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Water Budgeting and Cutback Approach in Aquaculture

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MESSAGE

Water is inextricably related to several Sustainable Development Goals (SDGs), given the role it plays in human existence and ecosystem sustenance. Notwithstanding its inherent nature to recycle and replenish, water availability is very much limited and the gap between demand and supply is widening over time due to unabated anthropogenic factors besides changing climate. Thus, the conservation and management of water resources are crucial for the food security of the country's burgeoning population. Particularly, aquaculture, which needs a huge volume of water warrants, focused attention. Recent technological innovations and user-friendly water budgeting protocols can certainly pave the way for long-term sustainable aquaculture production.

I take this opportunity to congratulate the authors for bringing out this Technical Bulletin on "Water Budgeting and Cutback Approach in Aquaculture" based on research and on-farm evaluation. The document would assist planners, policymakers, academicians and other stakeholders in water management in aquaculture.

8th May, 2023
New Delhi

(Himanshu Pathak)

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MESSAGE

Water is a precious natural resource and the elixir of life. In India, the agriculture and aquaculture sectors are having the highest share of water resources and employ a huge workforce to ensure the food and nutritional security of the Country. As water scarcity looms large in different parts of the Country because of the changing climate, it is pertinent to explore ways to maximize its utility. As aquaculture production needs to be increased in the backdrop of limited water supply, there is a need to implement a water budgeting approach leading to increased water use efficiency. Application of best management practices (BMP) through intensification of existing aquaculture systems emphasizing water management protocols is required to sustain aquaculture productivity.

I hope that the Technical Bulletin on "Water Budgeting and Cutback Approach in Aquaculture" brought out by the ICAR-Indian Institute of Water Management (IIWM) will be helpful to stakeholders associated with aquaculture. The document will also serve as a source of information to farmers, policymakers, entrepreneurs, researchers and extension workers for judicious water management in aquaculture for enhancing aquaculture water productivity.

8th May, 2023
New Delhi

(Suresh Kumar Chaudhari)

CONTENTS

INTRODUCTION

Water is elixir of life and a critical resource for the maintenance of social–ecological systems. Water represents at least 50% of most living organism and plays a key role in the functioning of the ecosystem. Freshwater resources are only 2.5% of all available resources, out of which 70% are locked up in glaciers. About 1,10,000 km^3 of freshwater received through rainfall, snowfall and all forms of precipitation annually, of which 70,000 km^3 evaporate in to the atmosphere. Out of the 40,000 km^3 only 12,500 km^3 is accessible for human use (Mohanty *et al*., 2014). Against the backdrop of global environmental and societal changes, water scarcity looms large in many parts of the world. Changes in water availability may heighten water conflicts between users at different scales, from the local to the transnational level. Land and water, the most basic resources in food production have attracted much attention in the global change debate for various reasons. Most obviously, there is the question of how we will be able to feed the burgeoning population with escalating demand of quality food and higher shares of livestock products (Kearney, 2010). The scarce resources of fertile land and freshwater are also diminished by non-sustainable use. Climate change has been and will also lead to changes in freshwater availability. As aquaculture production needs to be increased but water is in limited supply, there is a strong demand to increase aquacultural water productivity (AWP). Application of better management practices through intensification of existing aquaculture systems with emphasis on BMP (best management practice) is therefore would be the prime approach for improving the environmental performance of aquaculture. A wide-range of technical options is available to enhance aquacultural water productivity for a particular situation or hydro-ecological setting. Moreover, major requirements in improving aquacultural water productivity are the blue water required for culture and the input management, especially the feed. Minimization of unnecessary water exchange or replenishment and taking advantage of the compensatory growth response, also perceived as a way to increase water productivity and profits in aquaculture besides increasing production intensity.

Sustainability of aquaculture has been debated at different platforms and therefore, global and regional institutions proposed BMP to make aquaculture environmentally responsible, and to enhance sustainable production. Ecological sustainability of pond aquaculture, is also threatened by a range of risks such as extreme weather events; excessive fresh water consumption; organic pollution; disease; chemical contamination etc. Although aquaculture production has to increase to satisfy the growing demand, extending the area under aquaculture is also now constrained by the limited availability of land and water resources. Further, fish culture is a water-intensive proposition and requires much more water than conventional agriculture and its future growth would be constrained by the freshwater availability (Verdegem and Bosma, 2009). Unplanned wasteful use of water in aquaculture is also limiting further development of this sector. As evident, on-farm water use in aquaculture can be very high, attaining values of up to 45 m^3 per kg biomass produced in ponds (Verdegem *et al.*, 2006). Intensification of aquaculture or intensive aquaculture production systems are therefore required to minimize the on-farm water use per kg biomass product, to make the system more water-efficient. As water will be no longer available for inland aquaculture in an unlimited manner, special efforts on input management (mainly feed), water quality monitoring along with quantifying/ estimating the water requirement of commercially important high-value fish and prawn species will ensure higher water productivity and profitability. Therefore, it becomes imperative to use modern technologies, tools and approaches pertaining to enhancing water use efficiency or water productivity, nutritional water productivity and minimizing water footprint , which is expected to enable the future fresh and brackish water aquaculture systems more resource-efficient and sustainable.

Worldwide, water is essential to human well-being as well as aquatic ecosystems. Therefore, bringing aquaculture under ONE HEALTH umbrella is critical for issues related to zoonotic disease, AMR, food safety (Safe Water for Safe Food), environmental contamination, food security and occupational health. As such, aquaculture offers ample opportunities to reduce hunger and improve nutrition, alleviate poverty by sustaining economic growth through better use of natural resources. Modern sustainable approaches of aquaculture produce less

Fig 1. Sustainable aquaculture assists in achieving five SDGs.

waste and minimal carbon-nitrogen footprints than agriculture sector. Essentially, fish is a healthy super food, rich in quality animal proteins, polyunsaturated fatty acids especially the (ω)-3 eicosapentaenoic, docosahexaenoic acid and micronutrients (Mohanty et al., 2019), thus helps in achieving sustainable development goals (SDGs) 2 and 3. In addition, fish are more available and affordable than other sources of animal proteins in tropical countries. The importance of fish in the human diet and its beneficial effects has been proved in terms of food security as well as in combating under nutrition and micronutrient deficiencies in developing countries. However, success in aquaculture largely depends upon package of practice, water conservation and management, covering many agenda of SDGs, mainly SDGs 2, 3, 6, 14 and 17 (Fig 1).

Water management in Indian aquaculture

Aquaculture is one of the fastest-growing industries in the World and has been playing an important role in the economic development on account of its contribution to food and nutritional security, national income, employment opportunities as well as generating livelihood options (Mohanty et al., 2017 and 2018; Tacon, 2020). India has a rich and diverse fisheries resources (Fig. 2) and more than 11% of global fish and shellfish diversity. At present 2.41 million ha is under pond and tanks while 1.24 million ha area suitable for brackish water aquaculture. Globally, more than 87,52,000 ha freshwater ponds were in use (Verdegem & Bosma 2009) out of which, about 8,50,000 ha freshwater pond area is under carp cultivation in India (Ayyappan, 2006). DAHDF (2017) reported that about 0.895 million hactares of water area have been brought under freshwater aquaculture with an average yield of 3 t ha^{-1}. During the first census of water bodies in India, 24,24,540 water bodies have been enumerated, out of which 59.9% (14,42,993) are ponds, 15.7% (3,81,805) are tanks, 12.1% (2,92,280) are reservoirs whereas remaining 12.7% (3,07,462) are other water bodies (MoJS, 2023). Recent estimate reported that in India about 151,815 ponds/ tanks are currently in use for both freshwater and brackish water aquaculture (Gupta et al., 2021). Currently, India is the third largest fish producing country in the world accounting 7.96% of the global production and second largest in aquaculture next to China. The total fish production during FY 20-21 was 14.73MMT with a contribution of 11.25 MMT (million metric tonnes) from inland sector and 3.48 MMT from marine sector (DoF, 2022). Inland fish production constitutes about 76% of the total fish production of the Country. The estimated fisheries potential of India is 22.31 MMT including marine and inland fisheries potential of 5,31 and 17.0 MMT, respectfully. During FY 20-21, 66% of marine fisheries potential and 51% of inland fisheries potential have been harnessed (DoF, 2022).Latest available data reveal that fish production has reached all-time high of 16.18 MMT during 2021-22 (Fig. 3) as well as all-time high exports of 13.64 lakh tonnes valuing INR 57,587 crore mainly dominated by exports of shrimps (PIB, 2022).

Although substantial developments have been made under mariculture and cold water aquaculture in India, fresh water aquaculture and brackish water aquaculture are predominantly practiced. Freshwater aquaculture involves the breeding and culture of freshwater fish like major carps, minor carps, cat fish, murrels, prawn, pearl culture and ornamental fish farming. Brackish water aquaculture involves breeding and culture of mainly sea bass, mullet, milk fish, grouper, etroplus, shrimp and crabs. Aquaculture production from these inland sector is about three times that of capture sector. In order to fill the gap

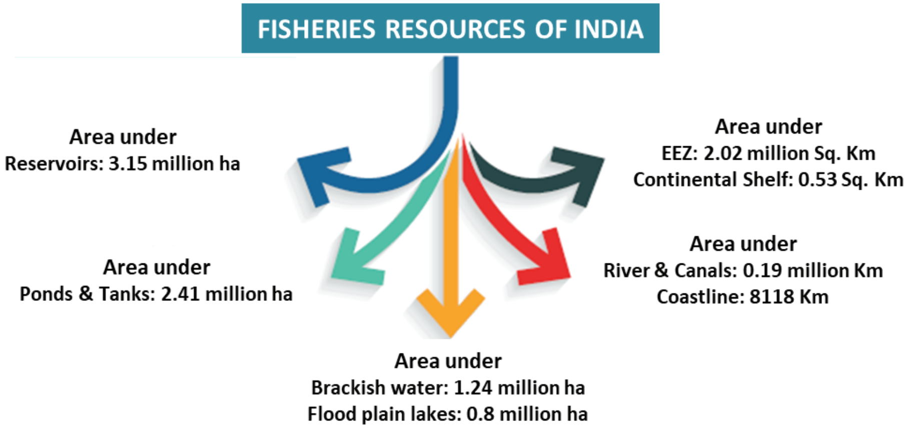

Fig 2. Fisheries resources of India.(*Source: DoF, 2022*).

between deficit of capture fisheries and demand of seafood, the viable option left behind is the brackish water aquaculture as among the global food resources, 31.4% of assessed fish stocks are over fished and 58.1% are fully fished (FAO, 2018). In India, brackish water aquaculture, almost exclusively dominated by shrimp, has been the most dynamic and socially emotive food production system. Exotic species *L.vannamei* represents almost 90% of farmed shrimp production. Until 2010, the giant tiger shrimp, *P. monodon*, constituted almost 100% cultured shrimp in India; however, it is progressively replaced by exotic *L. vannamei* from 2010 onwards. Presently the farmed shrimp production (*L. vannamei* + *P. monodon* + Scampi) has reached all-time high of 8,43,633MT utilizing 1,66,722 ha area

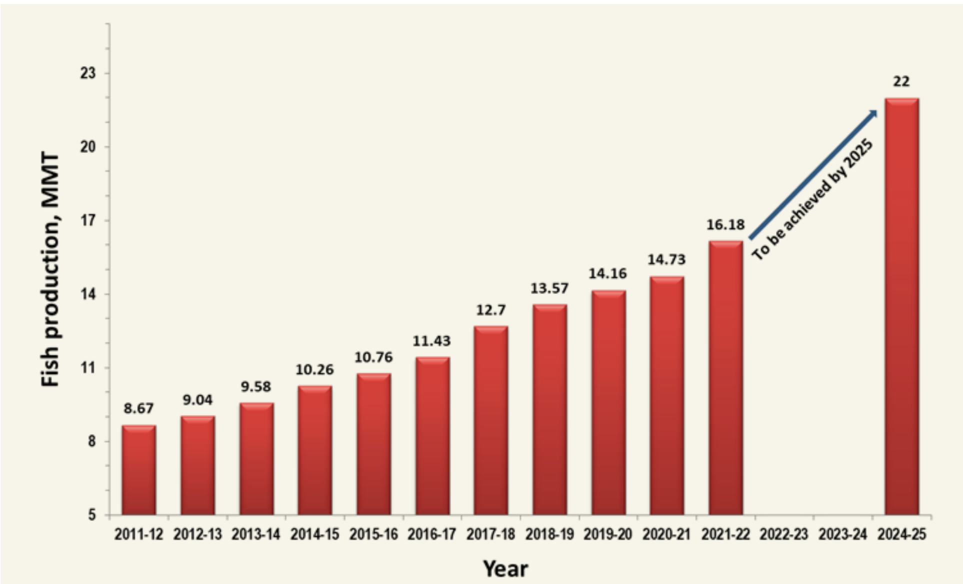

Fig 3. Year-wise fish production (MMT) in India and target to be achieved by 2025. (Source: DoF, 2022).

during FY 20-21 (MPEDA, 2023), mainly due to improvement in seed production, feed, genetically improved fast growing stock, specific pathogen free stock, adoption of better management practices and adherence to bio-security principles.

Further, enhancing water productivity in brackish water and freshwater aquaculture is prerequisite and there has been the necessity to determine ideal quantity of water essential for successful culture operation (Krummenauer et al., 2016). In addition to water quality assessment and monitoring in shrimp and fish culture, aquaculture water management also aims at quantification and minimization of water use. The future expansion of shrimp and fish culture requires responsible management to increase operational efficacy and help avert wasteful use of water, effluent release and environmental deterioration of receiving water bodies through water cutback approach. Water budgeting and density-specific water use are two major necessities in refining both the coastal grow-out shrimp culture and freshwater aquaculture practice (Mohanty et al., 2016; 2017; 2018a; 2018b).

Wasteful water use practice in aquaculture is being criticized for causing negative environmental impacts (Naylor et al. 2000; Boyd et al. 2007). Even with the application of water saving approach, shrimp farming is considered as a water-intensive effort in comparison to water guzzling agricultural crops like rice. Bauman (2009) reported that 1 m^3 water yields 400g of rice. On the contrary, it is reported by Mohanty et al. (2018b) that 1 m^3 of water can produce 580 g of shrimp biomass which is much richer in nutrient as compared to rice (Mohanty et al., 2018b). This endorses the fact that, though shrimp culture consumes 1.72-4.28 m^3water (Table 2), the value of shrimp production per unit of water used greatly exceeds that of irrigated agriculture produce (Boyd and Gross 2000).

Need of aquacultural water budgeting and water productivity

Due to the problem of low economic output in grow-out aquaculture (as a result of increased feed price, power supply, chemicals and aqua-drugs etc.), it has become imperative to minimize the operational cost by improving the water productivity. In fact, uncertainty in monsoon rain, scare and limited availability of freshwater resource necessitated judicious use of water in aquaculture sector to increase water productivity. Nowadays, water is increasingly becoming less available and costly to procure (pumping cost). World in general and India in particular, the freshwater supply and reserve is now under threat due to increased population pressure followed by increasing demand of water in agriculture, industry and domestic sectors. The limited nature of the water resource, therefore, warrants a more holistic approach to water management. Moreover, water budgeting and its judicious use should be a primary requisite towards development of protocols for best water management practice (BWMP) in commercially important grow-out aquaculture. In static water pond, evaporation, percolation and seepage represent the largest water loss, which results in poor water productivity due to nutrient loss and fluctuation in water quality. On average, 5.2 m^3 water per kg production is consumed through evaporation from ponds (Bosma and Verdegem, 2011). To substitute and maintain such water loss, pond fertility and survivability of stocked animal; replenishment or exchange of water becomes essential. Many a times, farmers replace muddy water with an intent of higher production without considering its necessity and operation cost which sometimes become counterproductive and uneconomical. However, quantification of water requirement plays a critical role which depends on various factors *i.e.*, species, stocking density, growth stage, biomass, plankton and nutrient status, water loss, agro-climatic condition etc. Water requirement is a function of soil, climatic condition, species to be stocked, culture method and management practices. Therefore, it is necessary to assess the necessity of replenishment or exchange followed by quantification of water for replenishment to minimize wasteful use of water. The water budgeting analysis pertaining to different species and aquaculture water productivity may form the practical tools for generating useful information for mitigating the water availability issues for aquatic production.

Water use in aquaculture may be classified as either total use or consumptive use. Total water use varies greatly in aquaculture depending mainly upon the culture method used. It is reported that the cage, biofloc and net pen culture use the least water, while intensive pond and raceway culture uses the most. Fish production typically requires total water use to 4 - 8 m^3/kg fish in embankment ponds (Embankment ponds are formed without excavation by building one or more dikes above ground level to impound water, usually drainable and fed by gravity flow of water or by pumping) and 8 - 16 m^3/kg fish in excavated ponds, however, water use in ponds varies with the intensity of production, frequency and amount of water exchange employed (Boyd, 2005, Boyd *et al*., 2007). Presently, on-farm water use in aquaculture can be as low as 500–700 l in super-intensive re-circulation systems and as high as 45m^3 of water per kilogram of produce in extensive pond system (Verdegem et al., 2006). Moreover, the degree of water exchange plays a key role in determining the water use efficiency in aquaculture. However, water exchange is not necessary in most types of pond aquaculture (Boyd and Tucker 1998). Reducing or eliminating water exchange saves water and reduces pumping costs. Also, less water exchange increases the hydraulic retention time (HRT) in ponds. This allows natural processes to assimilate wastes completely and reduces concentration of potential pollutants in effluent (Boyd, 2005). The hydraulic retention time (HRT) of static ponds is weeks or even months, and in ponds with water exchange, HRT usually is a week or little more (Boyd et al., 2007).

Reduced diversion of water for aquaculture and increased food requirements of 3 billion tons by 2050 would require enhancing aquacultural water productivity at different levels. In its broadest sense, water productivity aims at producing more food, income, better livelihoods and ecosystem services with less water. Water productivity is the net return for a unit of water used or the ratio of the net benefits from crop, forestry, fishery, livestock and mixed agricultural systems to the amount of water used to produce those benefits. Physical water productivity is therefore defined as the ratio of aquacultural output to the amount of water consumed and the economic water productivity is defined as the value derived per unit of water used. Generally, increasing or improving water productivity implies how best we can effectively improve the yield of aquaculture crop with the water currently in use. Higher water productivity reduces the need for additional water. To assess sustainability of water use, various aspects need to be considered *viz.* the water withdrawal, the consumed water and the virtual water use. Water withdrawal refers to water diverted from streams or rivers or pumped from aquifers for aquaculture use. Part of the water is returned after withdrawal and can subsequently be reused or restored to the environment. The retained part represents consumed water, namely water that is evaporated or incorporated into products and organisms. The virtual water use refers to the indirect water consumption through water used to produce the feed for the fish. The quantity of water consumed should include the virtual water use. At present, 1.7 m^3 water per kg of fish production is indirectly consumed through evaporation during the production of grains incorporated in fish feeds. In the future, grain associated water consumption would increase with increased inland aquaculture production but will level off at 3 m^3 water per kg production with present technology. On an average, 5.2 m^3 water per kg production is consumed through evaporation from ponds (Verdegem and Bosma,2009). Freshwater withdrawal in inland aquaculture is about 16.9 m^3 per kg production, but infiltration losses (6.9 m^3) and water replacement (3.1 m^3) can be considered green water, provided pollution is controlled. Infiltration and subsequent percolation besides lateral seepage depends on the soil type and on the topographical location of ponds and is usually estimated to be 5 to 10 mm/d. However, when the groundwater table is high, such as during the monsoon season, such losses from fish ponds will be restricted to lateral seepage to surrounding fields and waterways. Intensification of aquaculture can drastically reduce the evaporation loss per kg of production and thus research should focus on increasing pond water productivity while reducing environmental impacts.

Hydrological water balance study in aquaculture ponds

Hydrological water balance study in fish and shrimp culture ponds not only helps in estimating density dependent water use in aquaculture operations but also helps in enhancing water use efficiency and water productivity (Fig. 4). To make precise estimates of water use in ponds, hydrological water balance equation *i.e.* inflow = outflow ± change in volume (ΔV) is used. Water use in aquaculture may be categorized as either total water use (TWU) or consumptive water use (CWU). TWU (probable inflows to ponds) = initial water filling (W_f) + management additions or regulated inflows (I) + precipitation (P) + runoff (R). CWU (possible outflows) = intentional discharge or regulated discharge (D) + overflow (O_f) + evaporation (E) + seepage (S_o) + transpiration (T) + water content in the

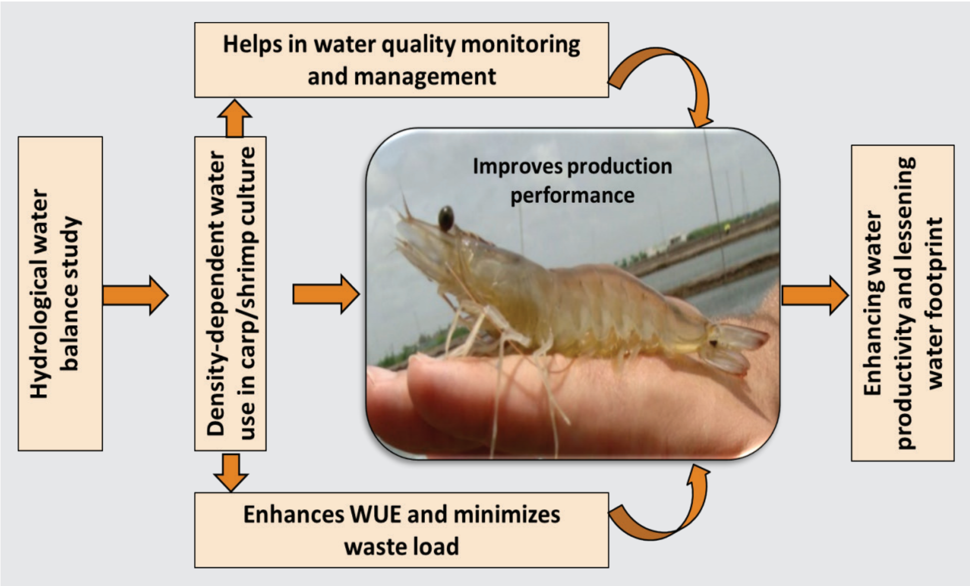

Fig 4. Advantages of hydrological water balance study.

harvested biomass (W_b). The difference between the total and consumptive water use, refers to non-consumptive water use (NWU). Commercial fish or shrimp ponds rarely receive direct inflow from streams or creeks. Further, aquatic weeds are disallowed from growing in and around edges of ponds and water is rarely used for activities other than aquaculture. Therefore, creek inflow and transpiration are seldom major factors. As embankment fish or shrimp ponds are small watersheds, runoff is therefore, negligible and groundwater inflow is also seldom a factor. Water content in the harvested biomass which is a negligible amount *i.e.*0.75 m^3/t can be ignored. Thus the governing water balance equation is:

$$P+I = E + S_o + O_f + D \pm \Delta V \quad \ldots\ldots(1)$$

To estimate the CWU, a water level gauge can be installed in each pond to measure the usual water loss (evaporation + seepage). Water level gauge is also used to record the outflow and inflow during water withdrawal and addition. Further, to separate the evaporation from the usual water loss, evaporation is estimated using the following equation:

Pond evaporation (mm) = Pond-pan coefficient × Class-A pan evaporation (mm) ....(2)

Pond pan coefficient of 0.8, most appropriate for ponds (Boyd and Gross, 2000; Mohanty and Mishra 2020), can be used in the Eq 2. Pond seepage is quantified by subtracting the evaporation loss from the total loss. The consumptive water use index (CWUI) that specifies the amount of water used per unit of fish or shrimp production is estimated as follows:

$$CWUI = CWU\ (m^3) / \text{total biomass (kg)} \quad \ldots\ldots(3)$$

Water use, water productivity and economic efficiency

Water being the prime natural resource, its conservation and wise-use for, enhancing productivity and maintaining the quality are considered to be of paramount importance these days. Increased diversion of water for agriculture, and industrial sector and increased aqua-food requirements by 2030 would require enhanced aquacultural water productivity. Aquacultural water productivity (the ratio of the net benefits from aquacultural systems to the amount of water used) reflects the objectives of producing more food, income, livelihood and ecological benefits at less social and environmental cost per unit of water consumed (Molden *et al*., 2010). Further, water productivity is an index of the economic value of water used (Boyd, 2005), a useful indicator of efficient water management (Dasgupta *et al*., 2008) and is used to define the relationship between crop produced and the amount of water involved in crop production (Ali and Talukder, 2008). Higher water productivity not only reduces the need for additional water, but also minimizes the operational cost.

Water use efficiency appears to be a useful indicator of efficient, environmentally responsible fish and shrimp culture. The demand driven water use not only helps in improving water use efficiency, total water footprint and water productivity but also important in lessening pumping cost (De Schryver et al., 2008, Mohanty et al., 2017). Though intensification aims at conserving fresh water, does not actually apply in shrimp culture, because shrimp farms use brackish water. Nevertheless, reducing water use per metric ton of shrimp/fish lessens the energy use for pumping. Pumping cost is important where total water is pumped in to aquaculture facility with expense of energy which ultimately reflects the operational cost. Thus, to evaluate the efficiency of water management and operational cost, the gross total water productivity (GTWP), net total water productivity (NTWP) and net consumptive water productivity (NCWP) can be calculated keeping the total volume of water used in to the account as shown below:

GTWP = Total economic value of the produce (Rs.) / TWU (m^3)……………………...….....(4)
NTWP = Total economic value of the produce (Rs.) - Production cost (Rs.) / TWU (m^3) ...(5)
NCWP = Total economic value of the produce (Rs.) - Production cost (Rs.) / CWU (m^3) …..(6)

To evaluate the efficacy of water management, total water use efficiency (WUE_t) and consumptive water use efficiency (WUE_c) are estimated as follows:

WUE_t (kg m^{-3}) = *Biomass production in kg* ha^{-1} */ TWU in* m^3 ……………………………(7)
WUE_c (kg m^{-3}) = *Biomass production in kg* ha^{-1} */ CWU in* m^3……………………………(8)

Importance of water quality assessment in fish and shrimp culture

Aquaculture is carried out in ponds, enclosures or in open water bodies and thus involves continuous interaction with the environment. Aquaculture can be a sustainable activity, if it is carried out in socially and environmentally responsible manner, by adopting good aquaculture practices. Adoption of Best Management Practice would result in enhanced production, productivity and returns on one hand and environmental and social responsibilities on the other. Rapid expansion of the coastal shrimp aquaculture may pollute the coastal water and interest of other users in agriculture and allied sector. Due to the disposal of organic and nutrient-rich shrimp/fish pond effluent through water exchange, environments of receiving water bodies can suffer from oxygen depletion, reduction of transparency, changes in benthic population structure and eutrophication. Deteriorating water quality has become one of the major factors that bottleneck the shrimp/ fish output and breakage of the production process. As water quality affects early life stages, reproduction, growth and survival of aquatic organisms, its monitoring and assessment play an important role in controlling harmful crisis in aquaculture. Particularly, in shrimp aquaculture, water quality suitability index (WQSI) can be used to transform large amounts of water quality data into a single number and provide the whole interpretation of the behaviour of the water quality parameters. Apart from water quality monitoring and assessment, WQSI also helps in determining water exchange requirement and minimization of water use in coastal shrimp culture.

Water quality suitability index (WQSI)

WQSI is estimated to evaluate the suitability of water quality for shrimp culture in ponds, prior to water exchange. Four critical water quality variables are chosen and weighted *viz.* salinity, turbidity, pH, and DO. The allocation of weights (from 1 to 5) is based on AHP. Salinity receives a greater weight as it is indispensable to shrimp culture. Contrastingly, turbidity, pH and DO are assigned lesser weights because they can be easily corrected during pond management. Once the variable weight (VW) and the variable weight range (WR) are defined (Table 1), VW is multiplied by WR to obtain the score of the variable for each sampling station (SVS) or pond (Eq. 9). The final score of the sampling station (FSS) or pond is obtained by multiplying the score of each of the four variables (Eq. 10).

$$SVS_{var} = VW_{var} \times WR_{var} \quad \text{..........(9)}$$

$$FSS = SVS_{salinity} \times SVS_{pH} \times SVS_{turbidity} \times SVS_{dissolved\ oxygen} \quad \text{..........(10)}$$

Applying Eqs.9 and 10, the FSS may vary between 0.0 and 18,750. To facilitate the understanding of the index, these values were recalculated (Ferreira et al., 2011) to values from 0 to 10 as follows:

$$WQSI = 0.8546 \times (FSS)^{0.25} \quad \text{..........(11)}$$

WQSI values are grouped into 5 classes of suitability as in Table 1.

Table 1. Range and classes of water quality suitability index (WQSI) for shrimp culture

Weight range	Salinity (PSU)	Turbidity (NTU)	pH	DO (ppm)
5	30	< 10	8.0	>7.0
4-5	20-30 or 30-35	10-20	7.5-8.0 or 8.0-8.5	6.0-7.0
3-4	15-20 or 35-40	20-35	7.0-7.5 or 8.5-9.0	5.0-6.0
2-3	10-15 or 40-45	35-60	6.5-7.0 or 9.0-9.5	4.0-5.0
1-2	5-10 or 45-50	60-100	6.0-6.5 or 9.5-10	3.0-4.0
0-1	0-5	100-150	5.5-6.0 or 10-10.5	2.0-3.0
Variable weight	5	3	2	1

WQSI range and classes of suitability: > 9.0- Suitable without restriction (excellent water quality), 7.5 to 9.0- Suitable with low restriction (very good, needs little management), 5.5 to 7.5- Suitable with medium restriction (good, needs moderate management), 3.0 to 5.5- Suitable with high restriction (acceptable, needs intensified management approach), < 3.0- Unsuitable (unacceptable).(*Source:Beltrame et al., 2006*).

Water footprint in Aquaculture

In general, blue and green water contribute to water footprint (cubic metre of consumptive water used per tonne of fish or shrimp produced, $m^3\ t^{-1}$) in aquaculture. Water footprint is estimated considering all four components of water loss to the catchment such as (1) evaporation or evapo-transpiration, (2) water content in harvested biomass, (3) contaminated water, and (4) non-returned water to the same area from where it was withdrawn. However, seepage and percolation loss is not considered for estimation of water footprint as these losses are not a loss to the catchment and later can be reused in the same area. Usually, blue (surface and groundwater) and green (precipitation) water contribute to water footprint in aquaculture. Thus, the appropriate equation is:

Total water footprint $(WF_t, m^3 t^{-1}) = (D_i + O_f + E + W_b)/E_{cy}$ ....(12)

Where, D_i = intentional or regulated discharge in m^3, O_f = overflow including other losses in m^3, E = evaporation in m^3, W_b = water content of harvested biomass in m^3 and E_{cy} = Economic crop yield in t ha^{-1}.

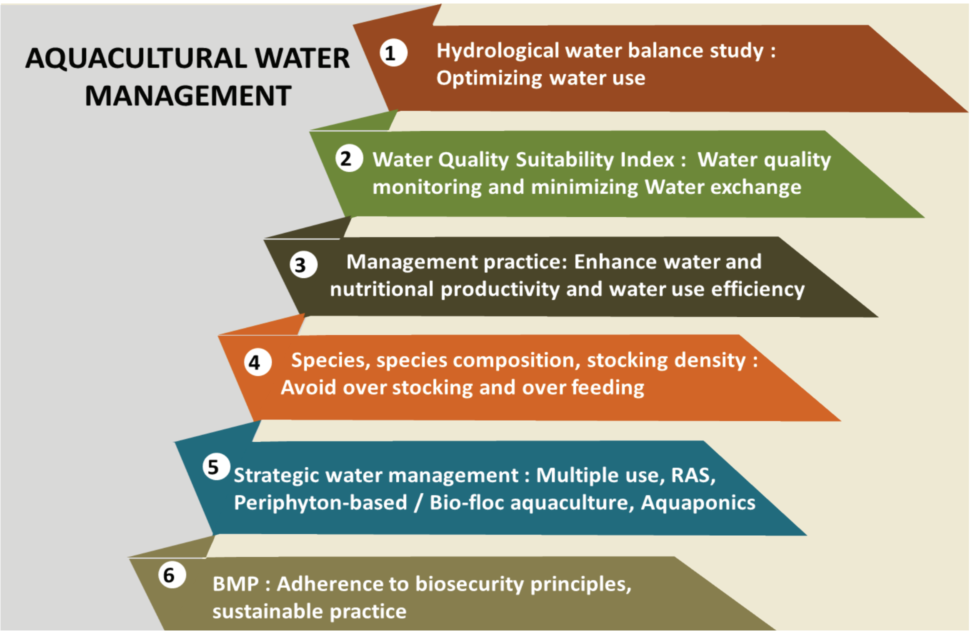

Fig 5. Factors affecting water management in aquaculture.

Water use in commercial aquaculture: Case studies from ICAR-IIWM

ICAR-Indian Institute of Water Management (Bhubaneswar, Odisha, India), a premier central government research organization having pan India presence with mandate on water management in agriculture, aquaculture and allied sector, had conducted field experiments on water requirement, WUE, water productivity and water footprint of high-value aquaculture and aquaculture-based integrated farming system (IFS) during 2011-2022.

In 'Pacific white shrimp'(*Litopenaeus vannamei*) culture, with best management practice (BMP) at the optimum stocking density of 5,00,000 shrimp seed (post-larvae, PL) ha^{-1}, total water use could be minimized to 32,600 m^3 and water exchange minimized to 6,300 $m^3 ha^{-1}$ without hampering the normal growth and production. With this stocking density, shrimp productivity enhanced to a level of 10.58 t ha^{-1} in 120 days (Table 2). Further, with this technique, total water productivity of ₹46.6 m^{-3}, consumptive water productivity of ₹ 83.3 m^{-3} was estimated while only 1.72 m^3 of water was required to produce 1 kg of *L. vannamei* shrimp (Mohanty *et al*., 2018a & 2018b). In this system, the total water footprint (WF_t) was estimated as 1229 m^3 t^{-1}. Various factors that affect the aquacultural water management are depicted in Figure 5. The experiment was carried out at Parikhi village, of Balasore district, Odisha.

In carp poly culture (Indian major carps, IMCs), with BMP at the optimum stocking density of 8,000 fingerlings ha^{-1}, total water use could be minimized to 28,200 m^3, without hampering the normal growth and production. With this stocking density, fish productivity enhanced to a level of 3.92 t ha^{-1} in 180 days (Table 2) with economic benefit (Output Value: Cost of Cultivation) of 1.81. Further, total water productivity of ₹5.9 m^{-3}, consumptive water productivity of ₹ 10.3 m^{-3} was generated while only 2.9 m^3 of water was required to produce 1 kg of fish biomass (Mohanty *et al*., 2016 & 2017a) In this system, total water footprint (WF_t) was estimated to be 1633 m^3 t^{-1}. The experiment was carried out at Chandipur of Balasore district, Odisha.

Similarly, in black tiger prawn (*Penaeus monodon*) monoculture, stocking density of 2,00,000 post larvae ha^{-1} gave significantly higher yield (4.58 t ha^{-1} 125 d^{-1}), economic benefit (OV:CC, 2.47), total water productivity (₹26.6 m^{-3}) and consumptive water productivity (₹ 37,9 m^{-3}). At this optimum stocking density, total water use could be minimized to 28,600 m^3 and water exchange minimized to 7,000 m^3 ha^{-1}, without hampering the normal growth and production while, only 4.28 m^3 of water was required to production 1 kg of *Penaeus monodon* biomass (Mohanty *et al*., 2014, 2015 & 2017b). In this system, total water footprint (WF_t) amounted to be 3079 m^3 t^{-1} (Table 2). The experiment was carried out at Parikhi village, of Balasore district, Odisha.

Table 2.Technologically validated field trial result of water use in high-value aquaculture.

Water management parameters	Carp polycul-ture	Monoculture of P. monodon	Monoculture of L. vannamei
Optimum density, ha^{-1}	8000 fingerlings	200000 PL	500000 PL
Culture duration	180 days	125 days	120 days
Water depth (m) maintained	1.2 up to 90 DOC 1.75 up to 180 DOC	1.0 up to 30 DOC 1.2 up to 125 DOC	1.2 up to 30 DOC 1.5 up to 120 DOC
Evaporation losses, (× 10^4, m^3)	0.58	0.63	0.62
Seepage losses, (× 10^4, m^3)	0.49	0.55	0.52
Regulated outflow, (× 10^4, m^3)	-	0.70	0.63

Other losses, (× 10^4, m^3)	0.06	0.08	0.05
Total loss (CWU), (× 10^4, m^3)	1.13	1.96	1.82
Initial water level, (× 10^4, m^3)	1.20	1.00	1.20
Precipitation, (× 10^4, m^3)	0.6	0.46	0.51
Regulated inflow, (× 10^4, m^3)	1.02	1.40	1.55
Total Water Use, (× 10^4, m^3)	2.82	2.86	3.26
Consumptive Water Use Index, $m^3 kg^{-1}$	2.88	4.28	1.72
Productivity, t ha^{-1}	3.92	4.58	10.58
Feed Conversion Ratio, FCR	1.74	1.40	1.63
Sediment load, m^3 t^{-1} biomass	53.0	42.1	46.3
OV-CC ratio	1.81	2.47	2.11
Total Water Productivity , m^{-3}	5.9	26.6	46.6
Consumptive Water Productivity, m^{-3}	10.3	37.9	83.3
Total water footprint (WF_t, m^3 t^{-1})	1633	3079	1229

(Source: Mohanty and Mishra, 2020).

Water requirement of different freshwater carp polyculture systems was also carried out to optimize water requirement. Out of four different production systems such as (1) IMC grow-out culture : *Single Stock-Single Harvest system*, (2) IMC grow-out culture : *Single Stock-Multi Harvest system*, (3) IMC grow-out culture : *Multi Stock-Multi Harvest system*, (4) intercropping of IMC-Minor carp; Multi Stock-Multi Harvest system (MSMH) was found to be more efficient, productive and profitable (Table 3) in terms of water use efficiency (0.57 kg m^{-3}), productivity (4.6 t ha^{-1}), FCR (1.51), total water footprint (998 m^3 t^{-1}) and net consumptive water productivity (INR 9.2 m^{-3}). Next to Multi Stock-Multi Harvest system, intercropping system of IMC-Minor carp was considered efficient, productive and profitable. The experiment was carried out at ICAR-CIFA and ICAR-IIWM research farm.

Table 3.Water use in different freshwater carp polyculture systems

Water use parameters	Single stock-single harvest	Single stock-multi harvest	Multi stock-multi harvest	Intercropping of IMC-Minor carp
Stocking density ha^{-1}	10,000 IMC fingerlings	10,000 IMC fingerlings	4,000 IMC fingerlings**	8,000 fingerlings Including 50% IMC
Culture duration	360 days	360 days	360 days	360 days
Water depth (m)	1.2 up to 180 DOC 1.5 up to 360 DOC	1.2 up to 180 DOC 1.5 up to 360 DOC	1.2 up to 180 DOC 1.5 up to 360 DOC	1.2 up to 180 DOC 1.5 up to 360 DOC
TWU, ($\times 10^4$, m^3)	2.40	2.53	2.5	2.43
CWU, ($\times 10^4$, m^3)	0.73	0.84	0.82	0.76
CWUI, m^3kg^{-1}	1.97	1.95	1.78	1.77
Productivity, t ha^{-1}	3.7	4.3	4.6	4.3
WUE_c (kg m^{-3})	0.50	0.51	0.57	0.56
FCR	1.76	1.63	1.51	1.72
NCWP, m^{-3}	7.7	8.1	9.2	8.3
WF_t, m^3 t^{-1}	1122	1093	998	1026

TWU-total water use; CWU-consumptive water use; CWUI-consumptive water use index, WUE-water use efficiency; NCWP-net consumptive water productivity; WF_t-total water footprint; WUE_c-Consumptive water use efficiency; FCR-feed conversion ratio; DOC-days of culture, **partial harvesting was carried out at 6^{th} and 9^{th} month followed by restocking @1.25 times of the harvested numbers. (*Source: Mohanty and Mishra, 2020*).

Water budgeting in aquaculture-based Integrated Farming System was carried out integrating various components such as aquaculture (carp polyculture), agriculture (*kharif* rice followed by green gram and vegetables with sprinkler and drip irrigation), on-dyke horticulture (banana and papaya with drip irrigation) and poultry '*Vanaraja*'. Out of System's total crop water use (3.14×10^4 m^3 240 d^{-1}), the estimated TWU, consumptive water use index (CWUI) and productivity in carp polyculture alone was 2.3×10^4 m^3 240 d^{-1}, 2.6 m^3 kg^{-1} fish production and 2.86 t ha^{-1}, respectively. The estimated evaporation and seepage losses were 2.8 and 2.1 m^3 water kg^{-1} fish production respectively and contributed significantly to CWU. System as a whole, resulted in net profit of Rs.1,77,117 ha^{-1} with an output value - cost of cultivation ratio of 3.1 and net consumptive water productivity of Rs.19.2 m^{-3}.

ICT in aquaculture water management

In Aquaculture, new ICTs are being used across the sector, from resource assessment, capture or culture to processing and commercialization. At the production level, ICT can be used for technical designs of sensors for automatically monitoring and controlling in-pond water quality assessment, continuously monitoring important water quality parameters such as temperature, dissolved oxygen, pH, salinity, etc., and instant adjustments to ensure the growth and survival of fish and shrimp (Antonucci and Costa, 2020). Integrating smart pipes and sensors within the aqua farms (reservoirs, feeder channel, pond inlet and outlet in shrimp farms, biofloc units, aquaponic units etc.) enables key functions such as the detection of events based on the monitoring of flow rate, pipe pressure, stagnant points, slow-flow sections, pipe leakage, backflow, and water quality to be monitored. A smart aquaculture management system (SAMS) based on the Internet of Things (IoT) has recently gained much attention for fulfilling the growing demand for aquaculture products. The SAMS uses cutting-edge sensing technologies with a modern networking system to continuously monitor water quality, water budgeting, health, and feeding management of cultured species to improve the productivity (Yadav et al., 2022). Introduction of IoT-based technologies, e.g., sensors nodes, software interfacing, artificial intelligence, cloud computing, and storage, to develop reliable and robust SAMS are very much essential for real time water quality monitoring and budgeting of various aquaculture systems.

Water saving approaches in Aquaculture ecosystem

Conventional earthen ponds, where fish are fed with supplemental feeds and without aeration generate annual yields of 2000 to 3500 kg/ha. On a global scale, even in India, most ponds produce on an average fish yield of 2000 kg/ha. The challenge is to enhance production by exploring the limits of fish production based on creating congenial water quality, natural pond productivity, minimizing water exchange requirement with water budgeting and to increase feed efficiency.

Large-scale expansion of extensive pond aquaculture is not possible because of constraints associated with the availability of suitable land. Assuming an annual production of 2000 kg/ha, 5m^2 of pond area is needed to produce 1 kg fish. Raising the annual fish supply by 14 kg/capita, even if under conservative assessment only 50% of this increase will be produced in extensive ponds, requires an additional 30 m^2/capita. Thus, a world population of 10 billion people would require an additional 300,000 km^2 of ponds. This analysis is conservative because it considers only productive water surface area, and not the additional area required for dikes, channels, roads and farm buildings, which would increase the need for land by an additional 20–30%. Considering growing population pressure and competitive uses of land in areas suitable for aquaculture development, such large-scale expansion of pond area is highly unlikely. Consequently, increased aquaculture production will have to come primarily from increased intensity rather than from area expansion besides greater water consumption, while decreasing the quantity of fish caught for feed. Considering the current contribution of small-scale farmers to global production, a large fraction of the production increase must be realized through low-cost technologies. Considering the future water demand and crisis as a challenge, apart from site-specific water budgeting, WQSI-based water management, multiple use management and adoption of best management practices (BMP) can also help in minimizing water use in aquaculture.

Restricted feeding protocol using floating feed for improving water quality

Introduction of floating feed can change the feed and water management scenario in aquaculture. Feed comprises about 65% of the production cost. In addition to extra expense, water quality can deteriorate unnecessarily due to over feeding. Extruded, vacuum coated floating feeds offer the advantage of watching the feeding response as opposed to a sinking, steam-pelleted feed. Floating feed has many advantages over sinking feeds such as minimal wastage of feed, minimal deterioration of water quality(thus lessening water exchange requirements), low FCR, easy to digest, faster growth, higher yield and water productivity. Further, one potential way of reducing operational cost/feed cost is to take advantage of the phenomenon of compensatory growth (CG). Compensatory growth offers the possibility of improving the growth rates of fish/prawn by a careful choice of feeding schedules/ protocol, in which periods of feed deprivation are followed by periods of satiation feeding. If CG can completely make up for growth lost during starvation, there could be an opportunity to save on fish feed by starving the fish and making up for lost growth when feeding resumes. Using CG is therefore, perceived as a way to improve water quality, water productivity and profits of aquaculture operations (Mohanty, 2015; Mohanty and Mohapatra, 2017). Usually, compensation is improved when the duration of growth restriction is short and is not too severe. Fish and very young animals often fail to express CG when severe feed restriction is imposed.

Biofloc technology (BFT)

Water exchange in BFT ponds is very low, with some systems operating with no water exchange for extended periods. Biofloc organisms (BFOs) play three main roles in BFT: (i) maintaining water quality by consuming nitrogenous compounds thus minimizing water exchange probability (Suita et al., 2015; Wang et al., 2016; Khanjani and Sharifinia, 2020), (ii) providing a source of nutrient-rich food for the cultivated species (Wang et al., 2016), and (iii) pathogen control (Emerenciano et al., 2013). The presence of BFOs in aquaculture, especially ciliates and nematodes, can make proteins, lipids, and vitamins available to the farmed species, thus promoting growth and reducing the need for these compounds in commercial feed (Khanjani and Sharifinia, 2020). Metabolic wastes from production animals stimulate the development of high-density microbial communities. From the perspective of microbial growth, metabolic wastes in aquaculture production systems are relatively rich in nitrogen compared to carbon. By adding carbonaceous substrates (e.g., molasses, cassava meal, bagasse, etc.) microbial production is enhanced while inorganic nitrogen, including potentially toxic ammonia and nitrite, are immobilized and hence controlled (Fig. 6). In addition, many aquatic species obtain nutritional benefit from the microbial biomass. Protein utilization in BFT systems can be twice as high as in conventional ponds. Microbial flocs utilized by fish or shrimp contain significant levels of vitamins and minerals. These systems are considered to be environmentally benign because few nutrients are released to the outside environment.

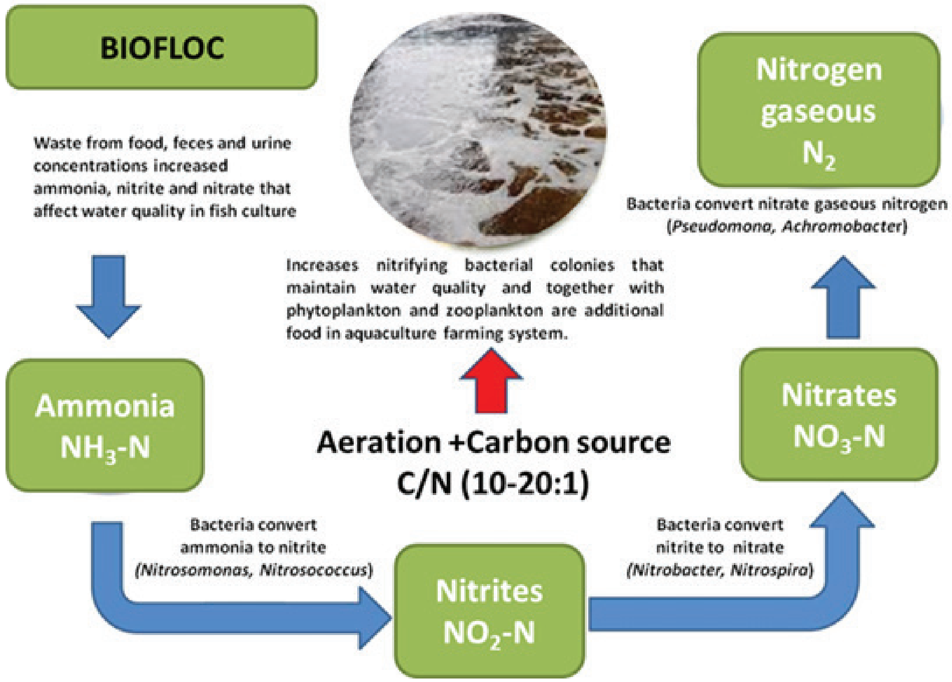

Fig 6. Schematic diagram of a biofloc technology system.

Aquaponics

Aquaponics is a term originates from the two words aquaculture (the growing of fish in a closed environment) and hydroponics (the growing of plants usually in a soil-less environment). Aquaponics is a modern food production system combines aquaculture and hydroponics (raising of plants without soil beds) together (Komives and Junge 2015; Azad *et al.*, 2016) and symbiotically in a balanced re-circulatory environment (Fig. 7). Many advantages are often associated with aquaponics, especially in terms of its water-use efficiency, its nutrient use efficiency, its sustainable nature, its ability to produce two crops from the one input source (fish feed) and its lowered environmental impact (Buzby and Lian-shin 2014; Wongkiew et al. 2017; Suhl et al. 2016). In Aquaponics system, nutrient-rich water from fish tanks is used as liquid fertilizer to fertilise hydroponic production beds. These nutrients in the water produced from fish manure, algae, and decomposing fish feed which otherwise increases the toxic levels in the fish tanks affecting the fish growth. The hydroponic beds function as a biofilter stripping off ammonia, nitrates, nitrites, and phosphorus so the freshly cleansed water can then be re-circulated back into the fish tanks. The nitrifying bacteria living in the gravel and in association with the plant roots play a critical role in nutrient cycling. These nitrifying bacteria convert ammonia to nitrate, a form of nitrogen utilised by the plants. Thus when the water returns to the fish tanks, nitrogen level are tolerable for the fish. Aquaponics can be more productive and economically feasible in certain situations, especially where land and water are limited.

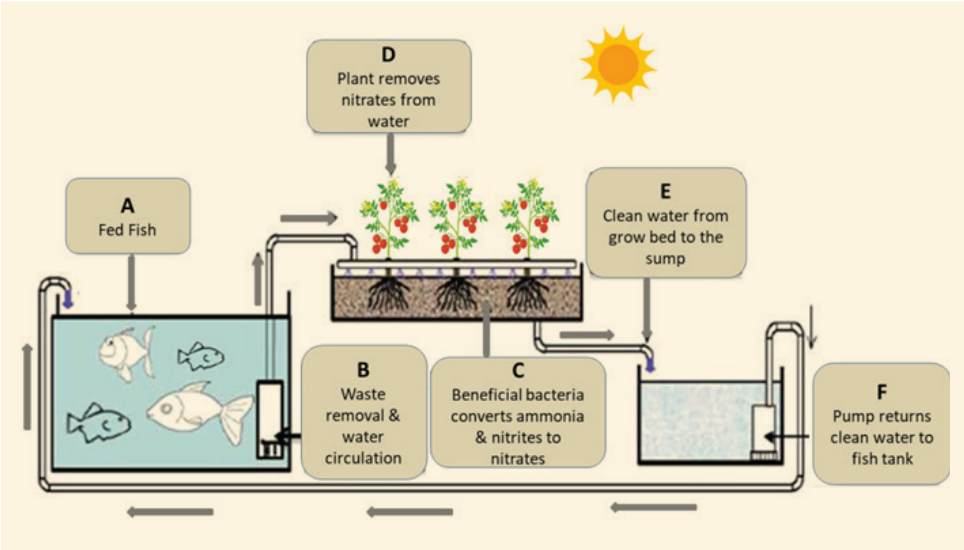

Fig 7. Factors affecting water management in aquaponics.

Recommendations

The aquaculture industry is under growing pressure to make production more resource efficient. The 'Blue Revolution' referring to the rapid growth of aquaculture must go green with the 'ecological aquaculture' by integrating aquaculture water management principles. Under such situation, a few specific recommendations would assist in enhancing aquaculture water productivity.

With the increasing scarcity of water resources and threats of environment pollution, there is a need to determine the ideal amount of water necessary for successful aquaculture. To achieve this,, integrated water depth sensing system need to be integrated under Internet of things (IoT) protocol to monitor the water depth of aquaculture ponds at regional scales. Data acquired from the water level depth sensors can be integrated with the volume of water required for aquaculture of different fish cultivars besides the best management practices to develop a mobile app on Aquaculture Water Management System for Enhancing Aquaculture Production (AWM-EAP).

It is imperative to develop a *nutrition sensitive aquaculture* to improve operational efficiency and prevent wasteful use of water and deterioration of pond water quality. In such cases the integrated water quality sensing systems need to be installed for real time water quality monitoring of aquaculture systems. Further, such system need to be IoT enabled and linked with mobile app to assist stakeholders in management of water quality for aquaculture.

Site-specific hydrological water balance study in catchment scale to determine density-dependent water use for improving aquaculture performance. The hydrological models need to be integrated with aquaculture water budgeting protocol to estimate the water availability and subsequent demand for enhancing AWP.

Water budgeting protocol under aquaculture system need to be integrated with climate change models or representative carbon pathways (RCP) scenarios to predict the future water requirement of different aquaculture systems.

Adoption of new aquaculture practices that require less water (biofloc system, aquaponics etc.) and pond-based aquaculture with demand driven low to moderate water exchange, not only serves to keep the water quality suitable for growth, but also improves water use efficiency, water productivity and helps in minimizing the water footprint, sediment load and effluent outputs.

Water budgeting, density-dependent water use and monitoring of water quality are three major requirements for sustainable aquaculture production under changing climate and One-Health regime.

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Why SAVE WATER?

- To lead a life of good health.
- To preserve the environment.
- To stay out of water scaricity.
- To be prepared for future droughts.
- To save all forms of life on our planet.
- To ensure water is available for future generations.

PRADHAN MANTRI MATSYA SAMPADA YOJANA

HOW IS THIS GOING TO REVOLUTIONISE THE FISHERIES SECTOR