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Review on water quality parameters in freshwater cage fish culture

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Abstract
Cage culture of fish is one of the proven methods of aquaculture. Cage culture is being looked up as an opportunity to utilize existing inland water sources with great production potential to enhance production from inland open waters and posed as an answer to the rising demand for animal protein in the country. Freshwater cage culture is an important industry as it provides a source of protein and fulfills the high market demand for freshwater fishes. Poor water quality can result in low profit, low product quality and potential human health risks. Success, however, of the new aquaculture businesses greatly depended upon the suitability of the reservoir's water quality, its water quality variabilities, pollution and seasonal climatic and mixing events occurring in the new aquatic ecosystem. This paper gives detailed information on water quality parameters such as water temperature, pH, dissolved oxygen, biological oxygen demand, chemical oxygen demand, alkalinity, hardness, nitrite, nitrate, ammonia, phosphate, sulphate, total dissolved solids and total suspended solids in freshwater fish culture as well as cage culture.

Keywords: water quality parameters, cage culture, freshwater

Introduction

Aquaculture has been a fast growing industry because of significant increases in demand for fish and seafood throughout the world (Cao *et al.*, 2007) [17] and it is accounted for 46% of total food fish supply (Nyanti *et al.*, 2012) [54, 72]. Cage aquaculture is getting increasing important worldwide due to the increasing demand for fish protein as well as due to the stagnant supply from wild catch (Yee *et al.*, 2012) [72]. Although cage culture is often seen as an avenue to increase fish production and provides employment opportunity, unplanned expansion of such practices, particularly when not taking into account environmental consequences of nutrient loading, could result in negative impacts, not only on cage culture operations, but also on the capture fisheries of such water bodies (Abery *et al*., 2005) [1].

CIFRI has conducted many case studies on cage culture practices in Indian reservoirs. In India, Natarajan *et al.* (1979) [51] conducted carp (*C. catla*, *L. rohita*, *L. bata and C. mrigala)* spawn rearing experiments in floating cages suspended in lentic waters. Conducted a series of cage culture experiments in three reservoirs viz., Walwan reservoir, Lonavala, Powai Lake, Mumbai and Halali reservoir, Bhopal. There are a few reports available on the stocking density and production details on the cage culture in Indian waters. Kumariah *et al.* (1986) [45] reported net production of 0.92 to 1.6 kg/m^3/month in tilapia cage culture. Kumariah *et al*. (1991) [44] obtained a net production of 0.7 kg/m^3 /month by stocking silver carp at 15 fish/m^3. Das (2012) [22] conducted cage culture study in Dahod reservoir, Bhopal and suggested that the raising of fingerlings from cages is profitable. Potential of cage culture in Indian reservoir was reviewed recently by Karnatak and Kumar (2014) [40].

Water quality parameters

Water quality is an important integral part of any aquaculture system. It plays a major role in fish health and any deterioration in water quality causes stress to fish and brings about diseases (Arulampalam *et al.*, 1998) [5]. Each water quality factor interacts with and influences the other parameters, sometimes in complex ways (Joseph *et al*., 1993) [39]. A good water condition is a necessity for the survival and growth of fish since the entire life process of the fish wholly dependent on the quality of its environment (Bolorunduro and Abdullah, 1996) [9].

Fish in the cultivation systems of floating cages are fed by external inputs, meaning a constant input of nutrients (nitrogen-N and phosphorus-P), proteins and carbon (Tacon and Forster, 2003) [66] that, depending on the scale, can result in deterioration of water quality. Water quality management is a key ingredient in a successful fish culture practice (Joseph, 2009) [38]. Thus, water quality is the determining factor on the success or failure of an aquaculture operation. The quality of water in any ecosystem provides significant information about the available resources for supporting life in that ecosystem. Good quality of water resources depends on a large number of physico-chemical parameters. Assessing and monitoring of these parameters is essential to identify the magnitude and source of any pollution load (Thirupathaiah *et al*., 2012) [69].

Water temperature

Water temperature is controlling factor for all aquatic life. All biological and chemical processes in an aquaculture operation are influenced by temperature. It is one of the most important external factors which influence fish production. At temperatures above or below optimum, fish growth is reduced and mortalities may occur at extreme temperatures (Joseph *et al*., 1993) [39]. Boyd (1982) [11] reported that the range of water temperature from 26.06 to 31.97°C is suitable for warm water fish culture. Research has shown that a temperature range between 25 and 32°C is ideal for tropical fish culture (Bolorunduro and Abdullah, 1996) [9]. Siti-zahrah *et al.* (2004, 2008) [62, 63] reported that the water temperature above 30°C causes high mortality rate in the cage culture of tilapia in Tasik Kenyir reservoir in Malaysia. Mondal *et al.* (2010) [49] recorded an average temperature of 21.38 °C in tilapia cage culture in Thailand. Zanatta *et al.* (2010) [74] recorded an average temperature of 23.58°C in Jurumirim reservoir, Brazil in tilapia cage culture system. High water temperature in most of the water bodies are experienced due to the low water level, high air temperature and clean atmosphere (Thirupathaiah *et al*., 2012) [69]. Jiwyam (2012) [35] recorded an average water temperature of 26.81°C from tilapia cage culture in Thailand. Nyanti *et al.* (2012) [54, 72] reported that the temperature decreases as depth increases in cage culture of the Batang Ai Hydroelectric dam reservoir, Sarawak, Malaysia.

PH

Hydrogen ion concentration plays a significant role in the productivity of a reservoir. Normally pH range from 6.4 to 8.3 is favourable for fish growth (Robert *et al.*, 1940) [58]. The pH limit for protection of aquatic life is 6.0 to 8.5 (ISI, 1974) [33]. Hepher and Pruginin (1981) [30] reported that this value ranging from 6.5 to 9.0 is good for fish culture. The pH may drop in fish cage culture because of waste deposits (Beveridge, 1984; Pitta *et al*., 1999 and Demir *et al*., 2001) [8, 55, 23]. Higher value of pH (7.8 to 8.8) was recorded in Halali reservoir during summer months by Jiwyam and Chareontesprasit (2001) [36]. This might be due to increased photosynthetic activity and decomposition of allochthonous matter present in the lake which increases the nutrient concentration at higher temperature, input of sewage and agricultural waste are also responsible for higher values of pH in water. Food decomposition and breathing release carbon dioxide, which reacts with the water and produces carbonic acid and hydrogen ions, acidifying the medium (Mallasen *et al.*, 2012) [48]. Nyanti *et al.* (2012) [54, 72] reported the decrease in pH towards the increasing depth due to decaying organic matter especially from the vegetation which were not removed prior to impoundment and contributions from feed and waste from the cage culture. Yee *et al.* (2012) [72] reported the lower pH value corresponded with low dissolved oxygen and high BOD values due to the oxygen consumption during the breakdown of organic matter from excess feed and fish waste. The slightly lower pH values attributed to respiration of aquatic animals and to the decomposition of organic matter from uneaten feed and fish excrement.

Dissolved Oxygen (DO)

Dissolved oxygen is an important parameter in water quality assessment and reflects the physical and biological processes prevailing in the water. DO concentration of 5 mg/l throughout the year in the reservoir is productive for fish culture (Tarzwall, 1957; Banerjee, 1967) [68, 6]. The DO values indicate the degree of pollution in water bodies (Amankwa ah *et al.*, 2014) [2]. It is important in the production and support of life. It is also necessary for the decomposition and decay of organic matter. Higher range of dissolved oxygen was recorded during rainy season due to mixing of water by heavy wind action and mixing of monsoon rains. DO has been attributed a great significance as an indicator of water quality especially the magnitude of eutrophication. DO concentration in water is mainly dependent upon temperature, dissolved salts, velocity of wind, pollution load, photosynthetic activity and respiration rate (Tamot *et al.*, 2008) [67]. The lower DO at some aquaculture sites is mainly caused by consumption of DO by microorganisms in decomposition of organic matter (Yee *et al.*, 2012) [72]. Oxygen levels never fell below 4.0 mg/l, which is considered to be the critical level for tropical fish rearing (Mallasen *et al*., 2012) [48]. Massive plankton growth can cause problems of DO depletion at night and the production of ammonia and other toxins. Nsonga (2014) [53] reported that the level of DO of 6.5 mg/l or above 5 mg/l is the ideal level for warm water fishes. It has been reported that oxygen depletion in water surrounding cages is due to the respiration of the caged fish (Cornel and Whoriskey, 1993) [20]. Swingle (1969) [65], Neill and Bryan (1991) [52] and Daniel *et al.* (2005) [21] stated that the DO concentrations below 3.5 mg/l is undesirable for fish farming. Boyd (1998) [14] concluded that the desired concentration of dissolved oxygen range in the water is 5 to 15 mg/l. The self-pollution of cage culture activities resulting in fish kills has been reported in Lake Taal, Philippines in summer months where wind conditions are low, resulting in low oxygen (Yambot, 2000) [71]. Rani *et al.*, (2004) [56] reported lower values of dissolved oxygen in summer season due to higher rate of decomposition of organic matter and limited flow of water in low holding environment due to high temperature. Karnatak and Kumar (2014) [40] reviewed that localized water quality problems, particularly low dissolved oxygen, are common in cage culture. Low dissolved oxygen within cages may not affect other organisms in the lake, pond or stream.

Biological Oxygen Demand (BOD)

Biological oxygen demand is a very important parameter in estimating the pollution status of the water body. BOD itself is not a pollutant and exercises no direct harm but it may cause an indirect harm by reducing DO concentration levels detrimental to fish life and other beneficial uses. BOD represents that fraction of dissolved organic matter which is degraded and easily assimilated by bacteria. BOD indicates the presence of biodegradable organic matter quantitatively, which consumes DO from water. The higher values of BOD produce obnoxious smell and unhealthy environment. A higher value of BOD is due to favourable environmental conditions for microbiological activities at higher temperature (Tamot *et al*., 2008) [67]. BOD is directly linked with decomposition of dead organic matter present in the lake and hence the higher values of BOD can be directly correlated with pollution status and has an inverse relation with DO concentration. The BOD values were observed between 0.0 and 4.0 mg/l in Hathaikheda reservoir in Bhopal (Namdev *et al*., 2011) [50]. Tamot *et al.* (2008) [67] reported that the BOD value ranged from 3.2 to 6.8 mg/l in Halali Reservoir. High values of BOD usually near the bottom of the cage aquaculture site where nutrients and organic matter from the fish, excess feed and waste accumulated, which resulted in high oxygen demand and in dry season, when water temperature increases, the rate of decomposition increases (Yee *et al*., 2012) [72].

Chemical Oxygen Demand (COD)

Chemical oxygen demand is an indicator of organics in the water, usually used in conjunction with biological oxygen demand (BOD). COD is a measure of the oxygen equivalent of the organic matter content if a sample that is susceptible to oxidation by a strong chemical oxidant (APHA, 1995) [3]. The COD is widely used as a measure of the susceptibility to oxidation of the organic and inorganic materials present in water bodies and in the effluents from sewage and industrial plants (Chapman, 1996) [18]. Thus the COD is a reliable parameter for judging the extent of pollution in water. The COD of water increases with increasing concentration of organic matter and inorganic matter (Boyd, 1981) [10]. Garg *et al.* (2010) [27] reported that COD ranged from 3.60 to 17.40 mg/l in Ramsagar Reservoir.

Alkalinity

The total alkalinity is the sum total of carbonates and bicarbonates alkalinity. Water with a high alkalinity is more strongly buffered than water with a low alkalinity. Moreover, bicarbonates can act as a storage area for surplus carbon dioxide, thus carbon dioxide will not be limited during photosynthesis. This will then ensure that there will be a continuous supply of oxygen in the system. The recommended level of alkalinity for freshwater system is 5-500 mg/l (Lawson, 1995) [46]. Boyd (1982) [14] advocated that total alkalinity should be more than 20mg/l in fertilized ponds as fish production increases with increase in total alkalinity. Bicarbonates are mainly responsible for variation of total alkalinity concentration. Total alkalinity may be used as tool for the measurement of productivity and conditions of water bodies (Jiwyam and Chareontesprasit, 2001) [36]. Tamot *et al.* (2008) [67] reported that the alkalinity ranged from 90 to 160 mg/l in Halali reservoir and the reservoir water could be considered as nutrient rich. Sugunan (2011) [64] reported that alkalinity value of Indian reservoir water ranged from 40 to 240 mg/l. Jiwyam (2012) [35] reported the alkalinity value of 156.75±19.16 mg/l in Nile tilapia cage culture. Lucas and Southgate (2012) [47] considered that the alkalinity value more than 20mg/l in water is desirable for tilapia culture.

Hardness

The hardness of water is mainly governed by the content of calcium and magnesium salts, largely combined with bicarbonates and carbonates (temporary hardness) with sulphates, chlorides and other anions of minerals (permanent hardness) (Jiwyam and Chareontesprasit, 2001) [36]. One degree of hardness equals 17 ppm $CaCO_3$. Soft water refers to water with 0 to 75 ppm $CaCO_3$ and has lowest buffering capacity. Moderately hard water has 75 to 150 ppm $CaCO_3$. Hard water has 150 to 300 ppm $CaCO_3$ and very hard water had a concentration of $CaCO_3$ greater than 300 ppm, which has the highest buffering capacity (Boyd, 1990; 1998) [13, 14]. Hujare (2008) [31] reported higher total hardness during summer than rainy and winter season. The increase in hardness can be attributed to the decrease in water volume and increase in the rate of evaporation at high temperature (Thirupathaiah *et al.*, 2012) [69]. Hardness value of more than 15mg/l is required for optimum health of warm water fishes (EPA, 1973; Jhingran, 1988) [25, 34]. Lucas and Southgate (2012) [47] reported that the hardness value more than 50 mg/l is desirable for tilapia culture.

Nitrite-N (NO_2-N)

Nitrite is a by-product of oxidized NH_3 or NH_4^+, an intermediary in the conversion of NH_3 or NH_4^+ into NO_3. This process is completed through nitrification which is done by the highly aerobic, gram-negative, chemoautotropic bacteria found naturally in the system. The conversation is quick, thus high nitrite concentrations are not commonly found. However, if high levels do occur, it can cause hypoxia, due to deactivation of haemoglobin in fish blood, a condition known as the “brown blood disease” (Lawson, 1995) [46]. According to Boyd (1998) [14], the desired concentration of nitrite in the water is less than 0.3mg/l in aquaculture. There were studies reported that the concentration of nitrite-N ranged from 0.001 to 0.28 mg/l in the cage culture systems (Siti-zahrah *et al*., 2008; Eglal *et al*., 2009; Mondal *et al*., 2010; Jiwyam, 2012; Gorlach-Lira *et al.*, 2013. Nyanti *et al*. (2012) [63, 24, 49, 35 54, 29, 54, 72] reported that the nitrite concentration at cage stations was higher than control due to the contribution from fish waste and excess feed. It is found that increasing pH, low dissolved oxygen and high ammonia can increase its toxicity.

Nitrate-N (NO_3-N)

Nitrate is formed through nitrification process, i.e. oxidation of NO_2 to NO_3 by the action of aerobic bacteria. Nitrate not taken up directly by aquatic plants is denitrified in anaerobic sediments (Furnas, 1992) [26]. Boyd (1998) [14] reported the desired nitrate concentration for the aquaculture is 0.2 to 10 mg/l. Surface water can also be contaminated by sewage and other wastes rich in nitrates. Higher concentration of nitrate in drinking water is toxic (Umavathi *et al*., 2007) [70]. As per the Environmental Protection Agency (EPA), the maximum contaminant level (MCL) of nitrate concentration is 10 mg/l for drinking water (Self and Waskom, 2008) [61]. Runoff from refuse dumping sited and farming activities affect nitrate concentration greatly in receiving waters. The fertilizers used on farms, through leaching and surface runoff into the stream during heavy rainfall could also contributed to the high levels of nitrate in receiving streams (Rao, 2011) [57].

Ammonia-N (NH_3-N)

It is the principal nitrogenous waste produced by aquatic animals, via metabolism and is excreted across the gills (Cao *et al.*, 2007) [17]. Ammonia was higher at fish culture site due to feces released by the fish (Nyanti *et al.*, 2012) [54, 72]. Ammonia strongly influences the dynamics of the dissolved oxygen in water, since 4.6 mg of oxygen is needed to oxidize 1.0 mg of ammonia. Ammonia levels between 3 and 4 mg/l may be toxic for tropical fish (Boyd, 2001) [15]. Swingle (1969) [65], Neill and Bryan (1991) [52] and Daniel *et al.* (2005) [21] concluded that ammonia concentration of more than 0.2 mg/l is undesirable for fish farming. Safe concentration of ammonia for freshwater fish is less than 0.05 mg/l (Lawson, 1995) [46]. Chen (1988) [19] stated that the ammonia value lower than 1 mg/l in pond water was acceptable for pond fish culture. Boyd (1998) [14] suggested that the ammonia value less than 0.1 mg/l is the desired concentration for fish culture system. Ammonia concentration of 0.02 mg/l is required for optimum health of warmwater fish culture (EPA, 1973 and Jhingran, 1988) [25, 34]. Lucas and Southgate (2012) [25, 47] suggested the ammonia concentration of less than 1 mg/l is desirable for tilapia culture. Some reports showed that the ammonia concentration ranging from 0.01 to 1.15 mg/l in the cage culture system (Eglal *et al*., 2009; Zanatta*et al*., 2010; Mallasen *et al*., 2012; Nyanti *et al*., 2012 [24, 48, 54, 72, 74]. Gorlach-Lira *et al*., 2013) [29]. Karnatak and Kumar (2014) [40] reviewed that the high fish densities, along with the high feeding rates, often reduce dissolved oxygen and increase ammonia concentration in and around the cage, especially if there is no water movement through the cage.

Phosphate-P (PO_4-P)

Phosphate is one of the important nutrient and limiting factor in the maintenance of reservoir fertility. It is recognized as the principle factor produced by the fish farm that has an effect in the lake environment (Jones and Lee, 1982; Ketola, 1982; Kelly, 1992; Guo and Li, 2003) [37, 43, 41]. The primary route by which phosphorus enters the aquatic environment from cage farming is through the feed administered to the fish (Gavine *et al*., 1995) [28]. A large number of cages in area can exceed the carrying capacity of the aquatic environment, which may cause problems by high levels of phosphorus (Mallasen *et al*., 2012) [48]. Kelly (1992; 1993) [41, 42] reported that the accumulation of decomposited solid waste releases labile phosphorus to the water column. Boyd (1998) [14] reported that desired concentration of phosphate in the water is in the range of 0.005 to 0.2 mg/l. As phosphorus is a limiting nutrient in tropical freshwater, it forms a major factors contributing to the cost of production (Barik *et al.*, 2001) [7]. Santos *et al*. (2012) [59] reported the acceptable value of phosphorus was 0.025 mg/l for Nile Tilapia. The phosphate concentration as per WHO standard is 2.5 mg/l for drinking water (Amankwaah *et al.*, 2014) [2].

Sulphate (SO_4^{2-})

Sulphate is a constituent of total dissolved solid (TDS) and may form salts with sodium, potassium, magnesium and other cations. It is not a toxicant in the category of heavy metals, pesticides or other toxic natural or manmade substances, but rather is a common salt necessary for life at some concentrations. It is usually diluted in the water body rather quickly and is non-bioaccumulative. According to Boyd (1998) [14], sulphate concentration of 5 to 100 mg/l is desirable for the freshwater aquaculture systems. In Northern and Central Illinois streams, sulfate levels ranged from 30 to 150 mg/l in streams without significant human-induced sulfate sources (IDNR, 2009). Sulphate is widely distributed in nature and may be present in natural waters in concentrations ranging from a few to several thousand milligrams per liter (APHA, 2012) [4].

Total Dissolved Solids (TDS)

Total dissolved solids are the solids present in the water in the dissolved state. It consists of inorganic salts and dissolved materials. Garg *et al*. (2010) [27] reported that TDS value from 166.37 to 239 mg/l in Ramsagar reservoir in Madhya Pradesh. Sawant and Chavan (2013) [60] recorded the maximum total dissolved solid values of 172.66 mg/l during summer season owing to loss of water due to evaporation and concentration of salts in the water.

Total Suspended Solids (TSS)

Total suspended solid is an indicator of the amount of erosion that took place nearby or upstream. This parameter would be the most significant measurement as it would depict the effective and compliance of control measures. Yi *et al*. (2004) [73] reported that the TSS values were 87.2 mg/l in the upstream water, 125.8 mg/l in the middle stream and 86 mg/l in the downstream water in Mekong River, Vietnam. A large accumulation of suspended solids will reduce light penetration; thereby suppress photosynthetic activity of phytoplankton, algae and macrophytes. Higher value of TSS in the cage culture site was due to the fish excretion and excess fish feed (Boyd, 2004) [16].

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