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Hazard Analysis Critical Control Point (HACCP) in Water-supply Phase for Sustainable Aquaculture.

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Abstract- ***Aquaculture production in Nigeria grew steadily between 1999 and 2015, but has been on the decline in recent years. Its development in Nigeria is constrained by such as: water-quality/quantity, high cost of feed, diseases, among other factors. Although fish, can be enhanced to meet globally acceptable standard and the quality of water during production, can largely affect the health and cost of getting the product to the market. Hazard Analysis Critical Control Point (HACCP) is a management system in which food safety is addressed via the analyses and control of possible hazards, all through the production process. This paper aims to look briefly at the origin and application of HACCP in aquaculture, the principles and procedures for developing a HACCP plan and to discuss the application of HACCP principles in the water supply for aquaculture. HACCP as a safety measure, was developed in the 1960s, in the United States, and was used to ensure the highest level of food safety that astronauts required during their exploration of the moon. It has met huge success and has been standardized by the Codex-Alimentarius (the global food-standard setting body). The production control system follows a two-step process: 1) setting-up a HACCP team and 2) applying the seven principles of HACCP to developing, verifying and implementing a flow diagram for operation. The principles of HACCP includes: conducting a hazard analysis, identifying critical control points (CCPs) in the process,HACCP includes: conducting a hazard analysis, identifying critical control points (CCPs) in the process, establishing critical limits, monitoring each critical limits, establishing corrective actions, establishing verification procedures, and establishing record keeping procedures. Developing a HACCP plan follows a logical sequence in its application to the specified operation, which is specific to the production location and specie in culture. Possible hazards in aquaculture could be biological, chemical or physical. The water sources for aquaculture may be ground water such as wells and springs or surface water such as rivers, lakes or streams, and must "ideally" be uncontaminated from excessive nutrients, chemicals, or heavy metals and sufficiently available. When applying the principles of HACCP to the water-supply phase: (i)Potential hazards such as contaminants and their preventive measures are analyzed and identified for water supply, which can be controlled at point or non point sources. (ii)With the use of a decision tree (consisting of a series of questions), each phase is determined to be a critical control point or not. (iii) Critical limits must be established, that do not exceed the regulatory tolerance. (iv) A monitoringsystem, consisting of regular checking of the water source for the content levels of contaminant is established (v) If the water supply has levels of contaminants greater than the regulatory tolerance, then the farmer must draw up a corrective action plan. (vi) This stage requires setting up routine verification activities to ensure critical limits meet regulatory tolerance, water supply still comes from the same source and that analyses are properly documented and recorded. (vii) Records related to water supply, such as: analyses and observed changes, among others, must be signed and retained by appropriate personnel/ management. HACCP has the potential to make an excellent contribution to: food safety, enhanced cost efficiency, prevention of work related accidents, and enhanced customer satisfaction, among many other benefits. However, there is a need for major national and international efforts to be focused on the exploitation of this concept, include awareness programs in extension activities and fish farmers should be open to the concept of HACCP, for better output.***

Keywords: HACCP, Hazards, Application, Principles, Water-supply

I. INTRODUCTION

Nigeria's National Aquaculture Strategy, aims to increase domestic fish production, on a sustainable and renewable basis to the level of self–sufficiency and fish export, at large (FMARD, 2017). Although aquaculture has the greatest potential for growth, yet the development of aquaculture in Nigeria is faced with constraints such as: water quality/ quantity, diseases, lack of technical man-power, trial-and-error approach, etc (Akinwole, 2016). Marketing and quality assurance for local consumption and export is also a key issue in Nigerian Aquaculture, as identified by the Federal Ministry of Agriculture and rural development (FMARD, 2017).

Fish can be enhanced to ensure consumer safety, meet globally accepted standards, avail access to international markets, and improve the profitability via the application of preventive/ operational management systems. The entirety of fish activities are carried out in the water, hence the quality of water in a production system, significantly affects the organism's health and cost of getting the product to the market (Cline, 2012). Water is both the raw material and the main vector of hazards in fish farming.

Recent studies have emphasized the structured hazard analysis, water quality monitoring, and critical control points (CCPs) in intake and verification with microbiological and chemical criteria tailored to species, system type, and local sources; as being essential to ensure food safety, reduce disease outbreaks, and meet international market standards. Hence, the need for Hazard Analysis Critical Control Point (HACCP) in the aquaculture water supply phase as a sustainable Aquaculture Strategy. HACCP is a preventive management system in which food safety is addressed. (FDA, 2018). It is achieved through analyses and control of biological, chemical, and physical hazards, from raw materials acquisition, through production, to consumption (FDA, 2018). HACCP involves seven key principles that can be adaptable to aquaculture processes.

This paper seeks to address the concerns of Aquaculture food safety, suggest a preventive management system of aquaculture production (the bulk of which comes from private farm owners), create a public awareness on aquaculture food safety, and proffer a production management system for achieving the policy objectives 6, 7 and 8 of the National Aquaculture strategy reviewed in 2017, by the application of a preventive management system, HACCP, throughout the entire production system, from the sourcing of raw materials, to the packaging and distribution of the finished aquaculture products. The successful application of HACCP requires the full commitment of the farm owner, and the workforce. (WHO, 2007), and its practice, although beneficial to large-scale production, presents a few constraints to its implementation, in subsistence fish farming. (WHO, 2007).

1.2 Objectives of the study

i. To give an overview of the current status of aquaculture in Nigeria.
ii. To highlight the origin of HACCP.
iii. To discuss the seven principles for developing a HACCP plan.
iv. To highlight the hazards in aquaculture water
v. To discuss a practical HACCP planning the water-supply phase of aquaculture.

1.3 Definition of terms

CCP Decision Tree: A sequence of questions to assist in determining whether a control point is a CCP.

Control: (a) To manage the conditions of an operation to maintain compliance with established criteria. (b) The state where correct procedures are being followed and criteria are being met.

Control Measure: Any action or activity that can be used to prevent, eliminate or reduce a significant hazard.

Control Point: Any step at which biological, chemical, or physical factors can be controlled.

Corrective Action: Procedures followed when a deviation occurs.

Criterion: A requirement on which a judgement or decision can be based.

Critical Control Point: A step at which control can be applied and is essential to prevent or eliminate a food safety hazard or reduce it to an acceptable level.

Critical Limit: A maximum and/or minimum value to which a biological, chemical or physical parameter must be controlled at a CCP to prevent, eliminate or reduce to an acceptable level the occurrence of a food safety hazard.

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Deviation: Failure to meet a critical limit.

HACCP: A systematic approach to the identification, evaluation, and control of food safety hazards.

HACCP Plan: The written document which is based upon the principles of HACCP and which delineates the procedures to be followed.

HACCP System: The result of the implementation of the HACCP Plan.

HACCP Team: The group of people who are responsible for developing, implementing and maintaining the HACCP system.

Hazard: A biological, chemical, or physical agent that is reasonably likely to cause illness or injury in the absence of its control.

Hazard Analysis: The process of collecting and evaluating information on hazards associated with the food under consideration to decide which are significant and must be addressed in the HACCP plan.

Monitor: To conduct a planned sequence of observations or measurements to assess whether a CCP is under control and to produce an accurate record for future use in verification.

Prerequisite Programs: Procedures, including Good Manufacturing Practices, that address operational conditions providing the foundation for the HACCP system.

Severity: The seriousness of the effect(s) of a hazard.

Step: A point, procedure, operation or stage in the food system from primary production to final consumption.

Validation: That element of verification focused on collecting and evaluating scientific and technical information to determine if the HACCP plan, when properly implemented, will effectively control the hazards.

Verification: Those activities, other than monitoring, that determine the validity of the HACCP plan and that the system is operating according to the plan.

II. CURRENT STATUS OF AQUACULTURE IN NIGERIA.

Aquaculture which is the science involving the rearing of fish, shellfish, and aquatic autotrophs currently emerges as the fastest and one of the pivotal sectors (Harris, 2024). From ancient carp ponds in China to a global industry, and by 500 BCE, Fan Li documented methods of carp farming, making aquaculture a structured practice (Alimentarium, 2023). Nigeria has emerged as a continental leader, particularly in catfish farming. Interestingly, aquaculture or fish cultivation offers a major source of animal protein and contributes heavily to household diets, livelihood, and economic development in many countries and regions of the world (Ajayi *et. al*., 2022; Elahi *et al*., 2024). The 19th century improvements in transportation made fish readily available and inexpensive, even far from the seas, leading to a decline in aquaculture. Overfishing and rising seafood demand revived aquaculture globally, and today, aquaculture supplies nearly half of the world's fish consumed, making it a cornerstone of food security.

Nigeria is now the second-largest aquaculture producer in Africa, with production increasing more than tenfold since 2000; an output rising from 25,718 metric tonnes to 261,711 metric tonnes, reflecting an average annual growth rate of 12.3%.

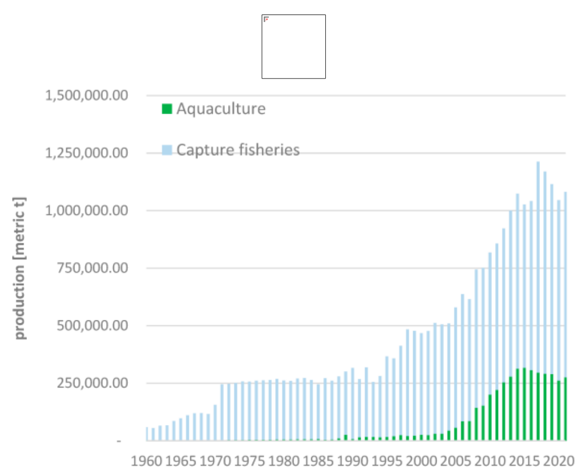

Chart 1: Aquaculture development in Nigeria.

Source: Ogunji and Wuertz, 2023.

Nigeria is the leading country in the production of African catfish (*Clarias gariepinus*) and African bony tongue (*Heterotis niloticus*). The great quantity of land, inland water surface, and coast-land, which are suitable for fish farming, have placed Nigeria at a very advantaged position to develop aquaculture further (Ogunji and Wuertz, 2023). However, in spite of Nigeria ranking in the overall total production in African countries, the protein consumption per individual in the country is still lower than the relative average recorded in Sub-Saharan Africa. For example, aquatic food is the only animal protein source which does not cost much (Babatunde et al., 2021), and is consumed at a rate of 11.2 to 13.3 kg per person annually in Nigeria (Ajayi et al., 2022). According to the Nigeria National bureau of statistic (NBS, 2023), Nigeria annual fish consumption is about 3.6 million tones, the countries' annual production as at 2022 is 1,043,230. Hence, the deficit which are mainly supply from importation is about 2, 556,770.

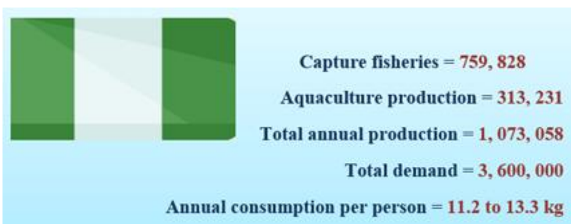

Figure 1: Current status of fishery sector of Nigeria

Source: Ogunji and Wuertz, 2023.

With the deficit rate, investors still stand higher chances to venture in to Aquaculture, to close the gap (Elezuo *et al.,* 2024). The aquaculture venture in Nigeria faces hurdles such as inadequate infrastructure, limited access to quality fish feed, poor cold-chain logistics, issues of poor production integrity, which restricts export potentials and profitability, and water quantity /quality.

III. AQUACULTURE WATER SUPPLY SOURCES

Water is the most common substance on earth covering seven-tenths of the world's surface and that is why earth is also called the blue planet. More than 97% occurs in the form of seawater, whose salinity makes it useless, while freshwater makes up only 2.6%. Fresh water has always been of vital importance to man as his early habitations were within easy reach of rivers, tanks, dams, ponds and lakes. In aquaculture there are mainly two water sources namely: Surface water source and Ground water source.

The success or failure of an aquaculture venture, depends largely on the quantity and quality of the water resource. An "ideal" water source for aquaculture must be: uncontaminated from excessive nutrients, chemicals, or heavy metals. And must be available in volumes sufficient for the aquaculture operation. Water sources for controlled fish production may be wells, rivers or streams, springs, etc, each of which present different problems. In most fish farms, the water used to fill the ponds come from a stream (brook) or from a small water body (lake or dam) located very near the farm. Depending on the flow in the body of water, the supply to the farm may be adequate or in excess.

A lake or any natural water body or a dam is another possible supply of water to a fish farm. With an approximate knowledge of the water body (supply) one can determine if the needs in water of the farm can be met. In cases where water is taken from a stream and if the flow drops considerably during some months in the year that the needs in water of the farm could not be met, then it's necessary to create a dam up-stream, for having a reserve of water for the months of scarcity. The dimension of the dam would depend on the volume of water to be stocked; the dam is placed where it is easier to block the valley above the site of the ponds so as to bring the water to the farm.

During the rainy season when the water swells, the volume of flow would increase and would create floods. In some regions, with a flat topography, considerable areas of lands are flooded and covered by water. These temporary water bodies are very productive and traditionally they are used for fishing. They constitute a spawning place for several species of fishes. Where the depth is adequate a pond retaining water for many months can be made and can be managed as an aquaculture pond.

The underground water is also used as supplies to the ponds. In this category we have the water from the wells, springs and the aquifers. Underground water has little or no oxygen and does not have any plankton. The water may contain dangerous gases such as methane or hydrogen sulfide. The chemical quality of

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the water depends on the nature of geological layers through which it has passed.

A spring is underground water rising at the ground and is fed by underground source and consequently its flow can fluctuate with changes of the level of the underground water. Considering the nature of the spring (temporary or permanent spring) and its flow, one can determine if the need of the farm can be met. A reservoir to store water is often built to overcome the scarcity of water during dry season. Spring water is taken as much as possible to the farm by gravity. Generally, the quality of this water is good; but the water should be aerated.

Wells are sunk to get access to the underground water. In most of the cases, the water has to be pumped up. Only the water from the artisan well rises to the surface or to a certain height by hydro-static pressure. This is caused by the geological morphology of the ground which keeps the water under pressure. The choice of the place of sinking the well, the depth, and the flow expected should be done by qualified staff. The water coming from the well should be aerated and is normally good for water supply to a hatchery because the water does not usually contain any contaminants.

Rain water is another possible supply to the ponds although it is difficult to depend on it solely. To determine the quantity of rain water one has to study closely the rainfall of the place where the farm will be sited and its seasonal variations. The quantity of rainfall would determine the amount of water which will flow into the sloping pond and influence the rise of the water in the collecting pond.

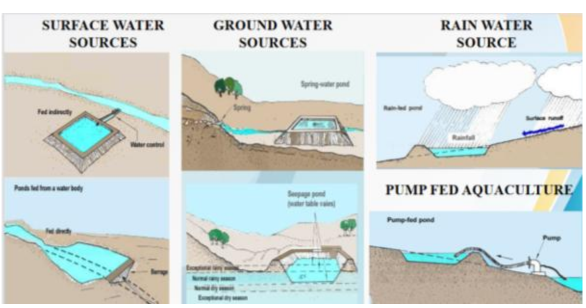

Figure 2: Aquaculture water supply sources

Source: FAO, 2025

IV. WATER QUALITY CRITERIA

Water is the home of the fish and its quality is one of the most over looked aspect of pond management until it affects fish production. Water quality involves physical, chemical and biological factors which determine the use of water for fish culture purposes. (Ehiagbonare and Ogundiran, 2010). Studies show that growth of fish in aquaculture mainly depends on feed consumption and quality (Slawski *et al.,* 2011); stocking density (Ma *et al.*, 2006); biotic factors such as sex and age (Imsland and Jonassen, 2003); genetic variance; and abiotic factors such as water chemistry, temperature (Imsland *et al.*, 2007), photoperiod (Imsland and Jonassen, 2003), and oxygen level (Bhatnagar and Devi, 2013). Therefore, successful management of fish ponds requires an understanding of water quality, which is determined by abiotic factors such as temperature, dissolved oxygen (DO), transparency, turbidity, water color, carbon dioxide, pH, alkalinity, hardness, unionized ammonia, nitrite, nitrate, and biotic factors such as primary productivity, biological oxygen demand (BOD), plankton population among others (Bhatnagar and Devi, 2013).

Concerns about pond water quality are directly related to its production and therefore water quality parameters of greatest concern to fish farming and important to consider in fish culture (Bryan *et al.,* 2011). Therefore, when evaluating and selecting sites for fish production, the source of water and its quality are some of the main factors to consider while ensuring that the water source has a high concentration of dissolved oxygen and optimal temperatures which should be kept at the right levels throughout the culture period among other critical factors (Ngugi *et al.,* 2007).

Studies show that a special set of water chemistry requirements and optimal water quality is essential to a healthy, balanced, and functioning aquaculture system (DeLong *et al.,* 2009). Fish growth is generally greater in ponds with optimal levels of DO, temperature among other parameters (Bartholomew, 2010), though different fish species have ideal levels of water quality parameters within which they grow optimally (Kausar and Salim, 2006). Within the growing aquaculture industry, it is accepted that good water quality is needed for maintaining viable aquaculture production. Poor water quality can result in low profit, low product quality and potential human health risks.

Production is reduced when the water contained contaminants that can impair development, growth, reproduction, or even cause mortality to the cultured species. Where aquaculture is concerned, any characteristic of water that affects the survival, reproduction, growth or management of fish or other aquatic creatures in any way is a water quality variable. There are many water quality variables in aquaculture ponds, but only a few of these normally play an important role. The knowledge of water quality criteria or principles will help in determining the potential of water for aquaculture, improving environmental conditions in ponds, avoiding stress related disease and parasite problem and ultimately producing aquatic creatures more efficiently.

4.0.1 Physical water quality variables

- Temperature

Temperature is defined as the degree of hotness or coldness in the body of a living organism either in water or on land. As fish is a cold-blooded animal, its body temperature changes according to that of environment affecting its metabolism and physiology and ultimately affecting the production. Higher temperature increases the rate of bio-chemical activity of the micro biota, plant respiratory rate, and so increase in oxygen demand. It further cause decreased solubility of oxygen and also increased level of ammonia in water. However, during under extended ice cover, the gases like hydrogen sulphide, carbon dioxide, methane, etc. can build up to dangerously high levels affecting fish health. The lower the pond water temperature, the less food the fish will consume and the slower their growth rate will be. The higher the pond water temperature is, the lower the solubility of dissolved oxygen in water. Warmer water holds less oxygen than cooler waters. Water temperatures above 32°C for prolonged periods can stress fish and reduce growth.

Desirable limits

Bhatnagar *et al.* (2004) suggested the levels of temperature as 28 to 32ºC good for tropical major carps; <12ºC is lethal for warm water species but good for cold water species; 25 to 30ºC is ideal for *Penaeous monodon* culture; < 20ºC is sub lethal for growth and survival for fishes and > 35ºC is lethal to maximum number of fish species and according to Santhosh and Singh (2007) suitable water temperature for carp culture is between 24ºC and 30ºC. Therefore, pond waters should be managed to maintain warm temperatures, the optimum for catfish being 28 to 32ºC.Temperatures between 20 and 36°C have been reported by various researchers as being suitable for tilapia culture. According to Kausar and Salim (2006), for instance, the preferred temperature range for optimum tilapia growth in ponds is between 25 and 27 °C. FAO (2011) reported the preferred temperature ranges of between 31 and 36 °C, while Ngugi et al. (2007) gave a range of between 20 and 35°C as ideal for tilapia culture. The most preferred temperature range for optimal growth of tilapia is 25 to 27 °C, while the ideal pH ranges between 6 and 9 (DeWalle *et al.,* 2011). The optimum temperature range for development of eggs and rearing of fry is between 26 to 28°C. If the temperature is too low hatching and development are prolonged, and fungi which thrive in cool waters often invade the egg mass. At higher water temperatures, embryos develop too fast and there may be a high incidence of malformed or nonviable fry. At temperature below 15ºC for warm water fish, growth stops and death occurs at extremes. At temperature of 15ºC, reduced feed intake and growth rates, higher FCRs, fish is more stressed at lower temperatures, therefore, more susceptible to disease, organic matter and other wastes are broken down at a slower rate when temperatures are low with high risk of eutrophication. When temperature is consistently above the recommended value (32ºC), there will be lower solubility of oxygen, stress and death at extreme temperatures.

- Turbidity/Transparency

Turbidity is a measure of the clarity of water. The colour of the water gives an indication of what sort of turbidity it is. If it is brown it is often due to clay and if it is greenish, it is due to plankton. Turbidity is the resultant effect of several factors such as suspended clay particles, dispersion of plankton organisms, particulate organic matters and also the pigments caused by the decomposition of organic matter. It is measured using a secchi disc.

Desirable limits

According to Bhatnagar *et al*. (2004) turbidity range from 30 to80 cm is good for fish health; 15 to 40 cm is good for intensive culture system and < 12 cm causes stress. According to Santhosh and Singh (2007) transparency between 30 and 40 cm indicates optimum productivity of a pond for good fish culture.

4.0.2 Chemical water quality variables

- pH

This parameter shows the quantity of hydrogen ions (H^+) in the water. It show if a water body is acidic, alkalinic or neutral. The scale for measuring the degree of acidity is called the pH scale, which ranges from 1 to 14. Conditions become more acidic as pH values decrease and more basic as they increase. All living organisms have optimal ranges of pH where growth is best. Natural waters range between pH 5.0 and pH 10.0 while seawater is near pH 8.3. A pH meter is an electronic instrument used to measure the pH of a liquid, and typically it consists of a special measuring probe (a glass electrode) connected to an electronic meter that measures and displays the pH reading. The pH is interdependent with other water quality parameters, such as carbon dioxide, alkalinity, and hardness. The pH can also affect fish health. For most freshwater species, a pH range between 6.5 to 9.0 is ideal, but most marine animals typically cannot tolerate as wide range pH as freshwater animals, thus the optimum pH is usually between pH 7.5 and 8.5. Simple hand-held meters or chemical test kits are available to monitor pH. The consumption of carbon dioxide causes pH to naturally fluctuate during the day. It is generally lowest at sunrise (due to accumulation of carbon dioxide during the night) and highest at afternoon when algae consumption of carbon dioxide is at its greatest.

Desirable limits

pH between 7 to 8.5 is ideal for biological productivity, fishes can become stressed in water with a pH ranging from 4.0 to 6.5 and 9.0 to 11.0 and death is almost certain at a pH of less than 4.0 or greater than 11.0 (Ekubo and Abowei, 2011). According to Santhosh and Singh (2007) the suitable pH range for fish culture is between 6.5 and 9.5 and ideal pH level is between 7.5 and 8.5 and above and below this is stressful to the fishes. Ideally, an aquaculture pond should have a pH between 6.5 and 9 (Bhatnagar *et al*., 2004). Bhatnagar *et al*. (2004) also recommended that <4 or >10.5 is lethal to fish/shellfish culture; 7.5-8.5 is highly congenial for *P.monodon*; 7.0-9.0 is acceptable limits; 9.0 -10.5 is sub-lethal for fish culture. The desired pH range for incubating eggs and rearing fry should be between 7.0 and 8.5. Exposure to pH values above 9 are undesirable and even short-term exposure to waters of pH 10 or above may kill fry and reduce egg hatchability.

- Dissolved Oxygen (DO)

Dissolved oxygen is considered as one of the most important aspect of aquaculture. It is needed by fish to respire and perform metabolic activities. Thus, low levels of dissolved oxygen are often linked to fish kill incidents. On the other hand, optimum levels can result to good growth, thus result to high production yield. In general, a saturation level of at least 5ppm is required Values lower than this can put undue stress on the fish, and levels reaching less than 2ppm may result to death. It can enter into the system through direct diffusion and as a by-product of photosynthesis. This means then that the level of dissolved oxygen in the water can be increased through mechanical aeration, e.g. paddle wheels, agitators, vertical sprayers, impellers, airlift pumps, air diffuse, liquid oxygen injection, considerable wind and wave action, and presence of aquatic plants and algae. However, caution should be considered on the latter since it can also cause oxygen depletion when the plant population becomes too dense. On the other hand, it is removed through respiration and decomposition. Oxygen concentration maybe reported in terms milligram per liter (mg/L) or its equivalent, parts per million (ppm). The oxygen concentration is measured in terms of parts per million (ppm) or mg/L; both units of measure are the same.

Desirable limits

Tropical fishes have more tolerance to low DO than temperate fishes. According to Bhatnagar and Singh (2010) and Bhatnagar *et al*. (2004) DO level >5ppm is essential to support good fish production. Bhatnagar *et al*. (2004) also suggested that 1to 3 ppm has sub-lethal effect on growth and feed utilization; 0.3 to 0.8 ppm is lethal to fish and >14 ppm is lethal to fish fry, and gas bubble disease may occur. DO less than 1ppm will lead to the death of fish, less than 5ppm, fish survive but grow slowly and will be sluggish, 5ppm and above is desirable. According to Santhosh and Singh (2007) Catfishes and other air breathing fishes can survive in low oxygen concentration of 4ppm. Ekubo and Abowei (2011) recommended that fish can die if exposed to less than 0.3ppm of DO for a long period of time, minimum concentration of 1.0ppm of DO is essential to sustain fish for long period and 5.ppm are adequate in fishponds. Adequate dissolved oxygen is critical in hatcheries because eggs and fry have high metabolic rates and thus a high requirement for oxygen. Dissolved oxygen concentrations should not fall below 4 to 5ppm at any time within the hatchery.

- Alkalinity

Alkalinity is the water's ability to resist changes in pH and is a measure of the total concentration of bases in pond water including carbonates, bicarbonates, hydroxides, phosphates and borates, dissolved calcium, magnesium, and other compounds in the water. If the alkalinity is low, it indicates that even a small amount of acid can cause a large change in the pH.

Desirable limits

Bhatnagar *et al*. (2004) suggested that <20ppm indicates poor status of water body, 20 to 50 ppm shows low to medium, 80-200 ppm is desirable for fish/prawn and >300 ppm is undesirable due to non-availability of CO_2. Stone and Thomforde (2004) suggested 50-150ppm ($CaCO_3$) as desirable range; an acceptable range of above 20 ppm, less than 400 ppm for ponds and above 10ppm for hatchery. According to Santhosh and Singh (2007) the ideal value for fish culture is 50-300ppm. Catfish eggs and fry thrive in waters with a wide range of alkalinity, although waters of very low alkalinity (<10 ppm as CaCO3) should be avoided as hatchery supplies if possible. These waters are poorly buffered and pH can fluctuate drastically with small additions of acid or base.

- Carbon-dioxide (CO_2)

Free carbon dioxide, highly soluble gas in water, main source of carbon path way in the nature, is contributed by the respiratory activity of animals and can exist in water as bicarbonate or carbonates in the dissolved or bound form in earth crust, in limestone and coral reefs regions. When dissolved in water it forms carbonic acid which decreases the pH of any system, especially insufficiently buffered systems, and this pH drop can be harmful for aquatic organisms.

Desirable limits

According to Ekubo and Abowei (2011) tropical fishes can tolerate CO_2 levels of over 100ppm but the ideal level of CO_2 in fishponds is less than 10ppm. Bhatnagar *et al*. (2004) suggested 5 to 8 ppm is essential for photosynthetic activity; 12 to 15 ppm is sub-lethal to fishes and 50-60 ppm is lethal to fishes. The free carbon dioxide in water supporting good fish population should be less than 5ppm (Santhosh and Singh, 2007). High levels of dissolved carbon dioxide interfere with respiration of eggs and fry. Ideally, water supplies for catfish hatcheries should not contain measurable levels of dissolved carbon dioxide, but concentrations up to at least 10 ppm seem to be well tolerated, provided that dissolved oxygen concentrations are adequate.

- Conductivity

Conductivity is an index of the total ionic content of water, and therefore indicates freshness or otherwise of the water. Conductivity can be used as indicator of primary production (chemical richness) and thus fish production. Conductivity of water depends on its ionic concentration ($Ca2^+$, $Mg2^+$, HCO_3^-, CO_3^-, NO_3^- and PO_4^-), temperature and on variations of dissolved solids. Distilled water has a conductivity of about 1μ mhos/cm and natural waters have conductivity of 20-1500 μ mhos/cm (Abowei, 2010). Conductivity of freshwater varies between 50 to 1500 hs/cm, but in some polluted waters it may reach 10,000 hs/cm and seawater has conductivity around 35,000 hs/cm and above.

Desirable limits

As fish differ in their ability to maintain osmotic pressure, therefore the optimum conductivity for fish production differs from one species to another. Sikoki and Veen (2004) described a conductivity range of 3.8 to 10 hs/cm as extremely poor in chemicals, Stone and Thomforde (2004) recommended the desirable range 100-2,000 mSiemens/cm and acceptable range 30-5,000 mSiemens/cm for pond fish culture.

- Salinity

Salinity is defined as the total concentration of electrically charged ions (cations – Ca^{++}, Mg^{++}, K^+, Na^+ ; anions – CO_3^-, HCO_3^-, SO_4^-, Cl^- and other components such as NO_3^-, $NH4^+$ and PO_4^-). Salinity is a major driving factor that affects the density and growth of aquatic organisms' population (Jamabo, 2008).

Desirable limits

Fish are sensitive to the salt concentration of their waters and have evolved a system that maintains a constant salt ionic balance in its bloodstream through the movement of salts and water across their gill membranes. Often salinity limits vary species to species level. Bhatnagar *et al*. (2004) gave different ideal levels of salinity as 10 to 20 ppt for *P. monodon*; 10 to 25 ppt for euryhaline species and 25 to 28 ppt for *P. indicus*. Barman *et al*. (2005) gave a level of 10 ppt suitable for *Mugil cephalus* and Garg *et al*. (2003) suggested 25 ppt for *Chanos chanos* (Forsskal). Channel catfish can breed and reproduce over a wide range of salinities. Eggs can hatch and fry will develop in waters with salinities up to at least 8 parts per thousand, but the optimum salinity for channel catfish hatchery supplies appears to be between 0.5 and 3 ppt (500 to 3,000 ppm).

- Ammonia (NH_3)

Ammonia is the by-product from protein metabolism excreted by fish and bacterial decomposition of organic matter such as wasted food, faeces, dead planktons, sewage etc. The unionized form of ammonia (NH_3) is extremely toxic while the ionized form (NH_4^+) is not and both the forms are grouped together as "total ammonia". Ammonia in the range >0.1ppm tends to cause gill damage, destroy mucous producing membranes, "sub- lethal" effects like reduced growth, poor feed conversion, and reduced disease resistance at concentrations that are lower than lethal concentrations, osmoregulatory imbalance, kidney failure. Fish suffering from ammonia poisoning generally appear sluggish or often at the surface gasping for air.

Desirable limits

Maximum limit of ammonia concentration for aquatic organisms is 0.1ppm (Santhosh and Singh, 2007). OATA (2008) the levels below 0.02ppm were considered safe. Stone and Thomforde (2004) stated the desirable range as Total NH_3-N: 0-2ppm and Un-ionized NH_3-N: 0ppm and acceptable range as Total NH_3-N: Less than 4ppm and Un-ionized NH_3-N: Less than 0.4ppm. Bhatnagar *et al*. (2004) suggested 0.01-0.5ppm is desirable for shrimp; >0.4ppm is lethal to many fishes and prawn species; 0.05-0.4ppm has sub-lethal effect and <0.05ppm is safe for many tropical fish species and prawns. Bhatnagar and Singh (2010) recommended the level of ammonia (<0.2 ppm) suitable for pond fishery. Ideally, water in rearing troughs should be free of ammonia for optimal health and growth of fry, and the maximum concentration of un-ionized ammonia that should be allowed is about 0.05 ppm NH_3-N. Above this concentration, fry develop more slowly and are more susceptible to infectious diseases.

- Nitrite (NO_2^-)

Nitrite is an intermediate product of the aerobic nitrification bacterial process, produced by the autotrophic *Nitrosomonas* bacteria combining oxygen and ammonia. Nitrite can be termed as an invisible killer of fish because it oxidizes haemoglobin to methemoglobin in the blood, turning the blood and gills brown and hindering respiration also damage for nervous system, liver, spleen and kidneys of the fish.

Desirable limits

The ideal and normal measurement of nitrite is zero in any aquatic system. Stone and Thomforde (2004) suggested that the desirable range 0-1ppm NO_2 and acceptable range less than 4ppm NO_2. According to Bhatnagar *et al*. (2004) 0.02-1.0ppm is lethal to many fish species, >1.0 ppm is lethal for many warm water fishes and <0.02ppm is acceptable. Santhosh and Singh (2007) recommended nitrite concentration in water should not exceed 0.5ppm. OATA (2008) recommended that it should not exceed 0.2ppm in freshwater and 0.125 ppm in seawater.

- Nitrate (NO_3)

Where ammonia and nitrite were toxic to the fish, Nitrate is harmless and is produced by the autotrophic *Nitrobacter* bacteria combining oxygen and nitrite. Nitrate levels are normally stabilized in the 50-100 ppm range.

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Desirable limits

According to Stone and Thomforde (2004) nitrate is relatively nontoxic to fish and not cause any health hazard except at exceedingly high levels (above 90 ppm). Santhosh and Singh (2007) described the favourable range of 0.1 ppm to 4.0 ppm in fish culture water. However, OATA (2008) recommends that nitrate levels in marine systems never exceed 100ppm.

- Plankton

Those aquatic pelagic organisms, which are carried about by the movement of the water rather than their own ability to swim are called planktons. The plant components are called as phytoplankton and animal components as zooplanktons and they serve as fish food organisms. For enumeration they are collected using plankton net. As plankton is at the base of the food web, there is a close relationship between plankton abundance and fish production.

Plankton Blooms and Fish kill

Fertilization may not be the only reason for eutrophication or excessive growth of planktons in pond water surface. The growth of certain species of blue green algae form dense scums in surface waters, cause shallow thermal stratification, less availability of soluble phosphate in the top layer and prevents the penetration of light for photosynthesis to depths below 1m so leading to anoxic conditions in the deep areas (lack of oxygen and high concentration of free carbon dioxide) resulting in fish kills.

Desirable limits

Bhatnagar and Singh (2010) suggested the optimum plankton population (approximately 3000-4500 Nos. L^{-1}) in pond fish culture.

Table 1: Water Quality Critical limit (upper and lower) of Various Cultured Species

Species	Temp °C	Dissolved Oxygen mg/L	pH	Alkalinity mg/L	Ammonia %	Nitrite mg/L
Baitfish	16-24	4-10	6-8	50-250	0-0.03	0-0.6
Catfish/ Carp	18-27	3-10	6-8	50-250	0-0.03	0-0.6
Hybrid Striped Bass	21-29	4-10	6-8	50-250	0-0.03	0-0.6
Perch	10-18	5-10	6-8	50-250	0-0.03	0-0.6
Salmon	7-20	5-12	6-8	50-250	0-0.03	0-0.6
Tilapia	24-34	3-10	6-8	50-250	0-0.03	0-0.6
Tropical Ornamentals	20-29	4-10	6-8	50-250	0-0.03	0-0.5

Source: Adapted from David 2012

V. KEY HAZARDS IN AQUACULTURE WATER AND WHERE THEY ARISE

1. Microbiological hazards: Pathogens (e.g., Vibrio spp.), indicator organisms, viruses, and parasites introduced via surface water, wastewater mixing, or biofouled infrastructure; risks are amplified in hatcheries and RAS due to high biomass and recirculation; as well as larvae of predatory fishes and insects
2. Chemical hazards: Agricultural runoff (pesticides), heavy metals, disinfection by-products, and nitrogen compounds; source-dependent and often seasonal, especially where abstraction is from rivers or shallow wells.

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3. Physical hazards: Suspended solids, turbidity, and debris that can protect microbes from disinfection and stress fish; biofilm formation in pipes acts as a reservoir for contaminants.

Table 2: Possible hazards in Aquaculture water

Biological	Chemical	Physical
❖ Parasites of public health significance: *Taenia solium*, *Taenea saginata, Ascaris lumbricoides* etc. ❖ Pathogenic Bacteria: *Vibrio cholerae, Salmonella typhimurium, Shigella dysenteriae , Escherichia coli. etc.* ❖ Predatory fish or insects.	❖ Agrochemicals: disinfectants, pesticides, herbicides etc ❖ Veterinary drug residues: antibiotics, growth promoting hormones, other feed additives from animal manures. ❖ Heavy metals: metals leached into the soil from industrial wastes, sewage or animal manure, such as cyanide, mercury, lead	❖ Glass ❖ Stones ❖ Wood ❖ Metals ❖ Bones ❖ Plastic

Source: WHO, 2007

VI. THE CONCEPT OF HAZARD ANALYSIS CRITICAL CONTROL POINT (HACCP)

HACCP is a management system in which food safety is addressed through the analysis and control of biological, chemical, and physical hazards from raw material production, procurement and handling, to manufacturing, distribution and consumption of the finished product.

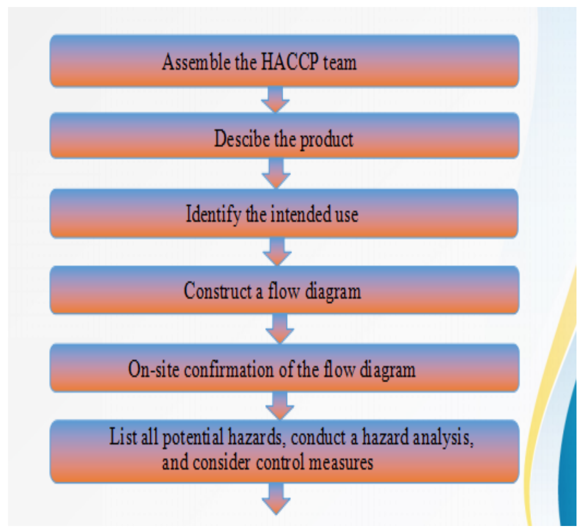
VII. THE ORIGIN OF HACCP

HACCP is a method that was developed in the 1963, in the United States of America. (NRAC, 2005) and was established by the United Nations Food and Agriculture Organization (UNFAO) and the World Health Organization (WHO). (USDA, 2017). It ensured the highest level of food safety that astronauts required during their exploration of the moon. Since then, it has met huge success and has been standardized by the Codex Alimentarius Commission, the global food-standard-setting body. (NRAC, 2005). The FDA, and the USDA, use mandatory HACCP programs as an effective approach to food safety and protection of public health. (USDA, 2018). Between 1966 and 1969, African countries such as Ghana, Cote d 'lvoire, Kenya and Nigeria became codex members, with their National Standards-setting-bodies as affiliates (CODEX, 2018).

VIII. DEVELOPING A HACCP PLAN

The format of HACCP plans will vary. In many cases the plans will be product and process specific. However, some plans may use a unit operations approach. Generic HACCP plans can serve as useful guides in the development of process and product HACCP plans; however, it is essential that the unique conditions within each facility be considered during the development of all components of the HACCP plan. In the development of a HACCP plan, some preliminary tasks need to be accomplished before the application of the HACCP principles to a specific product and process.

A



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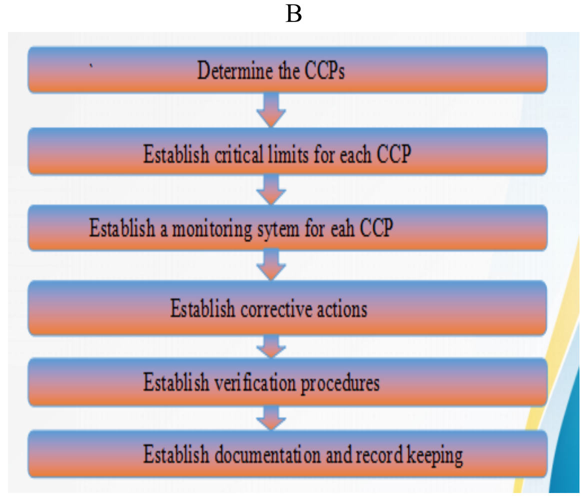

Figure 3a&b: Preliminary Tasks in the Development of the HACCP Plan

Source: FDA, 2004

8.0.1 Assembling the HACCP Team

The first task in developing a HACCP plan is to assemble a HACCP team consisting of individuals who have specific knowledge and expertise appropriate to the product and process. It is the team's responsibility to develop the HACCP plan. The team should be multi -disciplinary and include individuals from areas such as engineering, production, sanitation, quality assurance, and food microbiology. The team should also include local personnel who are involved in the operation as they are more familiar with the variability and limitations of the operation. In addition, this fosters a sense of ownership among those who must implement the plan. The HACCP team may need assistance from outside experts who are knowledgeable in the potential biological, chemical and/or physical hazards associated with the product and the process. However, a plan which is developed totally by outside sources may be erroneous, incomplete, and lacking in support at the local level.

Due to the technical nature of the information required for hazard analysis, it is recommended that experts who are knowledgeable in the food process should either participate in or verify the completeness of the hazard analysis and the HACCP plan. Such individuals should have the knowledge and experience to correctly: (a) conduct a hazard analysis; (b) identify potential hazards; (c) identify hazards which must be controlled; (d) recommend controls, critical limits, and procedures for monitoring and verification; (e) recommend appropriate corrective actions when a deviation occurs; (f) recommend research related to the HACCP plan if important information is not known; and (g) validate the HACCP plan.

8.0.2 Describe the food and its distribution

The HACCP team first describes the food. This consists of a general description of the food, ingredients, and processing methods. The method of distribution should be described along with information on whether the food is to be distributed frozen, refrigerated, or at ambient temperature.

8.0.3 Describe the intended use and consumers of the food

Describe the normal expected use of the food. The intended consumers may be the general public or a particular segment of the population (e.g., infants, immuno-compromised individuals, the elderly, etc.).

8.0.4 Develop a flow diagram which describes the process

The purpose of a flow diagram is to provide a clear, simple outline of the steps involved in the process. The scope of the flow diagram must cover all the steps in the process which are directly under the control of the establishment. In addition, the flow diagram can include steps in the food chain which are before and after the processing that occurs in the establishment. The flow diagram need not be as complex as engineering drawings. A block type flow diagram is sufficiently descriptive (see Appendix B). Also, a simple schematic of the facility is often useful in understanding and evaluating product and process flow.

8.0.5 Verify the flow diagram

The HACCP team should perform an on-site review of the operation to verify the accuracy and completeness of the flow diagram. Modifications should be made to the flow diagram as necessary and documented.

After these five preliminary tasks are completed, the seven principles of HACCP are applied

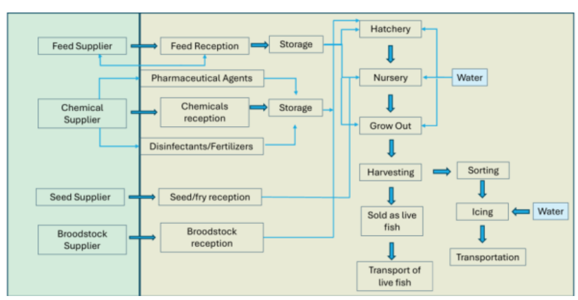

Figure 4: Aquaculture Operation Flow chart

Source: FAO, 2025

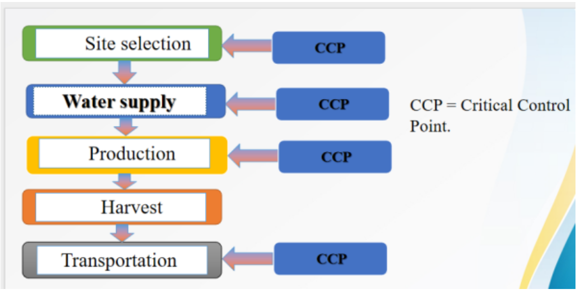

Figure 5: CCPs in an Aquaculture Operation

Source: Adapted from FAO, 2005.

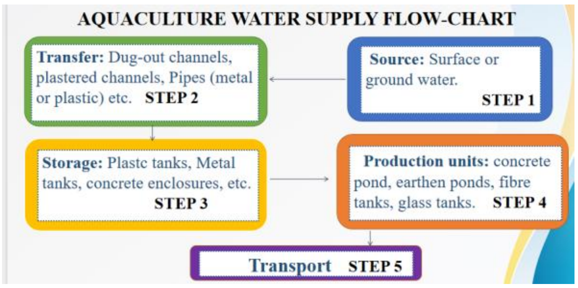

Figure 6: Aquaculture water supply (Flow chart)

Source: Adapted from FAO, 2005

IX. THE SEVEN BASIC PRINCIPLES OF HACCP

The basic principles of the Hazard analysis critical control points includes: Conduct a hazard analysis, Identify critical control points (CCPs) in the process, Establish critical limits, Monitor each critical limits, Establish corrective actions, Establish verification procedures, Establish record keeping and documentation procedures. (FDA, 2004).

1. Conduct a Hazard Analysis: This principle involves identifying potential biological, chemical, and physical hazards in food production. The hazard analysis provides the scientific foundation for the HACCP plan (Schmidt and Newslow, 2007).
2. Determine the Critical Control Points (CCPs): CCPs are steps where control can be applied to prevent, eliminate, or reduce hazards to acceptable levels. Decision trees are often used to identify CCPs (FAO, 2023).
3. Establish Critical Limits: Critical limits are maximum or minimum values (e.g., temperature, pH, time) that must be met to ensure a CCP is under control (FAO, 2023).
4. Establish Monitoring Procedures: Monitoring ensures that CCPs remain within their critical limits. It involves planned measurements or observations to detect deviations quickly (Schmidt and Newslow, 2007)
5. Establish Corrective Actions: Corrective actions are steps taken when monitoring shows that a CCP is not under control. They prevent unsafe food from reaching consumers and restore process control. (Schmidt and Newslow, 2007)
6. Establish Verification Procedures: Verification confirms that the HACCP system is functioning effectively. It includes validation of critical limits, review of monitoring records, and periodic reassessment (FAO, 2023)
7. Establish Documentation and Record Keeping: Accurate records provide evidence that HACCP controls are in place and maintained. Documentation supports traceability and demonstrates due diligence in case of food safety incidents FAO (2023).

Critical limits must be validated for the specific system and species; FAO/WHO recommends using microbiological and physicochemical indicators and performance targets tied to treatment efficacy, and risk assessment. The FAO farm-level HACCP guidance provides a decision-making framework for selecting CCPs at intake, treatment, and distribution points.

X. APPLICATION OF THE BASIC PRINCIPLES OF HACCP IN AQUACULTURE WATER SUPPLY.

Principle 1: Conduct a hazard analysis.

This is done by identifying the hazards and assessing the risks associated with them at each step of the culture water supply and describing the possible control measures. Potential hazards for water supply are harmful chemical, biological and physical contaminants which can be controlled through the source (FDA, 2004). In this stage, the possible hazards are analysed and preventive measures are identified, which may include: reviewing geological and hydrological survey data, reviewing water quality data records, and controlling point and non-point source contaminants. (FDA, 2004)

Principle 2: Determine the Critical Control Points (CCPs)

A critical control point is a step at which control can be applied and is essential to prevent or eliminate a food safety hazard, or reduce it to an acceptable level. The determination of a CCP in a water supply chain of an aquaculture venture can be facilitated by the application of a decision tree, such as the one given below. A decision tree consists of a series of questions which is used to determine if the water supply phase is a critical control point or not. The following questions are used to determine the water-supply phase as a critical control point:

Question 1: Could preventive measures exist for the identified contaminants in water? (If yes, proceed to question 2).

Question 2: Is that water supply phase specifically designed to eliminate or reduce hazards? (If no, proceed to question 3).

Question 3: Could contaminants occur in acceptable levels or increase to unacceptable levels? (if the later, proceed to question 4).

Question 4: Will subsequent steps eliminate or reduce the contamination? (If no, the water-supply phase is a critical control point). (FDA, 2017).

Principle 3: Establish critical limits.

Each control measure or parameter associated with a critical control point, must have an associated critical-limit which separates the acceptable from the unacceptable control parameter. This is done by the establishment of critical limits for the identified contaminants, which is in line with the regulatory tolerance ranges already existing for contaminants and water quality parameters (FDA, 2004). See critical limits for water quality parameters in content Table 1. The most challenging public health risks arise from shellfish production in open, surface waters, where both naturally-occurring and trace environmental residue contaminants can bioaccumulate in tissues and may cause disease outbreaks (and, in severe cases, death). Health problems may arise when abuse of regulations and carelessness occur. Other public health risks in some locations are linked to the transmission of diseases by insect or snail vectors, such as schistosomiasis, malaria and filariasis, associated with water and potentially poorly managed aquaculture environments which may also require attention by public health officials and mitigation practices.

Human illness as a result of environmental chemicals is commonly associated with long-term exposure only. Illnesses linked to a single exposure (meal) are rare. Maximum residue limits (MRLs), action levels, guidance levels or tolerances in fish have not yet been established for many pesticides used world-wide. Pesticides used in aquaculture to control aquatic weeds or other pests should be approved for food fish and aquatic sites. Pesticide products should be used only according to label directions, and containers should be properly disposed of to prevent contamination of waters. In areas where agricultural crops are grown in close proximity to aquacultural ponds, an adequate buffer zone should be established to avoid potential drift from aerial spraying: alternatively, the use of careful manual methods of pesticide application are recommended. The past land-use history of a prospective production site should be investigated to avoid any heavily contaminated 'hot spots'. Persistent organochlorine pesticides, such as aldrin, endrin, dieldrin, chlordane, toxaphene, chlordecone, dichlorodiphenyltrichloroethane (DDT), dichlorodiphenyldichloroethylene (DDE), l,l-dichloro-2,2-bis(p-chlorophenyl)ethane (DDD), heptachlor epoxide and more can pose safety risks for many years after use. Organic contaminants, specifically polychlorinated biphenyls and dioxins residues, can also cause potential problems (Nriagu 1980; Best 1993).

Principle 4: Establish a monitoring system

Monitoring is the scheduled measurement or observation at a critical control point to assess whether the step is under control, i.e. within the critical limit(s) specified in Principle 3. A monitoring system f regularly checking the water supply source for the content levels of : heavy metals, pesticides, parasites of public health concern, pathogenic bacteria and chemicals, that pose potential threats to the supply of water. (FDA, 2009). This must include what, how, how often the above must be monitored and who will do the monitoring. (FDA, 2009)

Principle 5: Establish a procedure for corrective action.

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This step defines what the farmer must do when a problem is identified in the monitoring process, i.e a corrective action plan (FDA, 2004). If the water supply has levels of contaminants greater than the regulatory tolerance, then the farmer must:

- Draw up a sampling plan.
- Carry out the required analysis.
- Alternate decisions for the use/disposal of the water, and
- Correct the hazard in the water supply. (FDA, 2004)

Principle 6: Establish procedures for verification of the corrective actions' effectiveness.

Such procedures include auditing of the HACCP plan to review deviations and product dispositions, and random sampling and checking to validate the whole plan. The HACCP system in the water supply phase, sets forth 3 routine verification activities, which are:

- Verify that the critical limits meet regulatory tolerances.
- Verify that water supply still comes from the same source.
- Verify that analyses are properly documented and recorded. (FDA, 2004)

Principle 7: Establish documentation

Documentations concerning all procedures and records appropriate to these principles and their application are salient. Records related to water supply, such as: Analyses, observed changes, Verification activities, Correction actions, and Disposition of product, must be signed and retained by appropriate personnel/management (FDA, 2004). Intake events, treatment parameters, lab results, deviations, and corrective actions mapped to lots/cohorts can be used to support product safety claims and regulatory compliance.

Table 3: A Practical HACCP plan with typical Critical Control Points and Critical Limits in the Aquaculture Water Supply Phase

AN AQUACULTURE WATER SUPPLY HACCP PLAN

CCP	Significant Hazard	Critical limit	Monitoring	Corrective action(s)	Verification	Records
Water Supply	Biological, Chemical and Physical Hazards.	Thresholds for each parameter, as established by Regulatory Bodies.	What: Key water quality parameters How: Using standard water quality test proceedures. Frequency: Daily Who:Farm supervisor	1. Change polluted pond water. 2. Change water source. 3.Aerate pond.	Cheking water quality after te corrective intervention.	Documentat all procedures and records to ensure accountability and traceability.

XI. CONSTRAINTS TO THE APPLICATION OF HACCP IN AQUACULTURE, IN NIGERIA.

- HACCP is majorly limited in practice to farming activities linked to international trade.
- Limited information and exposure to the concept.
- Complexity (analysis/identification of risks associated with fish produced under different farming systems such as: single-pass, water re-use, aquaponics, etc).

XII. CONCLUSION

Although the application of HACCP in aquaculture is in its infancy in Nigeria, the concept has potential to make an excellent contribution to: Food safety of aquaculture product, enhance customer satisfaction and confidence in aquaculture product, better control of the production process, compliance to regulatory standards, improve brand quality for international market access, better control of human and animal pathogens, achieve the sustainable development goals 3,6 and 12.

XIII. RECOMMENDATIONS

Given the above discuss, I would recommend the following:

- Nigerian National regulatory and standard-setting bodies such as Federal Ministry of Agriculture and Rural Development (FMARD), National Association of Food and Drugs Administration Commission (NAFDAC), and Standard organisation of Nigeria (SON), are encouraged to adapt systems such as the HACCP in the assessment of aquaculture product quality.

- Awareness programs for aquaculturists should be included in extension activities to educate them on the need to subscribe to HACCP, for safer and healthier products.
- Awareness on food safety should be encouraged in the media, to stir up public interest/concern in this regard.
- Researchers and Universities should be encouraged and funded to develop simplified workable HACCP systems that can serve the private fish farmer.

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