Best management practices minimize impacts of aquaculture effluents. Global Seafood Alliance. https://www.globalseafood.org/advocate/best-management-practices-minimize-impacts-of-aquaculture-effluents/#:~:text=Best%20management%20practices%20minimize%20impacts%20of%20aquaculture%20 effluents,Minimizing%20impacts%20...%206%20Best%20 management%20prac
33. Yeo, S., Morris, J., & Binkowski, F. (2004). Aquaculture effluents and waste by-products characteristics, potential recovery, and beneficial reuse. Iowa: North Central Regional Aquaculture Center. file:///C:/Users/admin/Downloads/noaa_37672_DS1.pdf.
34. Boyd, C. E., & Tucker, C. S. (2012). Pond aquaculture water quality management. Springer Science & Business Media. https://books.google.co.in/books?hl=en&lr=&id=2r8GCAAAQBAJ&oi=fnd&pg=PR10&dq=Pond+aquaculture+water+quality+management.+&ots=pKA--y_dKs&sig=siRNVk_yS-8NIPvLPaRIbLbmSWk&redir_esc=y#v=onepage&q=Pond%20 aquaculture%20water%20quality%20management.&f=false.
35. Halfhide, T., Åkerstrøm, A., Lekang, O. I., Gislerød, H. R., & Ergas, S. J. (2014). Production of algal biomass, chlorophyll, starch and lipids using aquaculture wastewater under axenic and non-axenic conditions. Algal research, 6, 152-159.
36. Guldhe, A., Ansari, F. A., Singh, P., & Bux, F. (2017). Heterotrophic cultivation of microalgae using aquaculture wastewater: a biorefinery concept for biomass production and nutrient remediation. Ecological engineering, 99, 47-53.
37. Coldebella, A., Gentelini, A. L., Piana, P. A., Coldebella, P. F., Boscolo, W. R., & Feiden, A. (2017). Effluents from fish farming ponds: A view from the perspective of its main components. Sustainability, 10(1), 3.
38. Frimpong, E. A., Ansah, Y. B., Amisah, S., Adjei-Boateng, D., Agbo, N. W., & Egna, H. (2014). Effects of two environmental best management practices on pond water and effluent quality and growth of Nile tilapia, Oreochromis niloticus. Sustainability, 6(2), 652-675.
39. Emara, E. K., Farfour, S. A., & Mousa, I. E. (2016). Environmental studies on the effects of aquaculture and drainage wastewaters on Lake Burullus. Am. Eur. J. Agric. Environ. Sci, 16, 410-423.
40. Pihlainen, S., Zandersen, M., Hyytiäinen, K., Andersen, H. E., Bartosova, A., Gustafsson, B., & Thodsen, H. (2020). Impacts of changing society and climate on nutrient loading to the Baltic Sea. Science of the Total Environment, 731, 138935.
41. Igwegbe, C. A., Ighalo, J. O., Iwuozor, K. O., Onukwuli, O. D., Okoye, P. U., & Al-Rawajfeh, A. E. (2022). Prediction and optimisation of coagulation-flocculation process for turbidity removal from aquaculture effluent using Garcinia kola extract: Response surface and artificial neural network methods. Cleaner Chemical Engineering 4.
42. Avnimelech, Y. (2009). Biofloc Technology. A Practical Guide Book. Baton Rouge, La, USA,: The World Aquaculture Society.
43. Chiquito-Contreras, R. G., Hernandez-Adame, L., Alvarado-Castillo, G., Martínez-Hernández, M. D., Sánchez-Viveros, G., Chiquito-Contreras, C. J., & Hernandez-Montiel, L. G. (2022). Aquaculture—Production System and Waste Management for Agriculture Fertilization - A Review. Sustainability, 14(12), 7257.
44. Kloas, W., Groß, R., Baganz, D., Graupner, J., Monsees, H., Schmidt, U., . . . Wuertz, S. (2015). A new concept for aquaponic systems to improve sustainability, increase productivity, and reduce environmental impacts. Aquaculture environment interactions, 7(2), 179-192.

45. Delaide, B., Goddek, S., Gott, J., Soyeurt, H., & Jijakli, M. H. (2016). Lettuce (Lactuca sativa L. var. Sucrine) growth performance in complemented aquaponic solution outperforms hydroponics. Water, 8(10), 467.
46. Boyd, C. E. (2004). Farm-level issues in aquaculture certification: Tilapia. Report commissioned by WWF-US in, 1-29.
47. Coloso, R. M., Basantes, S. P., King, K., Hendrix, M. A., Fletcher, J. W., Weis, P., & Ferraris, R. P. (2001). Effect of dietary phosphorus and vitamin D3 on phosphorus levels in effluent from the experimental culture of rainbow trout (Oncorhynchus mykiss). Aquaculture, 202(1-2), 145-161.
48. Kimera, F., Sewilam, H., Fouad, W. M., & Suloma, A. (2021). Efficient utilization of aquaculture effluents to maximize plant growth, yield, and essential oils composition of Origanum majorana cultivation. Annals of Agricultural Sciences, 66(1), 1-7.
49. Al Juboury, M. F., Abdulredha, M., & Nile, B. K. (2022). Photocatalysis and flocculation processes for recycling aquaculture effluent into nutrient-rich irrigation water. Water Supply, 22(3), 3103-3113.
50. Gross, A., Boyd, C. E., & Wood, C. W. (2000). Nitrogen transformations and balance in channel catfish ponds. Aquacultural Engineering, 24(1), 1-14.
51. Igwegbe, C. A., Onukwuli, O. D., & Onyechi, P. C. (2019). Optimal route for turbidity removal from aquaculture wastewater by electrocoagulation-flocculation process. UNIZIK Journal of Engineering and Applied Sciences 15(1), 99-108.
52. Dauda, A. B., Ajadi, A., Tola-Fabunmi, A. S., & Akinwole, A. O. (2019). Waste production in aquaculture: Sources, components and managements in different culture systems. Aquaculture and Fisheries, 4(3), 81-88.
53. Yogev, U., Barnes, A., & Gross, A. (2016). Nutrients and energy balance analysis for a conceptual model of three loops off grid, aquaponics. Water, 8(12), 589.
54. Verdegem, M. C. (2013). Nutrient discharge from aquaculture operations in function of system design and production environment. . Reviews in Aquaculture, 5(3), 158-171.
55. Turcios, A. E., & Papenbrock, J. (2014). Sustainable treatment of aquaculture effluents—what can we learn from the past for the future?. Sustainability, 6(2), 836-856.
56. Pouil, S., Samsudin, R., Slembrouck, J., Sihabuddin, A., Sundari, G., Khazaidan, K., & Caruso, D. (2019). Nutrient budgets in a small-scale freshwater fish pond system in Indonesia. Aquaculture, 504, 267-274.
57. Yeo, S., Morris, J., & Binkowski, F. (2004). Aquaculture effluents and waste by-products characteristics, potential recovery, and beneficial reuse. Iowa: North Central Regional Aquaculture Center.
58. Tucker, C. (1998). Characterization and Management of Effluents from Aquaculture Ponds in the Southeastern United States. 49: Southern Regional Aquaculture Center Final Project No. 600.
59. Tucker, C., Boyd, C., & Hargreaves, J. (2002). Characterization and management of effluents from warmwater aquaculture ponds. Aquaculture and the Environment in the United States. U.S Aquaculture Society. A Chapter of the World Aquaculture Society, 35-76.
60. Ahmad, A. L., Chin, J. Y., Harun, M. H., & Low, S. C. (2022). Environmental impacts and imperative technologies towards sustainable treatment of aquaculture wastewater: A review. Journal of Water Process Engineering, 46, 102553
61. Van Wyk, P., & Davis, M. (2006). Regulatory policies to promote the developmentof sustainable aquaculture in the Caribbean.