E-ISSN: 2347-5129
P-ISSN: 2394-0506
(ICV-Poland) Impact Value: 5.62
(GIF) Impact Factor: 0.549
IJFAS 2019; 7(5): 39-48

www.fisheriesjournal.com
Received: 19-07-2019
Accepted: 23-08-2019

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Fish culture without water

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Abstract
The world’s appetite for fish is growing steadily. Aquaculture has bridged that gap between the growing demand for fish and the almost stagnated wild fish catch, contributing at present nearly 47% of the world’s total fish production of 171 million tonnes. Global aquaculture production has almost doubled between 2000 and 2016, it is estimated that, to meet the demands of the growing population, aquaculture production will need to more than double again between now and 2050. Being a young industry, aquaculture has still wide scope to meet the demand of the nine billion people in 2050, through horizontal expansion as well as improvements in production systems. But the industry is facing ‘access-limitation to freshwater resources’ due to growing global water crisis. With more than 40% of the global population already facing the problem of water scarcity, the scenario in coming days will be worse, where there will be no freshwater available to drink even for human, and thus utilization of water for fish culture will be hard. So, if we wish to make available fish- the cheapest animal protein for future generation, we need to conserve our water to the height above human needs. In aquaculture, improving water use efficiency through intensification and diversification will not only contribute to ‘future water security’, but also lessen the conflicts the aquaculture industry is facing with other water users. Fishes like Snakeheads (*Channa* spp.), climbing perch (*Anabas testudineus*), which can live out of water for few days and tolerate extremely unfavourable water conditions, can also be promoted for ‘future water-stressed aquaculture’.

Keywords: Water scarcity, agriculture, aquaculture, intensification, diversification

1. Introduction

Water is not only the foundation of life; it is itself a rich environment for life forms and that is the reason Leonardo da Vinci called it "the elixir of life". Water is everywhere: at home, at work, in bottles on shelves and in ponds, rivers and other bodies of freshwater all around us and thus we often don’t realize how simply *vital* the ‘water’ is! Fish culture without water!! Is it possible? Everyone will answer NO. But we are pushing our future to that way. In coming days there will be no freshwater available to drink even for human, utilization of water for fish culture is far to think. So, if we wish to make available fish- the cheapest animal protein for future generation, we need to conserve our water to the height above human needs.

It is to be remembered that though earth appears as a ‘Blue Planet’ (Water planet) from the space, mere 0.003% of all water on Earth is both fresh and easily accessible, and thus water has to be treated as a scarce resource, with a far stronger focus on managing demand. Global freshwater withdrawals have increased by about 1% per year since the 1980s and as a result now, worldwide 32 countries are experiencing water stress of between 25 and 70%; 22 countries experience it above 70% and are considered to be seriously stressed; in 15 countries, this figure rises to above 100%, and of these, four have water stress above 1,000 per cent [1]. While we individually need just 2 to 5 liters of water for drinking and 20 to 400 liters of water for household use every day, in reality we are using far more- as producing a day’s food requirement takes 2000 to 5000 litres of water per head, depending largely on how productive our agriculture (Farming) is and what kind of food we are eating. This means the 'water we eat' daily through the food we consume is much more than what we drink. So, without proper attentiveness and increased efforts aiming at better using of water in the fields, future production of food and other agricultural products will not be possible.

2. Earth’s water count

In terms of volume, all of the water on Earth works out to about 1.386 billion cubic kilometers (km³) (Table 1 & 2.). Most of the earth's surface water is permanently frozen or salty, leaving only about one-third of 1% of the world's total water supply for human use, in lakes and rivers and the accessible ground water. But again most of the fresh water is remote from civilization or too difficult to capture for use and thus total usable freshwater is mere 0.003% of the world total volume of water. For example, if the entire world's water were fit into a gallon jug, the fresh water available for us to use would equal only about one tablespoon. The Food and Agriculture Organization of the United Nations (FAO) estimates that only about 9,000 to 14,000 km^3 water is economically available for human use each year [2].

Table 1: Few water related terminology

Water footprint	The water footprint is a way of measuring our direct and indirect water use. The water footprint is the total volume of freshwater that is used to produce the goods and services consumed by an individual or a community or produced by a given business. A water footprint consists of three components – the blue, green and grey water footprint.
Virtual Water:	The volume of freshwater used for an agricultural or industrial production, or a service. It refers to the sum of the water use in the various steps of the production chain.
Blue water:	Is the water in our surface and groundwater reservoirs. In irrigated agriculture, blue water is abstracted to maintain transpiration.
Green water	Refers to water stored in soil. It is the soil moisture from precipitation, used by plants via transpiration. It stored in soil from rain water or that which has been added through irrigation from blue-water reservoirs.
Grey water	Is the water that becomes polluted during production, say in agriculture because of the leaching of nutrients and pesticides.

Table 2: Estimated global water availability

Water storage	Water volume, in Km^3	Percent of total water	Percent of freshwater
Oceans, Seas & Bays	1,338,000,000	96.5%	0%
Ice-caps, Glaciers & Permanent Snow	24,064,000	1.74%	68.7%
Ground Ice & Permafrost	300,000	0.022%	0.86%
Groundwater	23,400,000	1.7%	----
a. Fresh	10,530,000	0.76%	30.1%
b. Saline	12,870,000	0.94%	0%
Lakes	176,400	0.013%	---
a. Fresh	91,000	0.007%	0.26%
b. Saline	85,400	0.006%	0%
Rivers	2,120	0.0002%	0.006%
Swamp water	11,470	0.0008%	0.03%
Soil Moisture	16,500	0.001%	0.05%
Atmosphere	12,900	0.001%	0.04%
Biological water	1,120	0.0001%	0.003%
Total	1,386,000,000	100%	100%

(Source: Gleick [3] and Nace [4])

The 'Water scarcity'

Water scarcity (Table 3, 4 & 5) is the deficiency of adequate water resources that can meet the water demands for a particular region. By one definition, human populations face water scarcity when annual renewable water supplies in a region fall below 1,000 m^3 $person^{-1}$, which currently occur throughout most countries in Northern Africa and the Arabian Peninsula [5]. The combination of growing populations, increasing demands for resources associated with improving standards of living, climate change and various other external forces of change are increasing demand pressures on water supplies required for irrigation, energy production, industrial uses and domestic purposes. In fact use of water is growing at twice the pace of population growth. While the global population tripled in the 20th century, use of water increased six-folds during this period [6]. As a result per capita freshwater availability has been dropped about 55% globally compare to 1960, and currently water scarcity affects more than 40% of the global population [6]. By 2050, an additional 2.3 billion people are expected to be living in areas with severe water stress, especially in North and South Africa and South and Central Asia [7]. It is also estimated that, between now and 2050, global water demands will expected to be increase by 400% from manufacturing, by 130% from household use and by 15-20% to produce 70% more food that will be needed by 2050 [6, 7].

Table 3: Conventional definitions of levels of Water Scarcity

Water stress	Is the difficulty of obtaining sources of fresh water for use during a period of time likes during a temporary drought and may result in further depletion and deterioration of available water resources.
Water shortage	Is when there is not enough potable drinking water for every person and may be caused by climate change such as long droughts, increased pollution so the water is no longer usable, increased human demand and overuse of water by agriculture.
Water crisis	Is a situation where the available potable, unpolluted water within a region is less than that region's demand.
Absolute water scarcity	This situation leads to widespread restrictions on water use. A threshold of 500 m^3/ person/yr is often used as a proxy to indicate absolute water scarcity [8].

Table 4: Stages of water stress (After falkenmark and widstrand [9])

Annual per capita water availability (m^3)	Category/Condition
>1700	No Stress/ Occasional or local water stress
1000 – 1700	Regular water stress
500 - 1000	Chronic water shortage
< 500	Absolute water scarcity

Table 5: Dimensions of water scarcity and correlated symptoms

Dimension of water scarcity	Definition	Symptoms
Physical water scarcity	An excess of water demand over available supply.	Symptoms of physical water scarcity are environmental degradation, declining groundwater levels, and water allocations that favour some groups over others, thereby causing conflicts
Economic water scarcity	The lack of adequate infrastructure due to financial, technical or other constraints.	Symptoms of economic water scarcity include a lack of adequate and equitable access to water for agriculture and domestic use.
Institutional water scarcity	The lack of an appropriate institutional framework or capacities for ensuring the reliable, secure and equitable supply of water.	Institutional water scarcity may arise when governments lack accountability to their constituencies, service providers are unaccountable to their users, or institutions are unable to address the management of supply and demand or deal with gender roles, relations and inequalities

India is one of the most water-challenged countries in the world and already categorised as water stressed country in terms of per capita freshwater availability. Serving safe and clear water to the planets second largest population at 1.3 billion, and expectant growth to 1.7 billion by 2050, with possession of only 4% of the world's fresh water is daunting enough for the country. As per CWC [10], total utilizable water resource in the country is 1123 billion cubic meters (BCM) [690 BCM surface water and 433 BCM replenishable groundwater] as against current usage of 634 BCM, reflecting a surplus scenario. But other international experts have estimated India's total utilizable water at only 654 BCM, uncomfortably close to actual usage [11]. The World Health Organization estimated that 97 million Indians lack access to safe water today, and almost 600 million people are at higher risk of surface-water supply disruptions as 54% of India's total area facing high to extremely high water stress (Figure 1). This water crisis in India is rooted in three causes: a) Population growth- resulting insufficient water per person; b) Poor water quality- resulting from insufficient water-treatment facilities; and c) Dwindling groundwater level- due to over-extraction by farmers, city residents and industries. Also per capita water availability in India estimated to be 1545 m^3/yr in 2011 is projected to be further decreased to 1140 m^3/yr by 2050 [11] (Figure 2). As water availability decreasing, competition for access to this limited resource is increasing and the future may be only worse, with the national supply predicted to fall 50% below demand by 2030.

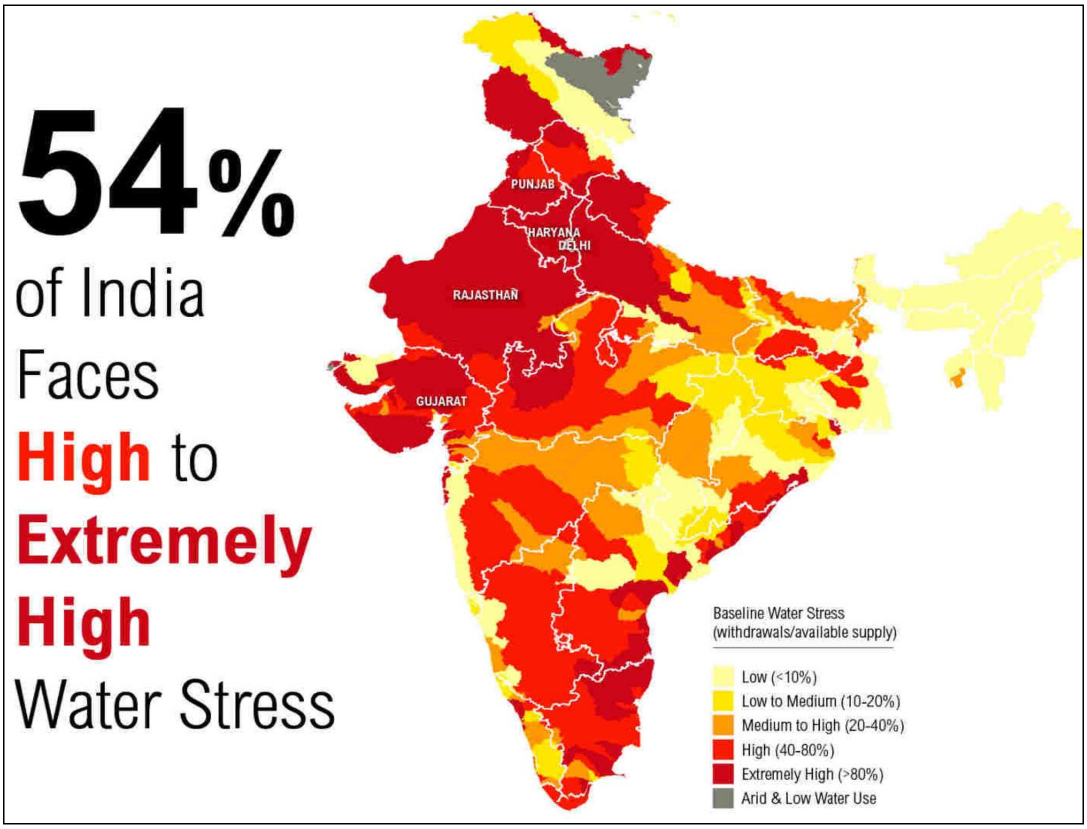
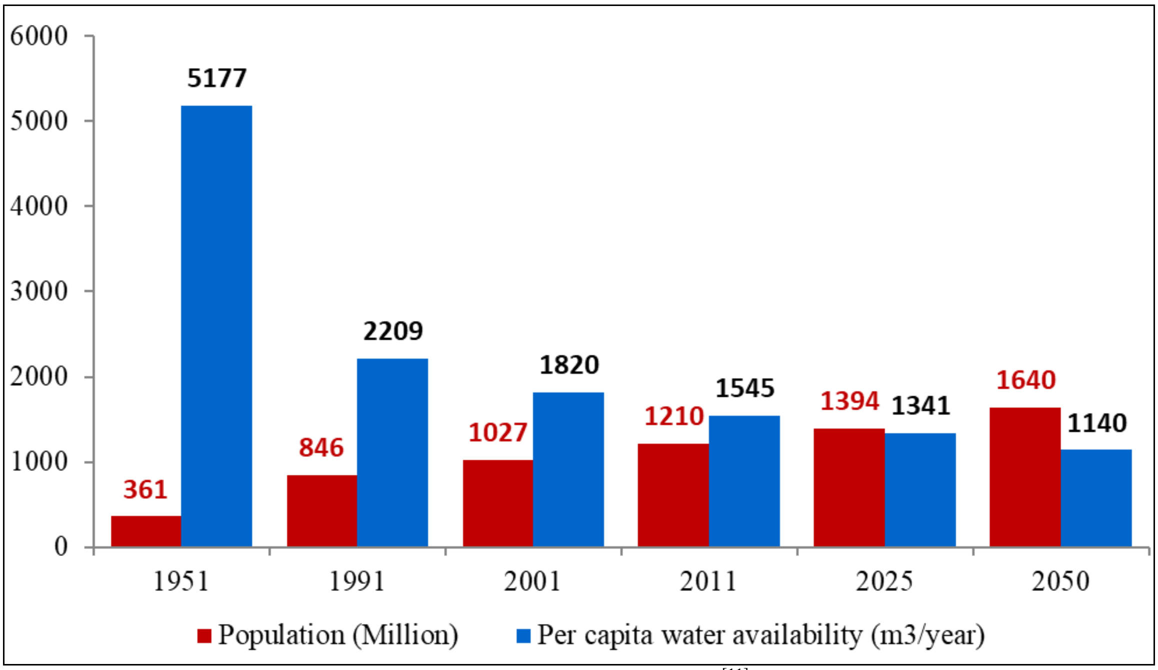


Fig 1: India's growing water risk (Source: www.indiawatertool.in)



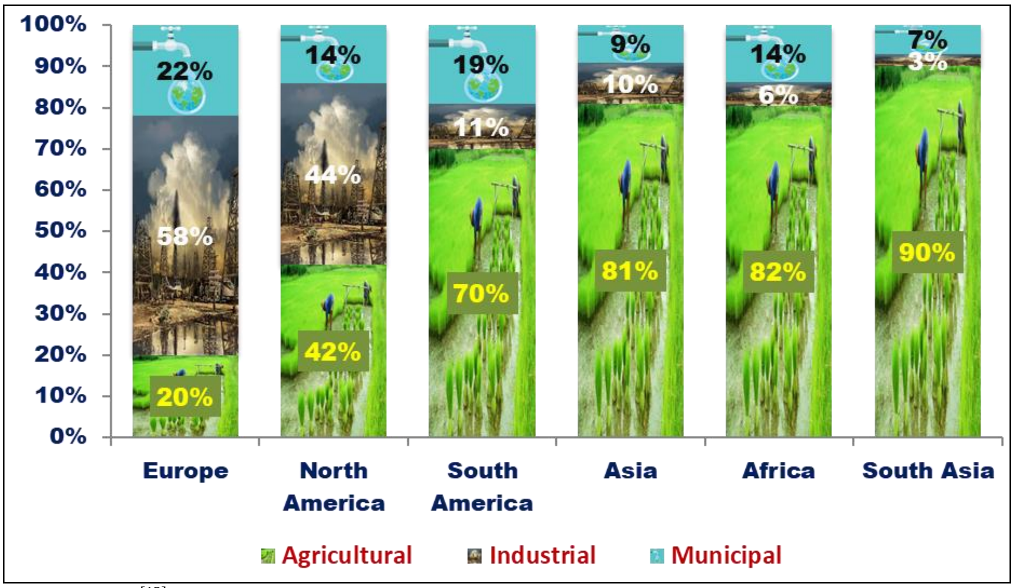
(**Source:** Government of India, 2009; UNICEF, FAO and Saci WATERs [11])

Fig 2: Population *vs* Per capita water availability in India

Contribution of 'The water we eat!!' to water scarcity

We eat 3496 litres of water every day!! 'Eating water' – it might sound strange, but it's the reality. This is the water associated with the production of food we consume daily. In fact the water we essentially need for drinking is only about 0.01% of the water we require to produce our food. Most of the world's freshwater goes to agriculture, mainly for the production of crops, livestock and aquatic organisms, such as fish and plants, as well as for the processing and preparation of these foods and products. At present agriculture accounts for nearly 70% of all freshwater withdrawn from rivers, lakes, and aquifers globally [1], which is equivalent to 3600 km^3 $year^{-1}$ (Including losses) [12] (Figure 3).

Rice, cotton and sugar are among the thirstiest crops; but meat production requires a much higher amount of water than crops/vegetables. But with rapid urbanization and incomes increase, human diets are shifting towards 'more meat consumption'; and it is expected that meat consumption will rise from 43 kg in 2014 to 52 kg in 2050 [13]. As per IME (Institution of Mechanical Engineers) estimate, while only 500 and 4,000 litres of water is required for producing 1kg of wheat; for producing 1kg of meat we need 5,000 and 20,000 litres of water. (Table 6). It is estimated that, by 2050 overall food production will need to increase further by about 70% compare to 2009, to satisfy the demand of an eventual population of more than nine billion. We also need to grow additional crop to feed the livestock production to meet the meat requirements due to dietary shift. All these will consequently raise global water demand for agriculture further [6].



(Source: FAO [12])

Fig 3: Thirsty agriculture: Water withdrawals for agriculture, industry and households in different world regions.

Table 6: Water productivity for different crops/foodstuff

Foodstuff	Unit/ quantity	Water consumption/ requirement (litres)
Bovine, cattle	head	4,000,000
Sheep and goat	head	500,000
Beef	1 kg	15,400
Sheep meat	1 kg	10,400
Goat meat	1 kg	5,500
Chicken meat	1 kg	4,500 – 6,000
Rice	1 kg	3,000 – 5,000
Soyabean	1 kg	2,145
Wheat	1 kg	1,830
Maize	1 kg	1,220
Pulses (beans, lentils and peas)	1 kg	1,000
Roots (onions, garlic, carrots, radishes etc.)	1 kg	1,000
Citrus fruits (lemons, limes, oranges, grapefruits etc.)	1 kg	1,000
Milk	1 l	1,000
Apple	1 kg	822

(Source: FAO [14])

Does aquaculture contribute to water scarcity?

Worldwide aquaculture is growing and it is now the world's fastest growing food sector. Between 1990 and 2010 aquaculture sector grown at an annual rate of 7.8% worldwide; a rate that substantially exceeded that of poultry (4.6%), pork (2.2%), dairy (1.4%), beef (1.0%), and grains (1.4%) over the same period. In aquaculture, direct use of water primarily refers to the water where the fish is raised (System-associated water uses) and primary indirect usage of water derives from feed ingredients produced in terrestrial agriculture (Feed-associated water uses). Aquaculture in inland freshwater contribute maximum to the world aquaculture production (Contributed 63% of the world aquaculture production in 2016) [15] and at the outlook, inland freshwater aquaculture seems as a highly water-intensive endeavour, requiring much more water than conventional agriculture, withdrawing on average 16.9 m^3 water for per kg production. But as infiltration losses and water use for recharging/filling of ponds including water exchange replacement contribute to groundwater recharge, in true sense total system associated water losses in aquaculture is only what is got evaporated, which is 5.2 m^3 per kg production. If feed associated water losses of 1.7 m^3 are included, total water losses per kilo freshwater fish production comes to 6.9 m^3 (Table 7).

Table 7: Estimated water consumption in inland aquaculture

	Water use variable	Water consumption per kg production	World total water use in inland aquaculture (in km3/yr)
A. System associated water consumption			
1.	Evaporation losses	5,200 L (5.2 m^3)	131
2.	Infiltration losses	6,900 L (6.9 m^3)	175
3.	To regulate water exchange	3,100 L (3.1 m^3)	79
B. Feed associated water consumption		1,700 L (1.7 m^3)	44.1
C.	Gross total water consumption (A + B)	16,900 L (16.9 m^3)	429.1
D.	1. Recycled water (Infiltration losses + water exchange losses) (A2 + A3)	10,000 L (10 m^3)	254
E.	2. Net total water consumption (C – D)	6,900 L (6.9 m^3)	175.1

(Source: Verdegem and Bosma [16]).

Globally, total pond area dedicated to freshwater aquaculture is around 8,750,000 ha consuming around 429 km^3 water yr^{-1}, which is 3.6% of global flowing water [17]. There are also 2,333,000 ha of coastal brackish water ponds. Though in low-lying coastal brackish water aquaculture, with daily tidal water exchange, freshwater use is negligible; in coastal ponds constructed more inland sites, freshwater use is significant. It is calculated that, when fresh water shrimp ponds were operated year round, the total water consumption is around 30,300 m^3 ha^{-1} yr^{-1} [18]. In many brackish water aquaculture, food-associated water use is also comparatively higher; like in case of shrimp the food-associated water use is 2.9 m^3 per kg produced. Globally aquaculture uses approximately 40 million tonnes of compound feed, largely formulated using significant volume of food quality crops and/or their by-products and thus indirectly consumes large volume of water [19]. World Bank has estimated that, aquaculture's contribution to world's fish consumption will rise from current 40% to roughly 62% by 2030; and thus consequently water demand for the sector will rise significantly.

6. Is aquaculture without water possible?

The straight answer is: "NO" with a parsec hope of 'YES'. 'NO' because fish depends on water for their survival, and generally extract dissolved oxygen from water through their gills, though few species of fishes have additional capacity to extract oxygen directly from the air. Fishes that can breathe air can survive relatively long out of water; others that can't breathe air, die sooner. Species or species groups that dominate the current world aquaculture production by volume, *viz. Ctenopharyngodon idellus, Hypophthalmichthys* spp., *Cyprinus carpio, Labeo* spp., *Catla catla, Salmo salar, Oreochromis* (=*Tilapia*) spp. and *Oncorhynchus* spp., are all non-air breathing fishes and die within minutes depending on the size of the fish and local conditions (e.g. humidity). So, aquaculture without sufficient quantity of water of appropriate quality is a 'dead idea' in the current scenario of world aquaculture.

But, following Edger Cayce's remark " Dreams are today's answers to tomorrow's questions", we can start dreaming for a 'future aquaculture', may be not without water, but with minimal water, may be with fishes that are able to live out of water for extended periods of time (Amphibious fishes). Valued food-fishes like Snakeheads (*Channa* spp.) can survive out of water for up to four days (https://en.wikipedia.org/wiki/Snakehead) and climbing perch (*Anabas testudineus*) can live out of water for six days (http://www.discovery.com) and also can tolerate extremely unfavourable water conditions. So, we can think of promoting these fishes for 'future water-stressed aquaculture'.

There are many other amphibious fishes, like Mudskippers (Oxudercidae) can survive out of water for three and a half days (*www.themudskipper.org*.), breathing through their skin, the lining of their mouth (the mucosa) and throat (The pharynx). Mangrove rivulus or mangrove killifish, *Kryptolebias marmoratus* can survive up to 66 consecutive days out of water, breathing air through its skin. African lungfish, *Protopterus annectens*, can live in suspended animation, called aestivation, for three to five years without food and water, only to wake up when water becomes available (https://www.dailymail.co.uk/sciencetech/article-3200788). But as of today these fishes are not valued as neither food fish nor they are a part of aquaculture; but they have potential to contribute to our protein requirement in water-stressed future.

7. Strategies to Support 'Water Security' as well as 'Farming Community'

Water security is the adaptive capacity to safeguard the sustainable availability of, access to, and safe use of an adequate, reliable, and resilient quantity and quality of water for health, livelihoods, ecosystems, and productive economies; and also the key to 'food security'. Agriculture (crops and livestocks) requires large quantities of water for production and of good quality for various post production processes. The way the water is managed in agriculture has caused wide-scale changes in ecosystems and undermined the provision of a wide range of ecosystem services. Hence, innovative technologies are required to reduce agricultural water stress and to ensure a greener and more sustainable food production. Reducing water stress can be achieved by, for example:

7.1 Improving crop water productivity

In current scenario of water scarcity, agricultural productivity should not only be looked at in terms of land, but also need to be looked in terms of water productivity. Increasing agricultural water productivity, i.e. the amount of output per volume of water used can be achieved either by increasing production from a given volume of water, or by reducing the volume of water while maintaining acceptable levels of production. According to Frank Rijsberman, Director General of IWMI "If we can improve water productivity by 40 per cent over the next 25 years we'll be able to reduce the global need for extra water for irrigation to zero". Simply, switching from flood irrigation systems to sprinklers or drip irrigation systems could help the agricultural sector save a tremendous amount of water. When combined with better soil management practices as no-till or limited tillage and mulching (which reduces evaporation from the soil), more efficient irrigation systems can significantly reduce water usage. Crop water productivity can also be improved through deficit irrigation – that is, by applying water to crops in only the most drought-sensitive periods and avoiding irrigating in other periods. In aquaculture systems, most water is depleted indirectly for feed production and through polluted water discharge, and efforts to improve water productivity should be directed at minimizing those losses. As a whole, sustainable improvement of agricultural water productivity, cutting across all agricultural subsectors, from crop to livestock production, aquaculture and agro forestry, based on introduction of best practices in soil and water management, need to be focused to address issues of water scarcity.

7.2 Reducing food losses and food wastes

FAO estimates that, each year, as much as 1.3 billion tonnes of food, that is approximately one-third of all food produced for human consumption in the world is lost or wasted [13]. Roughly two-third of this food loss occurs during the production, handling, processing and distribution of food and the other one-third at consumer-level [20]. Concurrently, this also means that, the water used for growing these crops is also wasted. Institution of Mechanical Engineers (IME) in 2013 estimated that, the amount of water wasted globally in growing crops that never reach the consumer is about 550bn cubic metres. So, actions to prevent, reduce, reuse and recycle food losses and wastes should not be a forgotten priority to reduce pressure on natural resources including water. *Jose Graziano da Silva, FAO Director-General, while addressing a High Level Forum in 2018 said that* "If we reduce food losses and waste we will also alleviate pressure on natural resources and mitigate the impacts of climate change,"

7.3 Intensification and diversification of production systems

Farmers must also grow more on the land they currently operate through what is called "sustainable intensification." This means using precision farming tools, such as GPS fertilizer dispersion, advanced irrigation systems, and environmentally optimized crop rotations. These methods can help produce more crops, also reduce the negative environmental impacts from over-stressing resources– preventing groundwater depletion and the destruction of fertile lands through over-use of fertilizer. It is important to explore options for less water-intensive and more climate-resilient production (e.g. different cropping patterns, climate-resilient crops and the production of salt-tolerant fish species in degraded waters) and synergetic resource use in integrated systems (e.g. integrated food–energy systems that use agricultural residues or algae for biofuel production). For example, Punjab Agricultural University (PAU) in collaboration with Columbia Water Center (CWC) has successfully implemented water-saving techniques in five district of Punjab through diversification of production coupled with other technologies like laser leveling of fields before sowing and use of tensiometer technology for effective irrigation scheduling. They found that a significant amount of water can be saved by diversifying rice production to less water-intensive crops such as basmati, sweet corn and baby corn-crops that have the potential to become increasingly profitable to farmers while consuming significantly less water than rice [21].

8. Promoting 'Smart aquaculture' for a 'Water-secure future'

Livestock require more than seven times more water than crops for each kilogram produced. This has led some to suggest that there is a need to change eating habits and slow or reverse the trend to meat-based diets. If so, from where the person's daily requirement of protein will be met cheaply? The answer is 'fish'- which is already playing an important role in fighting hunger and malnutrition both in developing countries and the developed world. FAO reported that global fish consumption per capita has risen to over 20 kilograms per year in 2016, as against approx. 12 kilograms in the 1980s, largely due to the growth of the aquaculture sector. At present aquaculture contributes nearly 47% (80 million tonnes) of the world's total fish production of 171 million tonnes [22] and the World Bank has estimated that by 2030, roughly 62% of the world's fish consumption will be supplied from aquaculture farming. Apparently, being water-intensive endeavour, aquaculture is already facing opposition in both the freshwater and marine environments from parties who perceive the industry to contribute to the demand for freshwater or to pollute fresh and marine waters. However, it requires only 50 litres of water to raise one kg of fish in a Recirculating Aquaculture System (RAS). So, if done properly, aquaculture has enormous potential to play a vital role to address water scarcity as an industry that can produce a healthy form of protein with minimal water usage. There is wide range of technologies and management strategies that can help in improving land, water and overall environmental efficiency of aquaculture.

8.1 Improving feed conversion ratio (FCR)

Fish or crustaceans have lower (more efficient) FCRs than large terrestrial animals. Typical FCRs for animals raised using commercial feeds and intensive production methods are as follows: beef cattle: 6.0–10.0, pigs: 2.7–5.0, chickens: 1.7–2.0, and farmed fish and shrimp: 1.0–2.4 [23]. On an average fish or crustaceans require less than 2 kg of grain concentrate for each kg produced, making them the most efficiently producing animals in terms of FCR, as well as in terms of feed-associated water use. Still there is relevant room for improvement of FCR in global aquaculture, especially in freshwater species production. Managing certain environmental aspects such as optimizing oxygen levels in rearing systems could significantly improve FCR in more tropical production systems, for species including carps, catfishes and tilapia. Development of species-wise system specific feeding standards, improving feed management and farm monitoring systems, would improve FCRs and 'water footprint' in aquaculture. For example, Salmon farming managed to reduce the FCR from about 2.8 to approximately 1.2 in less than 30 years, through technological developments and better feed and on-site management [23].

8.2 Intensification of pond aquaculture

Conventional freshwater and brackish water aquaculture systems are extremely water intensive, but intensifying operations can help produce more fish per unit of water. Water use by conventional land-based extensive ponds is about 45,000 liters/kilogram of fish produced, whereas intensive pond aquaculture with additional inputs uses only 2,700 liters of water per kilogram of fish produced [24]. It is also found that, in intensive pond culture with supplementary feeding and aeration and achieved production of 10 - 15 tonnes $ha^{-1}yr^{-1}$, the water productivity was almost double compare to semi-intensive pond culture where production of fish was 3 - 4 tonnes $ha^{-1}yr^{-1}$ (Table 8) [25]. In a study in Egypt van der Heijden *et al.* [26] found that the farms that applied intensive aquaculture techniques used the water most efficiently, requiring 2.7-3.1 m^3 water per kg fish produced. So, our future focus should be on using intensive and super intensive culture practices for aquaculture production.

Table 8: Water requirements of Indian Major Carps for production of one Kilogram fish under different production technologies.

Culture system	Production (Ton/ha/year)	Water requirement at CIFA Study Site in m^3/kg
Semi-intensive	3 – 4	7.65
Super semi-intensive	6 - 8	3.82
Intensive	10 - 12	2.43

* $1m^3$ = 1,000 litres (Source: Sharma *et al.* [25])

8.3 Diversification of aquaculture systems

As competition for land as well as freshwater is increasing, aquaculture operations need to intensify production in a manner that reduces the land requirements for fish culture and also reduces water use per kilogram of production. Use of alternative water source for aquaculture and multiple use of water can also contribute to improve overall freshwater productivity.

8.3.1 Recirculating aquaculture systems (RAS)

RAS is an intensive aquaculture production system, that treats and reuses wastewater and thus substantially reduces both water and land use. Water use per kilogram of fish produced in freshwater RASs can be as little as 50 liters (including water use in feeds) [27] and in marine RASs with artificial saltwater it can be far lower than, as low as 16 liters/kilogram of fish [28]. RASs can be designed around indoor or outdoor culture systems, and owing to their low water requirements it can be operated on land that is unsuitable for other types of food production, such as in deserts.

8.3.2 Aquaponics Systems

Aquaponics production systems join intensive recirculating aquaculture with hydroponics to use nutrient waste from aquaculture as an input to plant growth. In aquaponics water serves dual purpose: hosting fish and growing crops, generating two products at once, and generally water use per unit produced is only about 10%, compare to conventional fish farming and plant production systems. As high as 98% water recycling have been reported in some aquaponics systems, translating to water use of about 320 liters per kilogram of fish produced [29].

8.3.3 Integration of intensive aquaculture with agriculture (IIAA)

Double use of water, first for fish farming and next for irrigation, is an efficient way of using water in situations where the water supply is limited. Especially when intensive fish production systems are used, the application of the aquaculture system's effluent for irrigation purposes contributes to savings on fertilizer and other costs, and overall productivity and value generated per unit of water is improved. Integration of intensive production systems such as cages or raceways with irrigation systems is particularly water efficient. In a study in Egypt van der Heijden *et al.* [26] found that IIAA (Intensive fish production techniques involving concrete basins, aeration and high fish densities. The effluent resulting from partial water replacement of aquaculture unit was used to irrigate crops and fruit trees) increased the revenue return on per unit water use (U.S. \$0.63 - 0.65 per m^3 of water used) compare to single use of water for crops only (U.S. \$0.41 - 0.43 per m^3 of water used).

8.4 Aquaculture using alternative sources of water

Planned use of treated and partially treated wastewater for purposes like aquaculture, irrigation and industries can provide benefits to the ecosystems through reducing freshwater abstractions, recycling and reusing nutrients, allowing fisheries and other aquatic ecosystems to thrive by minimizing water pollution, and recharging depleted aquifers. Water GAP model estimated a global production of 450 km^3 of wastewater from domestic and manufacturing sectors in 2010; of which approximately 70% (315 km^3) was accounted by the domestic sector [30]. Use of this wastewater for purposes like aquaculture has great potential as practiced in East Kolkata Wetland, which currently produces over 15,000 metric ton of fish per annum using treated sewage of central Kolkata [31] (Figure 4).

Fig 4: Images of aquaculture activities in East Kolkata Wetlands, West Bengal utilizing treated wastewater of Kolkata City. a. Sewage water intake for aquaculture; b&c. Fish harvest from sewage-fed aquaculture pond; d. Depuration of harvested fish before marketing.

8.5 Aquaculture down the food chain

Though over 85% of total farmed finfish produced by world aquaculture is low trophic level (LTL) species (Table 9), in developed countries culture of high trophic level (HTL) species is increasing. Within developed countries, above 90% of the total finfish production is HTL species including Atlantic salmon (TL 4.43), rainbow trout (TL 4.42) etc. [32]. Raising HTL requires sizable amounts of fish feed inputs in the form of fishmeal and thus ultimately increases pressure on land and water resources. On the other hand, farming of fishes lower on the food chain (LTL Species) reduces animal protein requirement in feed and thus reduces pressure on land and water resources used directly by aquaculture. In a nutshell "Farming down the food web" has an environmentally positive meaning, while the opposite, "farming up the food web" is believed by some to be a more environmentally unsustainable [33].

Table 9: Few of the major finfish produced by world aquaculture (Within top 20) in 2016 and their trophic levels

Finfish	Trophic level[a]	Production (in million tonnes)[b]
Grass carp, *Ctenopharyngodon idellus*	2.00	6,068
Silver carp, *Hypophthalmichthys molitrix*	2.00	5,301
Common carp, *Cyprinus carpio*	2.96	4,557
Nile tilapia, *Oreochromis niloticus*	2.00	4,200
Bighead carp, *Hypophthalmichthys nobilis*	2.33	3,527
Catla, *Catla catla*	2.75	2,961
Atlantic salmon, *Salmo salar*	4.43	2,248
Roho labeo, *Labeo rohita*	2.01	1,843
Rainbow trout, *Oncorhynchus mykiss*	4.42	814
Snakehead, *Channa argus*	4.20	518

[a]Trophic levels of individual finfish species taken from Pauly and Christensen [34]
[b]FAO [22]

9. Conclusion

The global demand for water has been increasing at a rate of about 1% per year over the past decades as a function of population growth, urbanization, industrialization, rising living standards and changing consumption patterns, and it will continue to grow significantly over the foreseeable future. Agriculture being both, a victim and a cause of water scarcity, ensuring optimum agricultural water productivity (output per unit of water used) becomes essential to ensure sustainable growth. Aquaculture, one of the world's major and fastest growing food production sector, is already facing competition for water and aquatic habitat in many countries. Hence, future methods for aquaculture need to be more advanced and smarter, which will be able to support culture's sustainability as well as high culture efficiency in terms of space utilization, water resources and food. A shift from 'experience-driven to knowledge-driven approaches' is therefore essential to get aquaculture growth right and better optimize aquaculture production to contribute to a sustainable food future.

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