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UTILIZATION OF UNCONVENTIONAL WATER RESOURCES (UWRS) FOR AQUACULTURE DEVELOPMENT IN ARID AND SEMI-ARID REGIONS – A REVIEW

Mojtaba Soleimani-Sardo[1♦], Mohammad Hossein Khanjani[2♦]

[1]Department of Environmental Sciences and Engineering, Faculty of Natural Resources, University of Jiroft, Jiroft, Kerman, Iran
[2]Department of Fisheries Sciences and Engineering, Faculty of Natural Resources, University of Jiroft, Jiroft, Kerman, Iran
♦Corresponding authors: mojtaba.soleimani@ujiroft.ac.ir; m.h.khanjani@ujiroft.ac.ir, m.h.khanjani@gmail.com
Mojtaba Soleimani-Sardo: https://orcid.org/0000-0003-2652-7938
Mohammad Hossein Khanjani: https://orcid.org/0000- 0002-3891-8082

Abstract

Today, the increase of the world's population and climate change has resulted in the reduction of fresh water resources and the increase of arid and semi-arid areas, and thus, it is necessary to find a new solution to increase the production of food resources. Aquaculture is one of the sources of food production, which can play a key role in fighting poverty and hunger. Sustainable aquaculture is strongly dependent on water quantity and quality, and also, optimal fish production can be determined by the physical, chemical and biological quality of water. Due to the current restrictions and the global increase in demand for aquatic products, unconventional waters (UWs) have been used in aquaculture. UWs include: recycled water, sewage, saline water, agricultural drains and water resulting from the process of sweetening and desalination of salty water. Today, these water resources have been used to grow all kinds of aquatic animals to provide food and protein. Considering the limited water resources in the world, the use of UWs is very effective and efficient in managing drought, and is considered as one of the ways to develop food production for humans. Due to its importance in areas facing water scarcity, the use of unconventional water resources (UWRs) to supplement or replace the use of conventional fresh water sources has been considered. In this review study, the importance of UWs and their sources, aquaculture products and aquatics that can be cultivated with the help of UWs are discussed.

Key words: aquaculture, unconventional waters, arid and semi-arid regions

Water supply shortages have arisen as a result of climate change, global population growth, and urbanization (Murthy et al., 2016). Water stress affects 40% of the world's population. More than half of the world's population will live in countries where more than 40% of renewable resources are withdrawn for human use by 2025, an indication of high-water stress. As a result, many parts of the world are experiencing a fresh water crisis now, while others will face it in the near future (Smith et al., 2008; Odendaal, 2009). Due to climate change, low rainfall and reduction of fresh water resources, the production of livestock and aquatic products is limited, especially in arid and semi-arid regions (Fedoroff et al., 2010; Hussain et al., 2019). A scarcity of water has been identified as one of the main causes of conflict, unrest, and migration, while water is increasingly recognized as a means of achieving sustainable development through international cooperation. As the pressure is increased on limited water resources, it is important to assess all options in areas facing water scarcity. Growing freshwater demand in water-scarce regions cannot be met by conventional water supply methods that rely on snowfall, rainfall, and river runoff. Water-scarce countries have access to an increasing number of viable yet unconventional water resources (UWRs) that can support food production, livelihoods, ecosystems, climate change adaptation, and sustainable development (Qadir et al., 2022). By recycling wastewater for uses that do not require drinking water quality, countries and regions with limited freshwater resources can substitute limited freshwater resources with reclaimed water. Water availability from urban wastewater, which is usually constant throughout the year, is more reliable than freshwater, which is subject to seasonal variations and extreme events. Due to the increased likelihood of these patterns occurring as a result of climate change, interest has grown in the reuse of water in arid regions (Helmecke et al., 2020). In order to manage water scarcity, UWRs can be used as an alternative method. Water resource limitations are increasingly being addressed by utilizing UWRs, which are especially useful in arid and semi-arid regions (Gosling and Arnell, 2016; Yazdandoost et al., 2021). UWRs for irrigation are produced by specialized processes, require appropriate pre-use treatment, or are generated by special technology (Qadir et al., 2022).

UWRs refer to those types of water that cannot be used normally, in general, unconventional waters (UWs) include salt water, brackish water, fossil water, agricul-

tural drains and sewage (urban, industrial, agricultural, and aquaculture), the waters resulting from the fertility of clouds and the formation of fog and dew and the waters resulting from the process of sweetening and desalination of salty waters (Karimidastenaei et al., 2022).

In this study, there is a strong emphasis on the importance of UWs (saline waters, recycled water, and purified effluents and waters from the desalination process of brackish waters), as well as cultivable aquatics in UWs (finfish, shellfish, macroalgae) and live foods (artemia, copepods, microalgae).

Unconventional waters (UWs)

Population density and water resources are unevenly distributed around the world. Water-scarce countries and communities in arid and semi-arid climates should consider UWs as an alternative to narrow the gap between water demand and supply. The use of these waters requires a basic treatment and purification (Hussain et al., 2019; Karimidastenaei et al., 2022; Castine et al., 2013).

There are several types of UWRs, including saline water, brackish water, agricultural drainage water, water containing toxic substances, and treated or untreated wastewater effluents. As a matter of fact, these resource can be considered to be of marginal quality or even of inferior quality. In addition to desalinated water, water obtained by fog capturing, weather modification, and rainwater harvesting is also included under the definition of UWs (Hussain et al., 2019; Karimidastenaei et al., 2022). UWRs definitions have changed significantly over the years, both generally and individually. According to Brewster and Buros (1985), UWRs generally do not produce new water but merely treat and use previously unusable or inaccessible water sources, such as saline water and wastewater. According to Indelicato et al. (1993), UWRs are water resources with specific characteristics, such as high organic matter and microorganism content. UWRs were expanded early in the 2000s with the addition of rainwater harvesting (Jaber and Mohsen, 2001). According to Buchholz (2008), UWRs include saline water, brackish water, agricultural drainage water, wastewater, and water obtained by fog capturing, weather modification, and rainwater harvesting. The UWR concept has been applied to any water source other than freshwater that can be used as a complementary water source with the use of new technologies (Ahmed, 2014; Negm et al., 2018; Ji et al., 2020). The use of UWs is very effective and efficient in drought management due to the limited water resources, and their use is considered one of the ways to develop the aquaculture sector (Hussain et al., 2019). In order to use them, it is necessary to apply management, environmental policies and their physical, chemical and biological treatment. If practical and expert solutions and strategies are presented, by using UWRs, which are currently unusable, it is possible to increase the number of aquatic products and create new job opportunities (Hussain et al., 2019; Karimidastenaei et al., 2022). These solutions can have widespread positive economic-social repercussions in the world, especially in rural areas.

Saline waters

Marine aquaculture for the production of fishery products and seaweed has been growing rapidly in the recent years to meet human food needs. The use of saline waters in aquaculture is important and has a long history (Khanjani and Hajerezaee, 2020). Many coastal communities in developing countries rely on coastal aquaculture for livelihoods, employment, and economic development. Coastal ponds and gated lagoons, which are adjacent to the sea, are used as UWRs for this practice. Due to rainfall or evaporation, coastal aquaculture with saline water is less stable than mariculture. Modern and traditional coastal aquaculture ponds are found worldwide, but they are mostly concentrated in Southeast Asia and Latin America for raising crustaceans, finfish, mollusks, and seaweeds (FAO, 2020). The use of salt-tolerant plants such as Salicornia and fish for saline waters management has been proposed as an effective method to add economic value (Crespi and Lovatelli, 2010; Sánchez et al., 2015; Giwa et al., 2017; Jones et al., 2019).

In the southern part of Iran, the Persian Gulf and the Oman Sea, there are huge sources of salt water, where all kinds of marine aquatic species, including shrimps, Asian sea bass, sea bream, grouper, sobaity, snapper, cobia, white pomfret, croaker can be grown on the shore lagoons and sea cages. In the northern part of Iran, the Caspian Sea is a source of brackish water, which raised various species of fish including sturgeon, Caspian trout, trout and Caspian kutum in cages and beaches. It is possible to reduce its environmental effects with proper management and use of environmentally friendly technologies and achieve sustainable production along with job creation.

In Iran, there are the Caspian Sea in the north, the Persian Gulf and the Oman Sea in the south, Lake Urmia and many other saline rivers and lakes, which is very favorable in terms of economic exploitation of saltwater environments for aquaculture. The coasts of Iran have valuable resources of algal species with economic value, which also have many practical aspects (Rabiei et al., 2014; Salehi et al., 2011).

In addition to coastal saline waters, inland saline waters can also be used for aquaculture. Aquaculture with saline water in the interior regions is significant in several ways. First and foremost, there is a good consumer market for its products, especially fish and shrimp, at the world level. Therefore, there is no need to spend a lot of money and time for marketing, and in this activity, resources are needed that are not used for common agricultural purposes due to high salinity. Therefore, it will not be a competitor for agriculture in the use of high-quality land and water resources with suitable quality. Utilization of saline water resources for the aquaculture increases the economic productivity of water resources and provides the opportunity to create employment or diversify income for farmers and producers (Khanjani and Hajerezaee, 2020). The use of saline water can be consid-

ered in the development of aquaculture and employment in dry and saline areas.

There is a great deal of diversity involved in mariculture, which is also true for integrated farming. Four main categories can be distinguished among existing integrated mariculture systems: a) polyculture (co-culture of multiple species in a pond/tank/cage, also includes enclosure of different species), b) sequential integration (partitioned aquaculture systems, PAS) on land and in open waters (differs from polyculture by the need to direct a flow of wastes sequentially between culture units with different species), c) temporal integration (the replacement of species within the same holding site while taking advantage of the waste generated by previous cultures), d) the integration of mangroves (aquasilviculture, sequential practices – using mangroves as biofilters) (Troell, 2009). The tests have evaluated a wide range of possible combinations of species and systems, such as shrimp (*Penaeus monodon*), milkfish (*Chanos chanos*), tilapia (*Oreochromis niloticus*), and red seaweed (*Gracilaria* spp.). Some groups of aquatic animals that can be cultivated in coastal areas using salt water are presented in Table 1.

Recycled water (recirculation of water in fish farming systems)

There are a number of factors that affects the quality and load of pollutants discharged from fish farms including the quality of water they receive, the species of fish they culture, the technology they use in fish farming, the amount and quality of feed they receive, and the meteorological and physiographic conditions (Sikoki et al., 2012). When surface waters are used for fish production, this can negatively affect the quality and quantity of the water ecosystems that receive the discharge. Also, a fish pond's waste production is dependent on different factors such as the composition of the feed mixture, the type of fish, and the temperature. As a result, fecal wastes range in weight from 0.2 to 0.5 kg per kilogram of feed mixture (Sidoruk and Cymes, 2018). Regardless of the aquaculture system type, a portion of these wastes must be discharged as post-production waters to the environment. The density and quality of the wastes vary from system to system. In open systems like a flow-through system, solid and dissolved contaminants release into the receiving waters. Considering the lower water consumption in fish farms that use recirculation aquaculture system or RAS (both partially and fully RAS) as opposed to those that use standard flow-through systems, it is assumed that effluent generated by recirculation systems will be lower than that produced by standard flow-through systems (Blancheton, 2000; Sidoruk and Cymes, 2018).

RAS aims to minimize water consumption, waste disposal, and nutrient release, therefore, it can be an important component of sustainable aquaculture (Martins et al., 2010). Aquaculture recirculation systems reduce water consumption and release of nutrients into the environment by partially repurposing facility after mechanical and biological treatment (Zhang et al., 2011). As concerns increase about nutrient loading in receiving waters, RASs were developed as a solution to address both economic and environmental sustainability concerns (Martins et al., 2010). Furthermore, these systems can also be used in areas where there are water and land use restrictions (Martins et al., 2010). Additionally, RAS is useful in controlling the facility's hygiene and disease management (Summerfelt et al., 2004; Tal et al., 2009) as well as controlling biological pollution (Zohar et al., 2005). In addition, a wide range of seafood products can be produced within a short distance from their markets, thus reducing greenhouse gas emissions from transportation (Schreier et al., 2010; Martins et al., 2010).

Treated wastewater

Using treated wastewater for fish farming is a method of farming with a long history in a large number of Asian countries and some other countries. Compared to other methods of biological wastewater treatment (WWT) which are mainly based on degradation processes, wastewater-fed aquaculture is a productive WWT method. The wastewater is reused rather than disposed of. In spite of the fact that a wastewater-fed aquaculture is an ancient form of WWT and recycling, it is still an innovative and successful method. Nutrient-rich wastewater is discharged into a constructed aquatic ecosystem containing one or more water bodies with a food web. Assimilation of dissolved nutrients into biomass is the system's primary goal. The wastewater is simultaneously purified by either consuming organic compounds or mineralizing them (Jana, 1998; Edwards, 2000; Hu et al., 2017).

Table 1. Aquaculture groups cultivated in the tropical coastal zone (Troell, 2009)

Cultivable groups	Rearing system	Method
Plants		
Eucheuma, Kappaphycus, Gracilaria, Gelidium, Caulerpa	Stakes, rafts, longlines, beds	Extensive
Molluscs		
Oyster, Mussel, Cockel, Sea cucumber	Rafts, longlines, stakes, beds, tanks, ponds	Extensive, semi-intensive
Crustaceans		
Shrimps, Lobsters, Crabs	Ponds, pens, cages	Extensive, semi-intensive, intensive
Marine/Brackishwater fish		
Milkfish, Grouper, Snapper, Tilapia	Ponds, pens, cages	Extensive, semi-intensive, intensive
Seabass, Seabream, Cobia, Mullets, Drums, Amberjack, Croaker, Pompano, Siganids, Barramundi		

In culture ponds with effluents, due to the increase in the amount of photosynthesis during the day, the amount of oxygen and pH increases, but these values decrease at night (Pillay, 1992). In laboratory studies, it has been determined that fecal streptococcus and other organisms associated with human diseases (*Salmonellae, Escherichia, Klebsiella, Pseudomonas, Aeromonas*) are only found in the intestinal contents of Atlantic salmon and trout farmed in ponds fertilized with purified effluent and nothing was observed in other cattle and muscle tissues (Pillay, 1992). Refining fish cultured in sewage by keeping them in clean water for a few days before putting them on the market and not consuming fish cultured in sewage, raw or unprocessed, is a prudent and obvious measure to prevent disease transmission from fish to human. Many species of aquatic animals have been cultivated in sewage effluents and lagoons after treatment. They include common carp (*Cyprinus carpio*), Indian carp (*Catla catla, Cirrhina mrigala, Labeo rohita*), Chinese carp: grass carp (*Ctenopharyngodon idella*), silver carp (*Hypophthalmichthys molitrix*), big head *(Aristichthys nobilis*), tilapia (*Oreochromis* spp.), milkfish (*C. chanos*), cat fish (*Pangasius* spp.), kissing gouramy (*Helostoma temmincki*), and freshwater prawn (*Macrobrachium lanchesterii*) (FAO, 2014). Chinese and Indian carp are common species bred in sewage in China and India. In these countries, due to the increase in population and the need for food resources, UWs are optimally used. In China, these species are cultivated as polyculture in sewage. Tilapia fish species is less cultivated in wastewater than carp, but this species has a high ability to tolerate variable environmental conditions compared to carp. Milkfish are grown in marine effluents and estuaries in India and China (FAO, 2014). Species that tolerate certain conditions are suitable for cultivation in UWs, including tolerance to variable environmental conditions (dissolved oxygen, nitrogen compounds, and suspended solids) and filter feeding habits that can use phytoplankton and feed zooplankton in the wastewater.

UWs are rich in nutrients in which all kinds of small plant and animal organisms are able to grow and reproduce, which provides living biomass as live food available for aquatic life. High and stable production of fishery products in UWs has been reported.

For example, 2–6 tons of product per hectare in Indonesia, 2.7 to 9.3 tons of product per hectare in China, 5.3 to 7.8 tons of product in Taiwan have been reported (FAO, 2014). Aquatic plants are also able to grow well in unconventional sewage waters. In China and India, some aquatic macrophytes are grown in UWs as human food including water spinach (*Ipomoea aquatica*), Chinese water chestnut (*Eleocharis dulcis*), aquatic plants, mosses and water lentils, *Lemna, Spirodela* and *Wolffia* are also grown in unusual waters and are used as food for carp fish, chickens, duck and edible snails (Edwards, 1990). While wastewater-fed aquaculture is primarily used to generate animal protein (fish), plants play an important role as well. Chinese researchers have used microalgal bioreactors (Gao et al., 2016), ecological ditches (Liu et al., 2010), and biofilters to treat aquaculture wastewater (Lin et al., 2002; Zhong et al., 2011; Zhang et al., 2016; Li et al., 2020). As a result, the diverse assemblages of plants, microbes, fauna, and substrates in the circulated aquaculture wastewater, numerous physical, chemical, and biological processes can coexist in the multistage purification system to remove excess nutrients.

The characteristics of aquaculture wastewater are presented in different conditions, including municipal wastewater (MWW), intensive recirculating aquaculture waste-water (IRAWW), and land-based aquaculture wastewater (LBAWW) (Table 2).

Table 2. Characteristics of different wastewater: municipal wastewater (MWW), intensive recirculating aquaculture waste-water (IRAWW) and land-based aquaculture wastewater (LBAWW) (values are in mg L^{-1})

MWW	TSS			TAN	NO_2	NO_3	TN	TP
	800	100–200	340	39	<0.01	<0.01	52	10
References	Hammer and Hammer (2008)	Morari and Giardini (2009)	Dereli et al. (2010)	Woertz et al. (2009)	Woertz et al. (2009)	Woertz et al. (2009)	Dereli et al. (2010)	Dereli et al. (2010)
IRAWW	5–50	390	–	6.8–25.6	11.7	0.06	18.0	2.1
References	Cripps and Bergheim (2000)	Piedrahita (2003)	–	Castine et al. (2013)	Summerfelt et al. (2009)	Summerfelt et al. (2009)	Piedrahita (2003)	Piedrahita (2003)
LBAWW	5–30	40–119	76.8	0.41	0.19	0.23	1.5–3	0.22–0.28
References	Castine et al. (2013)	Jackson et al. (2004)	Castine et al. (2012)	Castine et al. (2012)	Castine et al. (2012)	Castine et al. (2012)	Jackson et al. (2003)	Jackson et al. (2004)

Abbreviation: TSS: Total suspended solid, TP: Total phosphorus, TN: Total nitrogen, TAN: Total ammoniacal nitrogen, NO_2: Nitrite, NO_3: Nitrate.

Water from desalination

By desalination, salts and other minerals are removed from brackish water or seawater, so the treated water which is converted into potable water, can be consumed by humans (Naira and Kumar, 2013; Sharifinia et al., 2022). A number of advantages are associated with desalination like providing potable water to areas suffering from water shortage (Darre and Toor, 2018; Sharifinia et al., 2022), but, during the process, the brine is produced. Brine is a concentrated saline solution (sodium chloride) produced after the separation of potable water. Brine is considered as a significant environmental problem because of its high salts and dissolved minerals contents. During desalination, large amounts of sea or ocean water are withdrawn and treated to make potable water. Based on the process efficiency, only a portion of this feed water is converted into potable water, and the remainder is considered brine. The discharge of brine is a problematic by-product of desalination because it can change the salinity, alkalinity, and temperature of seawater. Due to the presence of calcium carbonate and calcium sulfate, brine is alkaline because it contains concentrated salt. Marine organisms can be killed or harmed by any of these factors, which can cause significant changes in aquatic water. Due to brine discharge's high density, salt builds up in the seabed, causing hypersaline layers (Roberts et al., 2010). Local marine habitats and activities can be affected by salinity, and their growth can be affected by it. Ahmed and Anwar (2012) found that increasing salinity up to 50 ppt adversely affects the fish size and survival rate. As salinity increases in seawater, dissolved oxygen levels decrease, suffocating plants and leading to hypoxia in aquatic organisms and animals (Ahmed and Anwar, 2012; Alghamdi, 2019). The water obtained from seawater desalination can be used in rearing of aquatic animals that can tolerate high salinity, such as artemia.

Aquaculture products

Optimum production in aquaculture depends on water physical, chemical and biological factors (Bhatnagar and Devi, 2013), such as: temperature, dissolved oxygen, water clarity, turbidity, amount of inorganic nitrogen compounds, hardness, alkalinity, etc., which are among the important factors that should be analyzed before starting aquaculture activities in any type of water (river, drain, sewage). In aquaculture, water supply is the most important criterion for the location of farm units. A dynamic water quality is created by anthropological activities in water bodies that feed aquaculture facilities. The water must be of a suitable temperature, pH, and dissolved oxygen content, as well as low levels of nitrogenous compounds. These parameters need to be corrected in intake water if they are unfavorable. To maintain temperature and dissolved oxygen, a greater variable cost would be required. A significant contribution to global fish production has been made by aquaculture in the last twenty years, reaching 82.1 million tonnes (MT) in 2018 (FAO, 2020). As of 2018, world aquaculture fish production reached 82.1 MT, aquatic algae production reached 32.4 MT, and ornamental seashell and pearl production reached 26 thousand tonnes, bringing the total to an all-time high of 114.5 MT. In 2018, aquaculture fish production was dominated by finfish (54.3 MT, 47 MT from inland aquaculture and 7.3 MT from marine and coastal aquaculture), molluscs, mainly bivalves (17.7 MT), and crustaceans (9.4 MT).

Asian and African aquaculture production contribute more to aquaculture output growth. A number of countries depend on aquaculture to generate income and livelihoods, despite poor economic conditions and environmental problems. As the demand for fish grows, aquaculture will have to expand.

Aquatic animals that can be cultivated with the help of UWs

Finfish

Marine fish cultivation is considered as one of the most important subsectors of animal protein production in the countries of the world, especially in Southeast Asia. Based on the experiences made in the world and according to the statistics related to fish production in cage culture systems, it is very important. The most important advantages of culture of marine fish in cages are: the production of quality protein in the household consumption basket, the possibility of exporting products and earning foreign currency, the possibility of pushing fishing organizations towards sustainable marine aquaculture, the low fixed cost of fish farming in the sea compared to farming it in land systems, suitable conditions for culture of all kinds of species, job creation especially in deprived areas, and new and suitable job opportunities in coastal provinces, a very suitable and cost-effective method for cultivation and settling in deep water environments and using salty waters, the possibility of creating favorable rearing conditions without environmental stress, the possibility of moving in the presence of pollution, the need for small space and high production per unit area, attracting investors and national capitalists in the direction of a new activity, providing needed protein and fish meat, considering the increase in population and the limitation of fresh water resources, settlement and job creation in deprived areas and far from coastal areas, achieving mass production of valuable marine fish, multi-purpose use of water resources as recreation and fishing sport and rearing of various species (Sangirova et al., 2020).

Rearing in cages is a good opportunity for farmers to use water that is limited or not used for other activities. Different species of fish including *Epinephelus coioides*, *Lutjanus johni*, *Rachycentron canadom*, *Lates calcarifer*, *Pampus argenteus*, *Acanthopagarus latus*, *Acanthopagarus cuvieri* can be cultivated in saltwater environments. In Iran, various studies have been conducted in the National Research Center of Saline Water Aquatics using saline underground water to grow fish such as rainbow trout, beluga, mullet and tilapia, which indicates that

saline underground water is suitable for rearing all kinds of fishes and the growth is favorable.

Shrimp

Shrimp farming has grown rapidly in many countries since the last three decades to transform the production industry and its economic activity has been significant (Islam and Braden, 2006; Yeganeh et al., 2020). Due to its high economic efficiency, this industry plays an important role in the economic development of many tropical countries (Islam, 2008).

The preliminary research of shrimp culture using seawater in Iran was carried out since 1964 by Iranian Fisheries Science Research Institute (IFSRI) and Shrimp Research Institute (SRI) located in Bushehr. The achievements of these research activities led to the introduction of three important and commercial species of green tiger shrimp, Indian white shrimp and Pacific white shrimp to Iran's shrimp culture industry. However, evidence shows that sustainable production is somewhat limited by the carrying capacity of coastal ecosystems (including aquaculture) (Sa et al., 2013; Yeganeh et al., 2020). In addition, the rapid growth of this industry in an unconventional way has led to some environmental, technical, economic and social problems that have been widely reported in international research (Neiland et al., 2001; Khanjani et al., 2022 d). In aquaculture in salty environments, it is recommended to observe environmental and ecological points, including: proper sealing of the bottom of the pond to prevent water leakage into the underground water and raising the water level, preventing the escape of non-native species to the natural water bodies of the region (if these species are used), preventing the transfer of possible diseases and pollution to natural waterways and preventing water from leaving and transferring outside the area of aquatic production. In other words, disposal of aquaculture effluents in a proper manner should be done in the area and the place itself and the resulting effluent should not discharge into waterways or sensitive water environments (Sousa et al., 2006). In intensive shrimp farms, the water discharged from one farm is mixed with the incoming water from the neighboring farm, which leads to the contamination of the farms and the spread of disease among the shrimp population. Different shrimp farming systems have different effects on the environment, extensive systems require more land and thus, lead to the destruction of coastal ecosystems, but more dense systems cause more pollutions. Recently, the use of the new biofloc technique has been recommended to solve the problems (Khanjani et al., 2021 a, b, c; Khanjani and Sharifinia, 2022 a, b). In this technology, with proper management, the population of bacteria in water is used effectively (Khanjani et al., 2022 a, b). In this system, there is zero or minimal water exchange in order to maximize biological security and minimize the environmental effects of the farm (Khanjani and Sharifinia, 2021; Khanjani et al., 2022 c, d). Strong artificial aerators are used to inject and supply oxygen and suspend organic particles and develop heterotrophic microbial communities in the pond (Khanjani et al., 2022 e). Nitrifying bacteria and heterotrophic bacteria (*Bacillus* species with assimilation process) and *Pseudomonas* species with denitrification process play the main role in this system (Khanjani et al., 2022 e, f).

Macroalge

There are about 10,000 species of seaweed, of which 500 species are commercially exploited (Guiry, 2001). Seaweeds are a rich source of phycocolloids, which are widely used in various industries. These materials are polysaccharides, the most important products of which are agar, carrageenan, alginates, vitamins, unsaturated fatty acids, protein materials, as well as rich sources of iron and iodine elements (Keshri and Mukhopadhyay, 2012; Khanjani et al., 2019). Also, the macroalgae that are produced in salty waters have a wide range of useful and diverse products, including fiber, minerals, antioxidants, vitamins, pigments, beta-carotene, steroids, lectin. Halogen compounds, polysaccharides, proteins, unsaturated fatty acids are extracted from their various species (PPK, 2001), which are very important from a medicinal point of view. Many products such as carotenoid, phycobilin, fatty acids, polysaccharides, vitamins and biologically active molecules are widely used for human health, livestock, aquatic and biofuels and have a very good market (Ramirez-Merida et al., 2015; Stoyneva-Gärtner and Uzunov, 2015). So far, different species of seaweed such as *Ascophyllum nodosum* (Nakagawa et al., 1997), *Porphyra purpurea* (Soler-Vila et al., 2009), *Hizikia fusiformis* (Pham et al., 2006), *Gracilaria bursa-pastoris*, *Gracilaria cornea* and *Ulva rigida* (Valente et al., 2006), *Padina arborescens* and *Sargassum siliquastrum* (Ma et al., 2005) have been evaluated as fish food composition. Many of these studies have reported promising results for the use of seaweed as a partial substitute for fish meal. Various studies have shown that the use of macroalgae as a supplement in feeding aquatic animals leads to improved growth performance, increased safety of farmed aquatic animals, and reduced food conversion ratio. But it is clear that the effect of using seaweed in aquatic food depends on the type of seaweed, the amount of its use, and also on the type of fish tested with seaweed (Khanjani et al., 2019). In Table 3, some species of macroalgae that have been used in the feeding of various types of fish are presented. Macroalgae such as *Gracilaria* spp., *Ulva* spp. and *Caulerpa* spp. can be used as livestock, aquatic and human feed and they can be grown in salinity of about 30 g/l (PPK, 2001).

Live foods

One of the requirements for the development of aquaculture is the provision of larval food for all types of aquaculture. Successful rearing of aquatic larvae is an important stage in the production cycle for many aquatic species, one of the important problems in this way is providing suitable food for the initial feeding of larvae. During the larval stage in nature, most fish species feed

on phytoplankton (e.g. diatoms, microalgae) and zooplankton (e.g. copepods, rotifers) (Lavens and Sorgeloos, 1996). Providing fish larvae with suitable prey items is crucial to the success of aquaculture since undernutrition causes irreversible stunting (Cahu et al., 2003). Their survival rate should be improved if they are fed a variety of naturally occurring live foods in their early development stages (Tew et al., 2016). Despite the development of artificial feeds, the live feed is still irreplaceable for most fish larvae (Dhont et al., 2013). There are numerous zooplankton species that attract fish larvae due to their movements, including rotifers (Hagiwara and Marcial, 2019), copepods (Rasdi and Qin, 2018), and artemia nauplii (Abatzopoulos et al., 2013).

Artemia

Artemia is one of the important types of live food, which lives from brackish water to salty water, where the amount of salts may be several times that of sea water (Lavens and Sorgeloos, 1996). According to Abatzopoulos et al. (2013) and Nielsen et al. (2017), artemia increases the survival and safety of aquatic larvae and there is currently no substitute for feeding post-shrimp larvae. Fluctuations in the price of cyst in the world market and heavy dependence on cyst caused the production process to be carried out in salt production farms, hand-made basins with unconventional salty water and salty agricultural drains. Many Southeast Asian countries, such as China, Vietnam, Philippines, Thailand, and Sri Lanka, have made considerable progress in this regard and have achieved acceptable results in recent years. The amount of harvest in different countries is different according to the cultivation system, type of management, climatic conditions and final goals (consumable or industrial salt production). In other words, the management of harvest, production and processing of artemia cyst and biomass depends on the type of source, the amount of production and the volume of operations. Currently, in the world, the production and harvesting of artemia cysts and biomass is done using unconventional and salty water (Khanjani and Hajerezaee, 2021).

Copepod

Fish larvae feed on copepods as one of their primary sources of live food (Hong and Tew, 2022). A variety of indoor techniques have been developed to cultivate them intensively (Jepsen et al., 2019). Currently, feed copepods are mostly sourced from the wild, from extensive cultivation outdoors, or as a by-product of aquaculture ponds (Luo et al., 2019) due to the high cost of intensive indoor culture (Abate et al., 2015). Phytoplankton growth is promoted in copepod culture ponds by adding organic matter, such as animal manure (Kang'ombe et al., 2006), soybean meal (Adewumi, 2006), and alfalfa meal (Kaatz et al., 2011).

While copepod culture technology and applications have been improved recently (Alajmi et al., 2015; Radhakrishnan et al., 2020), marine hatcheries have increasingly used copepods in their breeding programs. In contrast, cyclopoid copepods have not been popular due to their indigestibility by larvae, and because they prey directly on fish larvae (Frimpong and Lochmann, 2005; Radhakrishnan et al., 2020). Many cultured marine larvae prefer copepods, especially calanoids (Camus et al., 2009). Protein content in copepods is high (44%–52%) and their amino acid profile is excellent, with the exception of methionine and histidine. As a source of essential fatty acids, copepods contain docosahexaenoic acid (DHA), eicosapentaenoic acid (EPA) and arachidonic acid (ARA) which are necessary for the growth and development of most fish larvae (Radhakrishnan et al., 2020). The use of copepods in feeding saltwater fish larvae leads to improved growth, survival and metamorphosis performance (Zeng et al., 2018; Olivotto et al., 2010). Due to the importance of copepods in feeding fish larvae, it is recommended to grow them in unusual waters, especially salty waters.

Table 3. Use of seaweed as food supplement in fish feeding

Fish species	Seaweed	Study period (days)	References
Oreochromis niloticus	*Ulva intestinalis*	42	Thi et al. (2015)
Clarias gariepinus	*Ulva lactuca*	70	Abdel-Warith et al. (2015)
O. niloticus	sp. *Ulva*	84	Silva et al. (2014)
Salmo salar	*Ulva ohno*	84	Marinho et al. (2013)
Paralichthys olivaceus	*Eucheumadenticulatum*	56	Shapawi and Zamry (2016)
O. niloticus	*Gracila riavermiculophylla*	84	Ragaza et al. (2015)
Oncorhynchus mykiss	*Gracilaria pygmaea*	49	Sotoudeh and Jafari (2017)
Lates calcarifer	*Sargassum polycystum*	56	Shapawi and Zamry (2016)
Paralichthys olivaceus	*Sargassum fusiforme* and *Ecklonia cava*	42	Kim et al. (2014)
S. salar	*Palmaria palmate*	98	Wan et al. (2016)
L. calcarifer	*Sargassum polycystum*	55	Nazarudin et al. (2020)
S. salar	*Laminaria* sp.	30	Kamunde et al. (2020)
Siganus fuscescens	*Asparagopsis taxiformis*	90	Thépot et al. (2021)
Labeo rohita	*Sargassum wightii*	60	Shambhulingaiah et al. (2021)
O. mykiss	*Gracilariopsis persica*, *Hypnea flagelliformis*, *Sargassum boveanum*	83	Vazirzadeh et al. (2022)
Scatophagus argus	*Sargassum* sp.	56	Yangthong et al. (2022)

Table 4. Some groups of microalgae along with their use in aquaculture (Shields and Lupatsch, 2012; Khanjani et al., 2019)

Microalgae	Application in aquaculture
Arthrospira platensis	In the production of aquatic diets
Tetraselmis suecica *Tetraselmis chui*	In the feeding of larvae and broodstocks of bivalves and the larval period of crustaceans (shrimp, lobster)
Chlorella vulgaris *Chlorella minutissima, Chlorella virginica, Chlorella grossii*	In feeding of rotifer as a livefood and also in making formulated diets for aquatic animals
Dunaliella tertiolecta *Dunaliella salina*	In the production of aquatic diets
Haematococcus pluvialis	In the production of natural pigments and in the production of formulated diets for aquatic animals
Nannochloropsis sp. *Nannochloropsis oculata*	In feeding of rotifer as a livefood and as a green tank in rearing marine fish larvae
Chaetoceros calcitrans *Chaetoceros gracilis*	In the feeding of larvae and broodstocks of bivalves and the larval period of crustaceans (shrimp, lobster)
Skeletonema costatum	
Thalassiosira pseudonana	
Nitzschia sp.	In the feeding of gastropod molluscs and starfish
Navicula sp.	
Amphora sp.	
Pavlova lutheri	In the feeding of larvae and broodstocks of bivalves
Isochrysis galbana, Tetraselmis sp.	In the feeding of larvae and broodstocks of bivalves as a green tank in rearing marine fish larvae
Crypthecodinium cohnii	In rotifer and artemia nutrition

Microalge

Microalgae are an important food source for feeding the larval stage of fish, shrimp and molluscs. Some important groups of microalgae used in aquaculture are presented in Table 4. Microalgae can be grown in UWs, especially wastewater from fish farming (Khanjani et al., 2019). In the wastewater removal process, algal biomass shows high efficiency in the production of fuels and biogas, various studies have reported the efficiency of microalgae in reducing wastewater pollution (Munoz and Guieysse, 2006). In WWT plants, microalgae are used for two main purposes: (a) to directly absorb or transform water contaminants, and/or (2) to improve bacteria's purification performance by providing oxygen (symbiotic cocultures), thereby reducing total energy costs associated with direct (gassing performance) or indirect (stirring performance) oxygen supply (Quijano et al., 2017).

Because conventional microalgae and cyanobacteria can accumulate high levels of starch and lipid, most research on algae-based WWT has been focused on *Chlorella* spp. (Chiu et al., 2015), *Arthrospira* spp. (Zhai et al., 2017), *Scenedesmus* spp. and *Nannochloropsis* spp. (Mitra et al., 2016). The review focuses on the potential applications of extremophilic microalgae (thermophilic, psychrophilic, and acidophilic), the technological approaches used for WWT (suspension versus immobilized systems), and algae-based WWT approaches that have already been successfully implemented (Wollmann et al., 2019).

It was reported by Henkanatte-Gedera et al. (2017) that *Galdieria sulphuraria* can grow well in primary-settled wastewater while lowering organic carbon (46–72%), ammonium (63–89%), and phosphate (71–95%). It is also possible to find more promising acidophilic microalgal strains among Chlorophyta (green algae). It has been found that *Chlamydomonas acidophila* grows in acidic rivers in mining areas with pH values ranging from 1.7 to 3.1 (Cuaresma et al., 2011). The growth of *C. acidophila* has been shown to be mixotrophic without CO_2 when it uses different carbon sources, including glucose, glycerol, and starch at pH 2.5, and its ability to remove NH_4 (Escudero et al., 2014). *C. acidophila* biomass from waste sources has the advantage of accumulating high concentrations of antioxidants, including lutein, a carotenoid. Several WWT processes require efficient removal of P and N from heterotrophically grown *Chlorella sorokiniana* cultures, as Kim et al. (2013 a) demonstrate. According to Kim et al. (2013 b), heterotrophic *C. sorokiniana* cultures exhibit superior removal behavior compared with photo- and mixotrophic cultures. Among the valuable bioproducts produced by *C. sorokiniana* are lutein (Chen et al., 2018), fatty acids, and proteins (León-Vaz et al., 2019). These bioproducts can be used for animal feed or biomass production for biofuels. *C. sorokiniana*'s P-removal efficiency was significantly enhanced by co-immobilization with *Azospirillum brasilense*, a microalgae growth-promoting bacterium (Hernández et al., 2013).

Challenges

The most important limiting factor for the use of UWs is their quality, which should be checked for their usability in aquaculture after physical, chemical and bio-

logical treatment. The density of a number of pathogens increases in wastewater, which is necessary to control and manage in the use of wastewater. Some pathogens, including nematodes and trematodes, use aquatic plants and fish as intermediate hosts (Strauss, 1985). *Clonorchis*, *Heterophys*, *Opistorchis*, *Schistosoma*, *Metagonimus* and *Diphyllobothrium* are among the dangerous pathogens whose control and management is important in the use of wastewater.

Clonorchis and *Schistosoma* are the most dangerous of all of them, and it is important to measure its density in wastewater for use in aquaculture, if the density is high, the use of these resources for aquaculture is limited (Strauss, 1985). The first stage of trematode pathogen (*Clonorchis*) development is spread in the body of the snail, then the snail transfers it to the aquatic body, and the aquatic organism transmits the pathogen to humans if consumed raw and half-cooked. Water snails are also indirect hosts of *Schistosoma* trematode, which causes schistosomiasis. When workers enter the rearing ponds, snails infected with trematodes that contain their larvae may attach to the worker's body and the larvae penetrate the skin. *Schistosoma* disease, especially *Schistosoma japonicum*, has been seen in aquaculture ponds using wastewater. Studies were conducted on the survival of bacteria and viruses in fish (Strauss, 1985) and it was concluded that if the density of coliform and *Salmonella* bacteria exceeds 10^4 and 10^5 per 100 ml, respectively, bacteria penetrate the muscle tissue of the fish.

• As the time of exposure of fish to pollution increases, the penetration of bacteria into the fish tissue increases,

• Less accumulation of microorganisms and bacteria and their penetration into fish tissue occurs when the coliform concentration in pond water is less than 1000 per 100 ml.

The World Health Organization (WHO) has imposed restrictions on the use of treated wastewater in aquaculture, according to the guidelines of the WHO, the wastewater used for aquaculture ponds must be free of nematode parasite eggs, and the total number of fecal forms in them should not be more than 1000 per 100 milliliters. In the use of urban wastewater in aquaculture, the most important limiting factor is coliform, fecal coliform, and nematode parasite eggs.

If health standards are met, it is possible to use UWRs in aquaculture, but it requires careful monitoring of production products and effluent entering the pond. Regarding the use of agricultural drains in aquaculture, according to the strict standards, poisons and herbicides are the most important limiting factors that limit the use of these resources.

Suggestions

Some suggestions for developing the use of UWRs include:

• Special investigation of UWRs in all regions and evaluation of the potential for increasing current water resources with UWRs in water-scarce areas.

• Programs, policies, and management of water resources and river basins should prioritize the use of UWRs operationally and support plans.

• Incorporating the experiences of leading countries in the use of UWRs, streamlining these experiences, and localizing them.

• Strengthening institutional cooperation to prevent fragmented approaches and clarify roles and responsibilities in UWs-related studies, feasibility studies, and project implementations.

• Educating skilled human resources on the environmental, ecological, and economic aspects of UWRs and strengthening their capabilities to assess and use them.

• The private sector should be encouraged to invest in sustainable projects regarding UWRs.

• Using the local community's capacity and the indigenous knowledge of the target communities to strengthen local interventions.

• Develop the resilience of water-scarce communities against climate change by utilizing UWRs in water scarcity adaptation programs.

• All local, national, and executive levels should enhance knowledge, train, and build capacity to utilize these resources.

• In order to convert UWRs into economic assets, research institutions and experts need to provide research-based technological solutions, develop models for assessing resource and risk, and examine the environmental consequences of using various types of UWRs.

Conclusion

The lack of water and food supply for the growing population has led to the use of UWs such as saltwater, urban and industrial sewage, water from cultivation workshops, flood basins and water from saltwater desalination. It should be considered as a valuable resource to increase the amount of aquaculture production, especially in arid and semi-arid countries. The most important use of wastewater and recycled water is in aquaculture (after water treatment and testing), agriculture, and also irrigation of green spaces and forestry around cities, enables these resources to be used with minimal adverse environmental effects. The most important limiting factor in the quality of effluents resulting from urban sewage treatment in various uses is the sanitary characteristics and organic substances of the effluent, which after physical, chemical and biological treatment can be used in aquaculture. The use of UWs is very effective and efficient in drought management due to the limitation of water resources at the global level, and its use is also considered one of the ways to develop the fisheries sector. The use of non-drinkable salty waters can be used to increase productivity and production in the cultivation of fish, shrimp, artemia and algae, which is of great importance. Therefore, haloculture as a practical, economic and sustainable solution can complement agricultural production in improving food security in arid and semi-arid regions. Therefore, the necessity of research in the field of UWRs

and its positive and negative consequences, especially in water-scarce areas and areas with poor water quality, is felt more than before.

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