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Review on Crisis of Water and Relationships of the Aquaculture Sustainability

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Authors' contributions

This work was carried out in collaboration among between both. Both authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Aquaculture plays a crucial role in global food production and nutrition security, with ongoing advancements essential for sustaining this industry. Global demand for fish is continuously rising. Between the almost stagnant wild fish catch and the increasing demand for fish, aquaculture has filled the void, currently accounting for roughly 50% of the 190 million tonnes of fish produced worldwide. Despite its youth, aquaculture still has a lot of room to grow horizontally and enhance its production methods in order to fulfill the needs of the world's 10 billion people by 2050. However, the developing worldwide water crisis is posing a "access-limitation to freshwater resources" challenge for the sector. With over 40% of the world's population currently experiencing water scarcity, the situation is expected to worsen in the near future when freshwater—even for human consumption—will become scarce, making it difficult to use for fish farming. Adequate quality and quantity of water are necessary for aquaculture's sustained growth and long-term viability. This may eventually limit opportunities for diversification in one's career and means of subsistence, as well as heighten social pressures that affect the aquaculture industry as a whole. Currently, several steps

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have been done by nations to address the problems associated to water. Aquaculture greatly depends on the preservation of green and blue water, integrated aquaculture-agriculture systems, recycling, and waste-water reuse. The sustainability of aquaculture should be maintained by taking comprehensive, multi-sectoral actions to lower vulnerability and increase resilience while adjusting to the water issue. In this assessment, an attempt has been made to look at the current situation and potential problems brought on by the water crisis while identifying workable, adaptable ways to keep aquaculture sustainable in order to inform future policy decisions. Therefore, we must conserve water above and beyond human demands if we hope to keep fish, the least expensive source of animal protein, available for future generations. Enhancing water use efficiency in aquaculture through intensification and diversification will not only help ensure "future water security," but also reduce disputes the sector has with other water users.

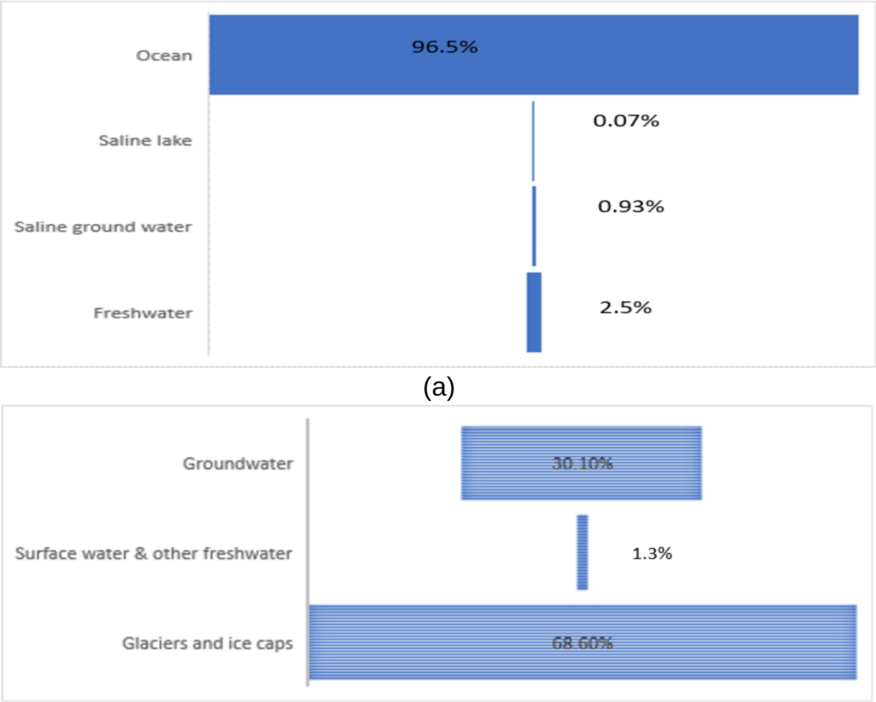
Keywords: Water scarcity; aquaculture production; freshwater resources; integrated aquaculture agriculture systems.

1. INTRODUCTION

The millenia ties between humans and fish have resulted in fish being an essential source of animal protein, as well as supplying millions of people with means of subsistence and food security [1]. Wild fish populations are under a great deal of stress due to the unprecedently high demand for fish protein brought on by human population expansion. As a result, aquaculture emerged as a possible remedy for the global fish crisis [2]. For the first time since 2014, the "Blue Revolution" produced more fish for human consumption than all worldwide fisheries [3]. Approximately 20.5 million people were employed in aquaculture in 2018, with inland aquaculture producing 51.3 million tonnes of aquatic animals, or 62.5 percent of the world's farmed food fish production [4,5]. However, aquaculture faces the same difficulties for sustainable development as all other methods of food production. Fostering sustainable development in aquaculture necessitates "enabling environments" [6]. Aquaculture systems are susceptible to climate-driven changes that have long-term effects on everything from agricultural systems to regions to organisms, according to a recent worldwide analysis spanning multiple countries [7]. The primary factors that impact the sustainability of aquaculture are fluctuations in precipitation over time, which can lead to extreme flood and drought conditions, the depletion of sufficient water with suitable quality, and conflicts with domestic, industrial, and agricultural users, particularly in areas where water resources are scarce [8,9]. This may eventually limit possibilities for a living, prevent professional diversification as a way to shift risk, and raise social pressures on the aquaculture industry as a whole. Nonetheless, among the marginal aquaculturists dealing with seasonal water constraint, these collisions are severe. Smaller ponds are more likely to have shorter growth seasons, lower harvests, and a more limited selection of species suitable for culture since they hold less water and dry up more quickly [10,11]. An quantity of high-quality water is necessary for aquaculture to be sustainable over the long term. However, freshwater makes up only 2.5 percent of the planet's water [12]. As a result, freshwater supplies are limited.

Due to population expansion, economic development, and shifting consumption habits, the world's water demand has increased by 600% in the last 100 years. By 2050, this demand is expected to rise by 20% to 30%, or 5,500–6,000 km3 year [13,14,15]. In many parts of the world, there is a critical imbalance between the supply and demand of water. In order to maximize food production while limiting water usage, a sustainable approach to water resource management is required [16,17]. There are various aspects to water scarcity: economic water scarcity arises from inadequate infrastructure to provide access to abundant water resources; physical water scarcity is caused by both natural and human factors, which are often interconnected and impact both humans and ecosystems; institutional water scarcity is the result of laws and institutions failing to guarantee a consistent, safe, and fair supply of water to users [18,19,20] (Fig. 2).

Given this, aquaculture's non-depletive and non-consumptive water usage makes it an efficient method of producing food using less water [21,22]. Although aquaculture poses a threat to world fish supply, it is also susceptible to climate-driven changes that alter water availability. Research conducted in a number of nations revealed that throughout the past few decades, there has been a focus on the expansion and transformation of the aquaculture industry, as well as its reliance on and conflicts around freshwater resources. According to recent reports on the drought in Thailand, flooding has occasionally devastated fish ponds, forcing 200 fish farms to close owing to a shortage of water supplies [23,24]. In the Yellow River Delta of China, groundwater extraction for fish farms is causing subsidence at rates as high as a quarter meter per year, according to Higgins et al. [25], A comprehensive body of literature clarified that disputes over freshwater access have also arisen from Chinese farms polluting fresh and coastal waters, Egyptian tilapia farmers refusing to use irrigation water, and claims that shrimp farms in Bangladesh and Thailand are causing saltwater intrusion [25,26,27].



(a)

(b)

Fig. 1. (a) Percent distribution of Earth's water (b) Percent distribution of freshwater

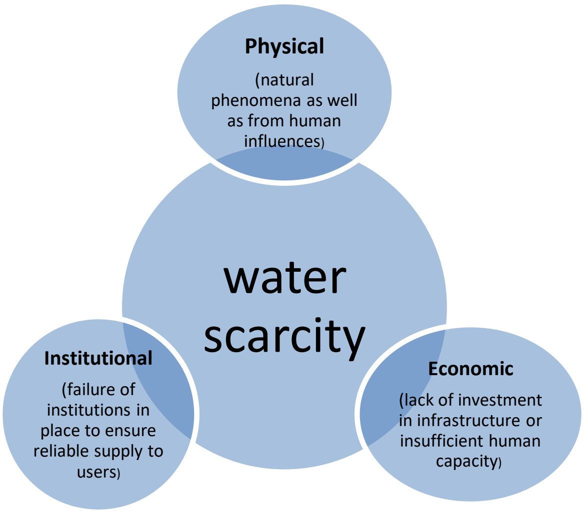


Fig. 2. Dimensions of water scarcity

There are few reliable data on water use in the aquaculture industry, and estimating it is clearly challenging [28]. Aquaculture uses water in a variety of ways depending on the species and production style. Aquaculture can utilize a lot of water—up to 45 m^3/kg of fish produced. Compared to terrestrial systems, aquaculture has a greater potential for improved water usage efficiencies [29,30]. Three distinct aquatic environments are used for aquaculture: freshwater, brackish water, and saltwater. These environments are primarily found in closed systems, such as ponds, tanks, cages, net pens, or raceways; semi-closed systems, such as canals, lakes; and open systems, such as rivers, seas [31,32]. The availability of brackish or saltwater is typically unaffected by coastal aquaculture. However, because freshwater aquaculture depends on consumptive water, it is facing the greatest difficulty. Only 3% of the planet's seas and 0.3% of its surface water are freshwater, however they accounted for 60% of the world's aquaculture production in 2008 [33,34]. Aquaculture's "blue revolution" increased the amount of surface and groundwater used. In 2010, aquaculture consumed 201 km^3 of freshwater worldwide. Fig. 3 shows how freshwater is used in various aquaculture systems and for the growth of various aquaculture species.

Groundwater depletion is more severe in arid settings, but it can also occur in humid climates, where well availability can decrease in the dry season, particularly during droughts [36,37]. Blue water and green water resources are two conceptual categories for freshwater resources. Blue water is essential to aquatic ecosystems because it sustains fisheries, aquaculture, and aquatic biodiversity [38,39]. Because blue water contains both surface and groundwater, access to it is essential for aquaculture [40]. Aquaculture on land, in the coast, and in the sea uses blue water from ponds, lakes, rivers, estuaries, and oceans. When ponds and rice fields have access to irrigated blue water from canals and streams, it plays a significant role in fish culture. Irrigated blue water can also be used for aquaculture. The term "Integrated Irrigation Aquaculture (IIA)" refers to the utilization of irrigation return water for aquaculture [41,42]. Green water is generally understood to be the portion of precipitation that seeps into the ground. Since precipitation supplies fishponds with green water, green water is crucial to aquaculture. Raising yields from rainfed aquaculture requires the use of green water. Pond water shortage due to lower groundwater levels has an impact on year-round fish culture. Due to high river discharge, poor drainage capacity, backwater effects from tidal surges from seas and oceans, and coastal flooding, aquaculture producing countries are sometimes more vulnerable to coastal flooding than inland aquaculture [43,44].

Because of changes in rainfall intensity and variability, global warming also affects the hydrology and hydrography of water bodies, which in turn affects the availability of blue and green water. Aquaculture harvest ultimately suffers as a result of this [45,46]. Because of climate change, the demand for water for aquaculture is greater in the Asian monsoon region (Bangladesh, China, India, Indonesia, Japan, Myanmar, the Philippines, Thailand, and Vietnam) [47]. Many nations are facing significant issues in their fish output because of the decrease in precipitation and rise in evaporation. One of the main environmental constraints to aquaculture is drought, and in many fish-producing nations, the frequency of seasonal droughts has recently increased as a result of climate change [48]. El Nino event combined with significant warming can jointly result in severe and protracted droughts, which shorten fish culture times [49]. Table 1 outlines the main factors that contribute to water-related vulnerability, which is a barrier to productive aquaculture.

2. MEASURING THE AMOUNT USED

The availability of freshwater is a major worry for global society in the twenty-first century, and as a result, it is becoming increasingly important globally and at risk from globalization and changes [50]. Freshwater aquaculture uses an average of 16.9 m3/kg of production, or 429 km3/yr, of water annually. This represents 1% to 4% of the global freshwater supply that is renewable, according to standard estimates. The amount of water used in aquaculture per kilogram of fish produced drops as production intensity rises. 17.5 m^3 of water are needed to create 1 kilogram of fish in an average large pond with an annual production of 2000 kg/ha and an evaporation and seepage loss of 35,000 m3 /ha [51]. When the production level doubles to 4000 kg/ha/yr, just half of this is required. Given the supply of water worldwide, growing fish production in large ponds is not sustainable [52]. However, rivalry with other water uses and water pollution from aquaculture are the main negative environmental problems associated with high freshwater aquaculture production at the national level. In this situation, it is critical to employ certain indicators for prudent water management in order to ensure the sustainability of aquaculture. Aquaculture's water use intensity and efficiency are regarded as crucial elements [53]. Water footprint is a useful indication for quantifying freshwater usage in aquaculture, both directly and indirectly. Water footprint (WF) as the total amount of freshwater consumed in the production of a product (fish, for example) across the course of the entire supply chain. Blue, green, and grey are the three aquaculture-related components of the WF [54]. Since a portion of a water withdrawal typically returns to the ground or surface water, the blue WF is frequently smaller than the water extraction. Green WF" is the amount of green water (rainwater) consumed. This is especially important for rainwater-fed aquaculture production. Despite the fact that aquaculture uses non-consumptive water [55], the water footprints associated with aquaculture include water lost from ponds through evaporation and seepage, water needed to produce fish feed [56], and water pollution, also referred to as the "grey water footprint" [57]. When achieving different objectives, such as reducing the blue water footprint, pollution, or the overall water footprint, these three color footprints have diverse ramifications [58]. In pond-based aquaculture, seepage and evaporation are the primary causes of water loss. Daily evaporation typically ranges from 2 to 10 mm, or 20 to 100 m3/ha, depending on the humidity and temperature of the season. Less than five millimeters of seepage per day occur in well-constructed ponds. The total amount lost by seepage and evaporation can be around 10 mm per day, or 3500 mm annually. Consequently, in order to replenish evaporation and seepage losses, a 1-ha pond will require 35,000m3 of water annually [59,60]. According to studies, the water footprint of aquaculture varies significantly depending on the farming systems and culture species. An additional kind of indicator is the AFR, which shows the ratio of freshwater aquaculture production to renewable freshwater (ton/km3). A study was carried out to comprehend AFR at the national level. The 137 countries that reported freshwater aquaculture production had AFR ranging from <1 to <5,000 tons/km3 in China, 11,324 tons/m3 in Israel, and 15,000 tons/km3 in Kuwait. The four classes of AFR that were observed were: low, comprising 80 countries with AFR <100 ton/km3, medium, consisting of 45 countries with AFR >100 but <1,000 ton/km3, and high, comprising 12 countries with AFR >1,000 ton/km3. The last two of them are small, water-restricted nations, whereas Egypt and Iran are two other huge, water-restricted nations in the high AFR class. Whereas Europe had the most countries with low AFR, Africa had the most with very minimal aquaculture production. Asia had the greatest number of countries with medium and high AFR. Nonetheless, the AFRs for each particular country were lower, suggesting significant room for growth within the current base of water resources [61,62]. An aquaculture facility's water use index, which links water consumption to output, may also be helpful. While both total and consumptive water usage might be used to generate this index, the consumptive water use index would have greater significance. The methods for calculating the aggregate and consumptive water usage of aquaculture operations. The water use index can be computed as follows:

> Consumptive water consumption (m2) / Production (t) equals the water use index (m3/t) [63].

The following formula can be used to calculate an index of the economic worth of water utilized in aquaculture: Production (t) x aquaculture crop value ($/t) / consumptive water consumption (m3) equals the water value index ($/m3). Since resource use efficiency is a concern for aquaculture, non-consumptive water usage should not degrade water quality or reduce its advantages to downstream water users [63,64,65].

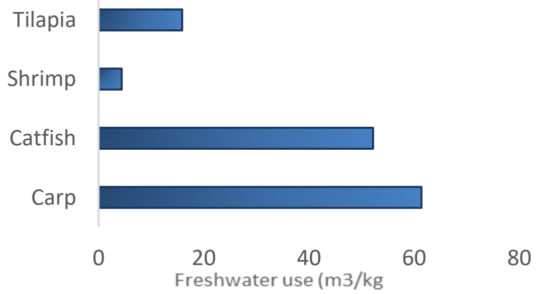
According to studies, in the next 30 years, more than 50% of the world's population would experience water shortages [66,67]. As the world population grows—it is expected to reach between 9.4 and 10.2 billion people by the year 2050—the burden on the water supply will likewise increase. Research has also indicated that by 2050, over half of the world's population (57%) will reside in regions experiencing water scarcity for at least one month out of the year [68,69,70]. The areas most affected will be those in developing nations, primarily those with vulnerable and unstable socioeconomic environments and high levels of poverty [71]. Since susceptibility is known to be a function of exposure, sensitivity, and adaptive capacity [72], conserving water can be achieved by implementing techniques for more efficient water use. Previous researchers proposed different water utilization strategies for aquaculture to understand the benefits of water conservation while reducing the cost. Conservative water use lessens effluent volumes and pollution loads from aquaculture operations [73, 74]. The water security means the capability of a water resource system to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods (UN Water, 2013). Therefore, it is critical to prioritize calls for a more ecologically sound and sustainable approach to managing the world's water abstraction. And the aquaculture managers should strive to conserve both water quantity and water quality. In the following section a comprehensive review has been done to understand present scenario of how to deal with the present water scarcity.

The projected reduction in renewable surface water and groundwater resources in most of the dry and subtropical regions leads to greater competition between aquaculture, agriculture and other sectors [75]. The understanding on the complementarity between green water and blue water is important in terms of water consumption for proper water resource assessments in aquaculture system [76,77]. However, previously while contemplating the conventional water resource estimation and management, only blue water was considered, while green water was ignored [78,79]. Though, green water may have a crucial role in arid and semi-arid areas for aquaculture [79,80]. Green and blue water are interlinked; changes in blue water also significantly changes in green water and vice versa [81]. Studies have reported that stored rainwater in ponds can conserve water and their use in aquaculture. Rainfed rice fields are often converted to fish farms due to the availability of blue water, and there is a significant contribution to rice-fish culture by irrigated blue water [82,83]. Rainfed green water agriculture is also suitable for rice-fish farming. Green water runoff from agricultural land can be used for cage culture. Utilization of rainwater in low lying rice fields can help rice-fish culture and supplement irrigation of horticulture. As terrestrial ecosystems play a crucial role in regulating hydrologic processes at global scale, it is desirable to consider terrestrial ecosystems in water resources assessments [84,85]. Hence researchers proposed various models for the proper integrated management of blue green water to simulate water resources requirement in aquaculture by combining the soil and water assessment tool (SWAT) model and a geographic information system (GIS) interface with the SUFI-2 calibration procedure or GIS-based erosion-productivity impact calculator (GEPIC) model. The dynamics of green and blue water availability in spatiotemporal scale can also be demonstrated by the water balance accounting model [86,87]. Several studies have shown the connotation between human-driven changes in land cover, land use and water use with the alteration of green water-related evaporation changes. In turn this can also distress run-off generation and therefore the consumptive use of blue water [88,89,90]. Hence, we should focus more on the interactions between the green and blue water resource instead of the traditional the resource assessments [91].

3. OASIS IN DESERT

About 41% area of the earth’s land surface and around 5.36 million km2 is arid zone. This zone is characterized by persistent water scarcity and frequent drought (rate of evaporation is greater than precipitation), high climatic variability, high wind velocity and various forms of land degradation, including desertification [92]. Large areas of these arid zones are located between latitudes of 15 and 30° in both northern and

(a)



(b)

Fig 3(a). Freshwater uses in different aquaculture system (b) Freshwater usage for different freshwater aquaculture species (Adapted from 34,35])

Table 1. Water related vulnerability as the constrain in productive aquaculture

- Global warming associated changes in the hydrology and hydrography
- Overexploitation of water resources and services
- Regional environmental limits with rainfall variability and intensity
- Competition for water with non aquaculture users
- Expanded usage of Virtual water

southern hemispheres in North and South America, North Africa, the Sahelian region, Africa South of the Equator, the Near East and the Asia and the Pacific regions [93, 94]. The availability of water for aquaculture species experience limits in these water-poor territories. In this harsh and remote areas where rainfed agriculture is usually not possible or likely to be irregular, the challenging opportunities of aquaculture can contribute a significant role in transforming the economies while contributing to social benefits to the people of this region [95]. Aquaculture development in semi arid and coastal areas is also the major difficulties for Caribbean, Mediterranean, Persian Gulf and Red sea coastal belts. Situated in the hilly and mountainous land, Israel cannot naturally hold water and suffered from a chronic water shortage for years. The kingdom of Saudi Arabia also experiences extreme weather condition with hot and arid climate with summer temperature 46ºC and average rain fall only 12 cm per year with water shortage and desertification. In addition to this, the country endures drought, and the annual rainfall was short of the multi-annual average in most of the recent years [96,97]. Most of the Australia's land is arid or semi-arid and 18 percent of Australia's continent is considered as desert. Though the groundwaters are found in abundance in these areas, but the water quality is major concern as it is with low levels of pH and varied ionic composition a lack of suitable water sources [98]. Central Asian countries are bounded in the northwest by the Aral Sea, a basin which dominates the whole region. The climate is extremely continental and arid. The average annual precipitation is about 100–200 mm in the plains; 30–50 percent of the total rainfall is in the spring, 25–40 percent in winter, 10–20 percent in autumn and 1–6 percent in summer [99,100]. In these regions, water is not exclusively available from underground sources and the future development of inland aquaculture in this region is multifactorial. To prevent the excessive use of underground water, as well as surface water resources in many countries with extensive arid regions have forced many fish farming entrepreneurs and research institutions in developing water-saving strategies. The appropriate use of subsurface waters using farming technologies can ensure the conservative use of this limited resource in these areas by developing a global partnership. A good water management practice can help to save the use of water by recycle practices while protection against strong solar radiations. The introduction of modern aquaculture technologies such as recirculation systems that usually occupy a relatively small area and are extremely efficient with water usage with fish productions (up to 50 kg/m3 of water) [101] is ecologically and economically efficient. The harvesting of run-off water, sharing water from reservoirs with agriculture, integration of aquaculture with agriculture and the exploitation of saline water sources not fit for human consumption or agriculture can also help to combat water crisis. Some of the aquaculture farm facilities of arid regions in different countries use geothermal wells to produce water ranging between 30–40°C [102,103].

Countries have taken different initiatives to alleviate this water related issues. Among them, Israel is certainly leading important innovations in the use of rain-fed irrigation water for integrated fish production systems. An estimated 19 000 tonnes of production in 2016 with about 17 000 tonnes from freshwater fish culture and 2 000 tonnes from mariculture [104]. In arid region geothermal water is passed through fish culture raceways, fish tanks are integrated to agriculture, and this form of aquaculture is expanding rapidly, many water reserves are built to collect water in the winter and are used as reserves for fish breeding [105]. The use of this technology does not necessarily require significant investments and can be used for commercial, as well as small-scale aquaculture initiatives. This secondary use of water for fish culture improves the efficiency in water usage and reduces the cost of water needed for fish culture in conventional earthen ponds [106]. In countries like middle east and north Africa, aquaculture is limited to brackish water or sea water from extensive to semi intensive and intensive. Studies have reported that various strategies can be implemented to surmount the water crisis including reservoirs to store rainwater during the wet season, fish culture in integrated farming systems and in large-scale highly-intensive recirculating systems. The desert water is free of pollutants, detrimental to parasites and hence beneficial for producing high-quality aquaculture products. With the advent of new technologies intensification using the desert water can be possible without environmental degradation [107]. This harsh, rigid, and variable environmental conditions impose the selection of species adaptable to these environmental conditions. In this aspect, species diversification remains an important issue and challenge in developing desert aquaculture. Worldwide, the most suitable fish species for water-limited aquaculture systems include the tilapias (Oreochromis spp.), red tilapia (Oreochromis mossambicus x Oreochromis niloticus), barramundi or the Asian seabass (Lates calcarifer), carps and mullets (Mugil cephalus and Liza ramada) and several catfishes species (Clarias gariepinus and Bagrus spp.), common carp (Cyprinus carpio), silver carp (Hypophthalmichthys molitrix), grass carp (Ctenopharyngodon idellus), flathead grey mullet (Mugil cephalus), European seabass (Dicentrarchus labrax), gilthead seabream (Sparus aurata) and a number of exotic species, mainly koi (Cyprinus spp.), fantail (koi variety) and molly (Poecillia spp.), Indian white prawn (Penaeus indicus). Several fish species are cultured in saline groundwater with high commercial potential include Japanese meagre (mulloway, Argyrosomus japonicus) and rainbow trout (Oncorynchus mykiss).

Aquaculture production in Egypt is the largest in Africa. Globally, Egypt ranks 7th in fish farming production with a total production quantities around 1.8 million tons with a market value of over $2.18 billion [108]. However, it is not always possible to extrapolate what amount of any given species is produced in areas considered deserts and arid land [109]. Approximately 100 commercial aquaculture desert farms have been set up in arid regions of Egypt. Around 90 percent desert-based aquaculture production in Egypt are based on Nile tilapia (Oreochromis niloticus) and eight other fish species. European seabass (Dicentrarchus labrax) and gilthead seabream (Sparus aurata) offer additional potential in higher salinity areas [110]. Though culture of marine species requires the use of advanced technology and technical skills which are not always available [111,112]. Water for desert farms comes from underground saline water reserves, desalination plants and/or agricultural drainage. But the success of farming fish in such arid territories is decisively be determined by the price that such fish can fetch from the market be it local or export. Therefore, the overall production costs which includes transportation expenses of farm inputs to the farm site itself and the transportation of fish to a receptive market will play an important role in determining the commercial feasibility of any such farm [113]. Still the farmed fish represents an additional crop and income for the small-scale farmers, as well as ensuring some fish supply in communities distant from the coast [114].

4. INTEGRATIVE APPROACH

The scarcity of availability and access to water has led to the development of innovative, integrated aquaculture-agriculture systems that make the best and most complete use of precious water resources. Studies reported that integrating different systems to produce multiple products with the same water increases efficiency. By integrated aquaculture we can incorporate farming based on diversification of agriculture towards linkages among subsystems. Integration as a key element of the ‘ecosystem approach to aquaculture (EAA)’ which ‘is a strategy for the integration of the activity within the wider ecosystem in such a way that it promotes sustainable development, equity, and resilience of interlinked social and ecological systems’ [115]. In this synergistic application, an output from one sub-system which may otherwise have been wasted becomes an input to another sub-system resulting in a greater efficiency of output based on the reliance on on-farm resources for recycling activities [116,117]. From human livelihoods perspective and with an expansion towards periurban areas or in arid or semi-arid areas, with increased linkages between different farms and specialised agro industries, integrated farming involving aquaculture acts as a concurrent or sequential linkage between systems (one or more of which is aquaculture), directly on-site, or indirectly through off-site needs and opportunities, or both [118] (Fig 4).

It is especially water-efficient to integrate irrigation systems with intense production units like cages or raceways. Considering integration from a broader angle, it has been seen as a component of Integrated Resources Management, with implications for landscape and/or watershed level management [119,120,121].

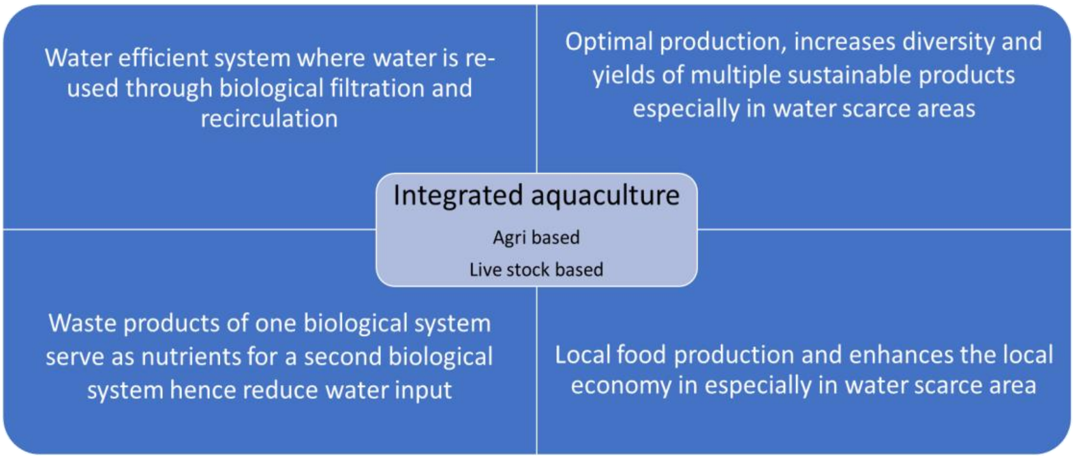


Fig. 4. Importance of Integrated aquaculture

5. MULTI-TROPHIC INTEGRATED AQUACULTURE (IMTA)

IMTA systems are culture systems that employ organisms from several trophic groups to establish a mutually beneficial interaction inside the same body of water or through other water-based connections, hence serving as a bioremediation tool. For dissolved and particulate wastes released by one species that serve as food for other species at a lower trophic level, water is the nutrient transport vector under this application. By decreasing water use and waste generation, increasing product diversity, and enhancing societal acceptance, IMTA can hence promote the sustainability of the aquaculture business. In nations where coastal aquaculture is susceptible to significant environmental fluctuations such as floods and droughts, sea level rise, and variations in rainfall that impact water temperature and salinity, as well as freshwater scarcity, a well-crafted IMTA can concentrate on the appropriate distribution of water resources. IMTA can be used in a variety of water situations, including closed and open water, brackish water, and freshwater. One benefit of using open-water IMTA is that it helps prevent disease outbreaks and parasite infestations by maintaining water quality [122,123,124]. At now, IMTA is utilized on a commercial basis or very close to it in China, Chile, Canada, Ireland, South Africa, Bangladesh, UK, and many more nations. However, there are a number of difficulties this system faces, especially when choosing which species to integrate and navigating current laws. However, it also has enough economic worth to draw funding [125].

Conventional freshwater aquaculture is sometimes viewed as a fringe industry that competes with agriculture for finite water resources, particularly in regions where water is scarce [126]. Aquaponics, a near-zero discharge system that gives economic benefits from both plant and fish production, has become a reality with the development of flexible and affordable technology. It also considerably minimizes the toxic environmental discharges from aquaculture sites. Aquaponic systems mix hydroponic plant cultivation with aquaculture within a recycled water system. A restricted variety of warm-water fish species, such as Asian seabass, catfish, and carp, including ornamental koi carp varieties, can be raised in aquaponics. These species include tilapia (Oreochromis spp.), which is hardy, easily accessible, grows quickly under ideal conditions, and is well-known to consumers [127, 128].

6. THE BENEFIT OF REUSE

Reusing and recycling waste water is crucial for aquaculture in order to address the scarcity of water resources, particularly in nations where it is illegal to use freshwater or drainage water. Examining the potential effects on public health is necessary, nevertheless, given the widespread use of treated waste water for waste processing and fish farming [129]. More than half of the world's rivers, lakes, and coastal waters are heavily contaminated with untreated domestic, industrial, and agricultural wastewater. This results in high levels of faecal bacteria [130] and an unprecedented burden of excreta-related disease on the world's poorest populations [131]. Nonetheless, the annual production of wastewater includes fish-nutrient-rich materials. For aquaculture, treated wastewater is thus a dependable water source, particularly in arid regions and those vulnerable to an increase in droughts brought on by climate change [132,133]. Therefore, in recent times, it has become extremely important to discover sustainable wastewater reuse solutions in communities that are facing water constraint. Aquaculture takes place in ponds, reservoirs, and lakes in urban and periurban settings (like Lake Taihu, China), and many of these enterprises are already using "non-traditional" (i.e., raw sewage or treated sewage effluent) waters, whether they realize it or not. The extent to which intentional or unintentional water reuse practices are now being used for aquaculture worldwide is unknown, although it is expected that these activities will become more prevalent in water-stressed areas, where 66% of the world's population will reside by 2025 [134]. When an 80% dependability requirement is used as the primary approach to evaluate the reuse of treated wastewater in aquaculture, studies have demonstrated that affordable, full-scale wastewater treatment plants can deliver a satisfactory effluent for wastewater reuse in aquaculture [135] Recirculating aquaculture systems (RAS) have garnered increasing attention due to its ability to significantly lower the water requirements for fish rearing at aquaculture locations. Following mechanical and biological purification, water in RAS is recycled in order to lower energy and water consumption as well as emissions to the environment [136,137]. Offshore cage technology and recirculated aquaculture systems (RAS) have been increasingly important in recent years due to their ability to minimize impacts on delicate freshwater or coastal habitats and reduce pressure on water resources [138]. RASs can be found in places where conventional forms of food production are not feasible due to low water consumption, such as deserts, postmining land, and urban areas [139]. In addition to being expanded to a wide range of species, from freshwater to seafood items and from hatchery/fingerling to grow-out production, RASs enable the treatment and recycling of both fresh and marine water to minimize water use [140]. When it comes to generated seafood, freshwater RASs can utilize as low as 50 liters per kilogram (including water used in feeds). In marine RASs that use artificial saltwater, the amount of water used per kilogram of fish can be as low as 16 liters. Water intensity in typical aquaculture systems varies between 3,000 and 45,000 liters per kilogram of fish. Nearly no freshwater input is needed for coastal marine RASs that rely on saltwater intake. While continuous advancements in RASs demonstrate two tendencies that center on (1) technical enhancements in the recirculation loop and (2) nutrient recycling via integrated farming, including the use of built wetlands (CWs) (Martins et al., 2010). One of the main concerns in other conventional aquaculture systems, such as flow-through and open-net pen aquaculture, is the potential for disease transmission between farmed stocks and wild populations. It has been well documented that the use of RAS in aquaponic systems also prevents this from happening [141,142]. On the other hand, sites with the dual difficulties of expensive land and scarce water also needed more intensive aquaculture systems, such as those using Biofloc techniques, which improved environmental control over production for more economical output [143]. This system works by recycling waste nutrients and exchanging very little water. In particular, nitrogen is converted into microbial biomass, which is then directly utilized by filter-feeding species like tilapia, carp, catfish, marine shrimp, and freshwater prawns. Aquaponics and biofortification technologies have the potential to significantly lower water treatment costs and increase fish output in water-scarce places [144,145].

By removing resources and energy from native or non-native ecosystems, humans modify the processes of natural ecosystems to create the species that are in demand through aquaculture. Because aquaculture expansion is physically limited, sometimes only to meet the heightened demand, these complex ecological relationships are broken [146]. Understanding the connection of ecosystems and industries is therefore essential for sustainable aquaculture. Regardless of whether overexploitation results from competition for resources with non-aquaculture users or is self-inflicted, aquaculture becomes unsustainable when environmental resources and services are overexploited [147]. In order to lessen vulnerability and increase resilience in the face of the water crisis, a comprehensive, multi-sectoral approach should be implemented, as the success of aquaculture depends on having access to enough water of appropriate quality [148]. (Fig 5).

This has to include coordination of preventive and mitigating measures, monitoring of the environment and spatial planning, better farm management, and the selection of farmed species [149]. It is possible to conduct vulnerability assessments that take social and biophysical factors into account. One way to measure water scarcity is quantitatively, using top-down methods such as modeling, or through stakeholder-based, bottom-up processes [150,151]. Given that both biophysical and social factors may be important in determining vulnerability, spatiotemporal hydrologic knowledge is required to understand the hydrologic variability in the availability of water resources, the type of water provision system, and sociodemographic characteristics for understanding the degree to which specific people and places are at risk to water scarcity [152,153,154]. Global research has shown, using a variety of analytical frameworks, that the likelihood of vulnerability tends to be higher in the case of least-developed nations, where the ability to adapt may be most constrained in the event of water scarcity [155]. Resolving the water Ponds must become more intensive with respect to water use" because traditional low-input pond aquaculture uses water inefficiently. Integrating aquaculture with man-made and natural water bodies, where fish culture, recreation, and nature reserves can all be done simultaneously, may result in more productive or efficient use of water [156,157]. It is possible to promote the optimal use of water in small water bodies by community or culture-based fisheries (CBF), which is still seen as a "underutilized opportunity in aquaculture development" [158]. Agricultural water storage reservoirs in arid places can serve a second purpose by being stocked with fish [159]. According to the studies, this strategy has produced fishery products in more than 27 nations, with an estimated 2 million tonnes of production [160]. There are 67 million hectares of tiny water bodies in Asia that are suitable for aquaculture. Even though CBF promises to provide greater yield more quickly, there are typically intricate institutional, social, and technical problems with biodiversity, water body access, social equity agreements, and water usage competition [161]. Cage aquaculture can be promoted in lakes, rivers, irrigation canals, and underutilized reservoirs in water-scarce places. However, due to purported freshwater limitations, aquaculture's future is believed to lie in the open ocean in order to boost worldwide production. In order to accommodate small-scale fish farmers in underdeveloped nations, efforts have been made to create low-volume, high-density aquapods and small-scale underwater cages that can accommodate significantly higher fish densities while utilizing little water. This invention can raise profit per unit volume of cage in addition to improving fish growth [162,163]. However, other nations, such as Egypt, have outlawed cage aquaculture in irrigation canals due to worries that it would decrease water flow and increase sedimentation [164,165]. Concerns regarding the availability of water to support future expansions in aquaculture were voiced by researchers. Renewable freshwater "appears adequate for considerable expansion of aquaculture, especially outside Asia," according to a recent study that suggests aquaculture would be a more efficient use of water, particularly in low-yielding rice fields [166]. Furthermore, in regions where water shortage is getting worse, aquaculture may present prospects for increasing water production. A crucial tactic for attaining food security, higher income, livelihoods, and water sustainability while halting environmental deterioration is raising water productivity [167,168]. Applying the fundamentals of ecological engineering to the current behavior of the aquaculture industry, where development and environment coexist harmoniously, is the true problem facing the sector today [169,170]. Research has shown that a crop system requires less resources and has fewer projected environmental effects the more it replicates and recognizes natural ecosystems [171]. In Malawi, pond aquaculture combined with conventional crops has successfully increased total productivity and profit while lowering farmers' susceptibility to drought. Reusing aquaculture water is a more advantageous system than producing crops and livestock on land [172,173]. However, due to drawdowns, varying water levels in reservoirs used for irrigation and hydropower production might have a negative impact on aquaculture [174]. Lands must be next to dependable water sources, such as lakes, rivers, or artesian wells, for aquaculture to be successful. However, these sites are also highly sought after for other uses, such as urbanization, agriculture, the preservation of wetland areas (including mangroves), recreation, and tourism; as a result, there are occasionally legal and popular opposition. There are periodically issues with local water accessibility as a result of this. Due to ecological sensitivity, expanding pond areas for aquaculture in coastal locations is prohibited. For example, the Indian Supreme Court ordered in 1996 to forbid the development of ponds within 500 meters of the high tide line in India, a country with a significant population density along the coast. establishment of vast pond aquaculture on a large scale [175].

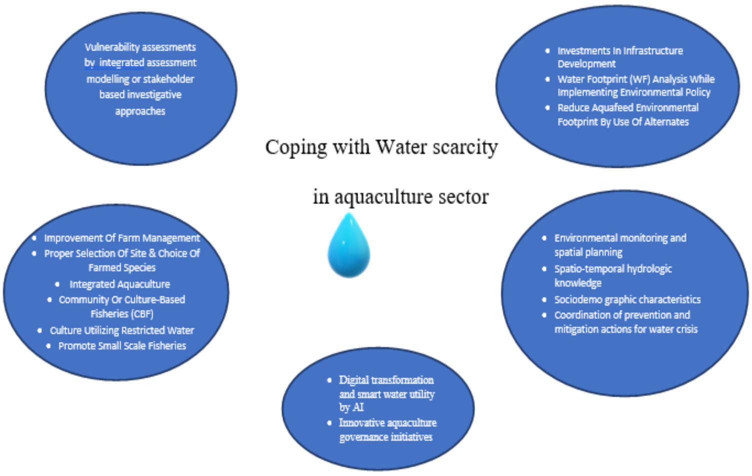


Fig. 5. Probable recommendation to prevail over the water crisis in aquaculture sector

When ponds are emptied, their water can be recycled by moving it to nearby ponds or storing it in a reservoir. Ponds can be built in sequence so that overflow from upper ponds passes into lower ponds in places with gently undulating topography [176]. Encouragement of water reuse is also necessary to improve water use efficiency. Future populations might benefit from increased infrastructure development investments in areas where an unequal distribution of precipitation over time is anticipated, such as dams and water delivery pipe networks [177]. We may significantly minimize the amount of water used by recycling and creating various feedbacks between the cultivated species and the ecosystem, as well as by culturing commercial species with poor oxygen tolerance and their prey within a mutual food web.

When assessing its environmental strategy for national food security, the national government should consider the water footprint (WF) in order to determine the contribution of aquaculture. However, the traditional national water use accounts ignore the sustainability of national consumption in favor of addressing issues at the local, national, and river basin levels with the goal of balancing national water supply and demands [178]. Understanding the worldwide scope of freshwater resources is thought to be essential to resolving the urgent water issue facing aquaculture. The environmental impact of feeding farm fish with economically viable, nutritionally adequate feed may be reduced in the current era due to the growing significance of alternative aquafeed [179]. However, because farming crops for aquafeed uses a lot of water and pollutes the environment, aquafeed based on land might put a major strain on freshwater resources. According to a recent study, replacing all 20–30% of the fishmeal with fishmeal might result in a 63% increase in freshwater demand, placing further strain on vital agricultural resources and having related socioeconomic and environmental implications. Another study examined the 2008 commercial feed production's projected 1629 m3/t, 179 m3/t, and 166 m3/t green, blue, and gray water footprints of cultured fish and crustaceans. The total water footprint of commercial aquafeed worldwide was between 31 and 35 km3 [180]. With a combined water footprint of 18.2 km3, Nile tilapia, Grass carp, Common carp, and Whiteleg shrimp are the top five contributors to the overall water footprint of commercial feed. However, it is also understood that the economic consumptive water productivity may be decreased by cultivating carnivorous species and promoting alternative aquafeed, such as insect meal [181,182]. The terms "virtual water" and "water footprint" are interchangeable. The amount of blue and green water needed to generate aquaculture goods that are traded to an importing or exporting country (or any region, corporation, individual, etc.) is known as virtual water in aquaculture. A significant amount of water is used in imports and exports, and the nations that are experiencing water scarcity could resolve this problem [183,184]. Thus, focus should be placed on promoting small-scale aquaculture and integrating aquaculture into the local community. Water management systems have drawn a lot of attention as viable solutions to the water dilemma. With the advent of artificial intelligence (AI) technology at the start of the twenty-first century, they were able to solve many of the societal problems of the day [185, 186, 187], particularly those involving water scarcity. The process of transforming a water utility into a "smart" one involves more than just integrating data technically. These methods, which primarily rely on developments in machine learning (ML), such as deep learning and evolutionary computation techniques, are dominated by statistical learning [189, 190, 191]. We can now create and implement appropriate hydraulic model creation and application thanks to the development of forecasting, perspective, and explanation tools. However, effective aquaculture requires collaboration between aquaculturists, water professionals, and data scientists, as well as the addition of knowledge from the social sciences and humanities[192, 193, 194]. Data scientists should not be the only ones using AI techniques for the water sector [195-196]. However, aquaculture is frequently subject to numerous regulations in highly developed nations, which hinders the sector's growth, while minimal, less stringent, or nonexistent laws exist in the majority of low- and middle-income nations. Public policies are generally intended to address concerns regarding absolute scarcity; nevertheless, localized patterns of relative scarcity are typically used to explain the effects of overdraft [197-201]. Therefore, the technology advancement combined with the novel and promising aquaculture governance initiatives can address the water issue while preserving the sustainability of aquaculture[202-203]

7. CONCLUSIONS AND RECOMMENDATIONS

Groundwater is a precious resource, which is highly essential for human health, social, agricultural development and preservation of our natural ecosystems along with flora and fauna. People in most of the areas are solely depends upon groundwater for their various use including drinking water [204-206]. Now the degradation of the quality of groundwater is a worldwide issue and multiple factors are recognised for contamination of groundwater, which includes both anthropogenic and natural factors. The unusual extensive human activity such as massive industrialization, use of synthetic fertilizers in modern agriculture, mining activities, improper treatment, management and disposal of wastewater from urban and industrial areas are the major cause of contamination of groundwater. The intrusion of seawater is now a problem recognised in most of the coastal regions throughout the globe, which leads to the raise in salinity and other pollutants in the groundwater resources of coastal region and make the water unfit for drinking. The radioactivity of the uranium series is the cause of increase in radon contamination with potential amounts of radon both in groundwater and soil. The groundwater contamination is owing to a huge variety of organic, inorganic toxic substances and synthetic industrial chemical pollutants [207-209]. There are some specific toxic pollutants such as nitrate, nitrite, sulphates and heavy metals in groundwater are the cause of potential risk to human health. Hence, to preserve the groundwater resources from contamination, depletion and maintaining the sustainability is now a great challenge to the scientist, researchers and govt. of various countries throughout the globe. It is a great threat for long term survival of not only human civilization, but also all flora and fauna throughout the globe [210-211].

Over the past few decades, the world's water demand has increased at a pace of roughly 1% annually due to factors like population expansion, urbanization, industrialization, rising living standards and shifting purchase habits, and it will keep expanding dramatically in the near future. Water shortage affects agriculture both as a victim and a cause, thus maintaining optimal agricultural water productivity—or output per unit of water used—becomes crucial to guaranteeing sustainable expansion. In many nations, aquaculture—one of the largest and fastest-growing sectors of the global food production industry—is already up against competition for water and aquatic habitat. Therefore, more sophisticated and intelligent aquaculture techniques are required in the future in order to support high culture efficiency in terms of space utilization, water resources, and food production, as well as the sustainability of the culture. Therefore, in order to properly manage aquaculture growth and better optimize aquaculture production, a move from "experience-driven to knowledge-driven approaches" is necessary to help ensure a sustainable food future.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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