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Managing Emerging Environmental Contaminants in Aquaculture and Fisheries

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Preface

The global demand for protein-rich food, particularly seafood, has been rising steadily and this trend continues to fuel the expansion of the aquaculture sector. As population grows and dietary preferences shift towards healthier protein options, aquaculture will be increasingly viewed as a crucial contributor to global food security. In regions facing water scarcity, one promising approach to sustain aquaculture productivity is wastewater reuse. This practice supports nutrient recycling, enhances production efficiency and helps to meet the escalating demand for aquatic food resources. However, despite its potential, wastewater reuse poses a significant challenge concerning the presence of contaminants of emerging concern (CECs).

CECs including pharmaceuticals, personal care products, industrial chemicals, and agricultural residues are now frequently detected in aquaculture environments - even at very low concentrations. Over the past several years, the proliferation of CECs in water bodies, sediments, and biological systems has attracted intense scientific and policy interest. Their entry into aquatic ecosystems through domestic wastewater, industrial discharge, agricultural runoff, and other pathways has led to concentrations capable of disrupting aquatic life and compromising environmental quality. In India, studies have confirmed the presence of CECs in surface waters and their accumulation in various aquatic species. Despite the growing evidence, efforts aimed at comprehensive monitoring, effective regulation, and advanced treatment remain inadequate. Furthermore, wastewater reuse is not limited to aquaculture; it is increasingly employed in agriculture for irrigation, raising additional concerns about the transfer of contaminants through the food chain.

Recognising the need, the Academy convened a brainstorming session on *"Managing Emerging Environmental Contaminants in Aquaculture and Fisheries".* The resulting policy paper underscores the seriousness of CECs related threats to human health, aquatic ecosystems, and long-term sectoral sustainability. It articulates key issues, examines current knowledge gaps, and presents strategic recommendations to guide future management and policy formulation. By offering a holistic framework for addressing CECs, the document seeks to support the responsible growth, resilience, and environmental sustainability of aquaculture and fisheries in the country. I appreciate the efforts of Conveners, Reviewers and Editors for bringing the document in the present form.

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(M.L. Jat)
President, NAAS

Managing Emerging Environmental Contaminants in Aquaculture and Fisheries

1. INTRODUCTION

Emerging contaminants in aquaculture and fisheries have become a growing environmental and public health concern due to their persistence, bioaccumulation, and potential ecotoxicological effects. Aquatic ecosystems and cultured species are increasingly being found to have these contaminants. The viability of global fish production systems, food safety, and the integrity of aquatic ecosystems are all at risk due to constant anthropogenic input. Rapid population growth and urbanisation, and excessive water consumption are critical factors for the depletion of freshwater resources, and climate change exacerbates these issues (Abisha *et al*. 2022). Nearly 70% of the irrigation water comes from surface water sources (rivers, canals, lakes) and the demand is expected to increase further by 2050. Reusing treated wastewater (TWW) is an excellent approach to addressing the water shortage issues and is attracting global attention. The United Nations (2016) has promoted the implementation of wastewater reuse globally to achieve the Sustainable Development Goals (SDGs) by 2030. Much of the world's wastewater, around 88 million m^3 per day including 15 million m^3 of untreated wastewater, is utilised daily for irrigation worldwide.

Reusing wastewater for irrigation and aquaculture (Jana *et al*., 2018; Lakra and Krishnani, 2022) becomes inevitable due to freshwater scarcity and groundwater depletion. However, the suitability of using treated wastewater for irrigation and aquaculture has become a bone of contention among government authorities and policymakers, due to the occurrence of newly identified synthetic or naturally occurring chemicals or biological agents coined as CEC (contaminants of emerging concern). The CECs are pseudo-persistent in nature, and detected in wastewater which are potentially hazardous to humans and ecosystems. CECs are categorised into various groups based on their occurrences, impact on safety, health and environment, and bioremediation potential. They include PPCPs (pharmaceuticals and personal care products), forever chemicals or PFASs (per- and poly-fluoroalkyl substances), emerging pathogens, synthetic hormones, veterinary drugs, off-flavor causing chemicals (geosmin and methylisoborneol), PBTs (persistent bioaccumulative toxicants), recently introduced new molecules of pesticides, industrial chemicals (e.g. plasticizers, surfactants, disinfection by-products, flame retardants), micro/nano plastics, antibiotics, ARGs (antibiotic resistance genes), cyanotoxins, geogenic chemicals etc. (Krishnani *et al*., 2008). However, the risks associated with these contaminants are not yet well studied in terms of their impacts on crops, animals, fish, microbes, humans, and natural ecosystems. Biotoxins are produced by bacteria, fungi, plants, and animals. These biotoxins released into water may cause illness and even death of fish due to ingestion. Emerging contaminants in fisheries and aquaculture and their potential impacts on aquatic biology and human health are illustrated in Figure 1.

Aquatic ecosystems are more susceptible to various pollutants, including CECs, compared to terrestrial farming. This is due to the universal solvent properties of water,

Figure 1. Emerging contaminants in fisheries and aquaculture and their potential impacts on aquatic biology and human health

which serves as a reservoir for all pollutants, including CECs, originating from diverse sources. The already elevated temperatures in tropical regions, further aggravated by global warming, amplify these risks by enhancing the metabolism and possible transformation of these substances, while also fostering conditions that promote bacterial growth and the spread of antibiotic resistance genes.

Several studies in India have ascertained the presence of CECs in surface waters and their accumulation in aquatic biota, yet monitoring and treatment efforts remain inadequate. Most treatment systems are assessed with conventional pollutants only. Reports on the occurrence of CECs in aquaculture and fisheries are scanty. Realising the importance of this, the National Academy of Agricultural Sciences (NAAS) organised a brainstorming session (BSS) on "*Managing Emerging Environmental Contaminants in Aquaculture and Fisheries*". This policy paper on CECs, that pose threats to human health and the sustainability of ecosystems, is the outcome of deliberations in the BSS. It presents the challenges and the way forward for a holistic management and policy options related to CECs in aquaculture and fisheries, identifies key challenges and provides strategic recommendations.

2. PRESENT STATUS OF THE CECs

2.1. Intensive Aquaculture and Culture-based Fisheries

India is the second-largest aquaculture producer, third in capture fisheries production, sixth in marine capture fisheries production, and the fourth-largest fish/fisheries products exporter. India is contributing around 8% to global fish production, with a record 18.4 MMT (million metric tons) produced in 2023-2024, as compared to 6.4 MMT in 2003-04, with a substantial focus on inland fisheries and aquaculture (13.9 MMT) followed by marine fisheries (4.5 MMT), registering an increase of 8.82 MMT in 10 years (2014-2024) as compared to an increase of 3.18 MMT during 2004-2014. The nation has an excellent potential for the development of culture-based fisheries in approximately 1.48 million hectares (Mh) of small reservoirs, 0.20 Mh of floodplain wetlands, and 40 thousand hectares of estuarine wetlands. Agriculture accounts for 6.72% of the Indian economy, while the fisheries sector contributes 1.1%. The National Fisheries Development Board (NFDB) is also working to improve production, livelihoods, and infrastructure, while a national development plan is in place to guide the sector towards sustainability, productivity, and competitiveness.

Approaches to the extensification and intensification of the aquaculture sector have become major areas of interest, owing to the high demand for aquaculture commodities and the insufficiency of capture fisheries (Abisha *et al*., 2022). As such, CECs are not used in intensive aquaculture and culture-based fisheries, as evidenced from the fact that antibiotic task forces have been constituted by all the maritime states at the initiative of the Marine Products Export Development Authority (MPEDA). Ministry of Health and Family Welfare has banned the import, manufacture, distribution, and sale of Chloramphenicol and Nitrofuran and their formulations for use in any animal rearing systems in India. As such, there are no reports on the occurrences of CECs in farmed fish and shrimp harvested through extensive, semi-intensive and intensive aquaculture and culture-based fisheries in India. The EU conducts sampling for 50% of Indian aquaculture consignments whereas 100% sampling for *L. vannamei* in consignments is done by Japan. MPEDA conducts the National Residue Control Plan (NRCP) and Pre-Harvest Testing for residue monitoring of various contaminants. Pre-Export Test is undertaken by EIC. NRCP positives have reduced from 20% to 3% at the hatchery level and from 0.06% to 0.01% at the farm level during the past 5 years. Hydrogel-based semi-biofloc, aquaponics, nanostructured material, plant-assisted bioremediation, and medicinal plants-based systems have been demonstrated for environmental and health management in intensive aquaculture (Krishnani *et al*., 2023; 2025). The gradual phasing out of conventional pond-based cultivation systems and the promotion of advanced production systems such as biofloc technology and multitrophic aquaculture have demonstrated potential for improved environmental control, reduced chemical inputs, and enhanced biosecurity.

2.2. Wastewater Reuse for Crop Irrigation and Aquaculture

Rising demand for seafood and protein-rich food sources is driving the growth of the aquaculture industry. Reusing wastewater for aquaculture offers opportunities for nutrient recycling and improving aquaculture production. However, the occurrence of CECs, even when detected in low concentrations in aquaculture products, water, and sediments from chemical residues, adversely affects human health, the environment, and aquatic species, continuously posing rigorous challenges. CECs negatively affect aquaculture production and productivity by causing toxicological stress, reducing growth rates, damaging reproductive health, and increasing mortality in cultured species. In the last few years, CECs have become a topic of great interest because of their widespread distribution through multiple sources in water, sediment, and biota, at concentrations detrimental to aquatic organisms.

The use of treated wastewater may nourish crops, avert water contamination, and reduce the pressure on freshwater supplies. However, only 1.6-6.3% treated sewage water is used for irrigation worldwide. Untreated wastewater contaminates rivers and oceans and may damage the fisheries. A recent study released at the World Ocean Summit found that India›s fishery sector faces an annual economic loss of approximately $2.2 billion due to untreated wastewater contamination. India›s low wastewater treatment rate of 21% may exacerbate the problem. In many countries, the application of wastewater by-products to land practice has been adopted; however, there is an urgent need to highlight and establish the global risks.

2.3. Wastewater Reuse and CECs Occurrences

Reusing treated wastewater for irrigation and fisheries has many advantages and drawbacks. The use of wastewater involves the modification of production processes and the utilisation of various inputs during production. The extensive use and improper disposal of CECs have led to their omnipresence in the natural environment, causing continuous contamination with potentially harmful chemicals from diverse sources (Krishnani *et al*., 2023). Pesticides are present in the environment in mixtures; hence, their interaction may lead to antagonistic, additive, or synergistic behaviour. Globally, CECs have been found in major crops, aquaculture water, sediment, and culture species due to the reuse of wastewater for crops and aquaculture. Antifoulants, microplastics, PPCPs, PFAS, emerging pathogens, PBTs, geogenic chemicals, disinfectants, fertilizers, soil and water conditioners/additives, hormones, antifungal, antiparasitic and antimicrobials, including antibiotics, are the commonly detected CEC. Among the different types of CECs, PPCPs are the most important and diverse category of substances comprising pharmaceutical drugs, ingredients in cosmetics, food supplements, as well as their transformed metabolites. The ever-increasing use has led to the continuous loading of PPCPs, such as triclosan and triclocarban, as well as industrial compounds like phthalates, BPA, and surfactants, into aquatic systems through various sources, including wastewater treatment plants, runoff from fields, improper disposal, leaching from landfills, industrial effluents, and municipal wastewater discharge. Pesticides in binary mixtures have been observed to affect the fish even when they are treated with low dosages, considered extremely safe to the environment. These low dosages may not cause mortality of aquatic organisms, nor leave residues above MRL, but hamper the activity of fish, probably due to synergistic effects of mixtures.

2.4. Status of PFASs

The PFAS, or aptly referred to as "*forever chemicals",* have been identified as major concern for environmental and human health due to their very high stability and persistence.

PFAS enter waterways during firefighting and training activities, industrial discharges, metal plating in the automobile industry, spills, and wastewater treatment. PFAS contamination of aquatic bodies and fish feed may lead to bioaccumulation and biomagnification in fish. Freshwater fish may have higher concentrations of PFAS compared to marine fish. PFAS contamination of the fisheries or associated aqueous streams is linked to health problems such as increased risk of cancer, liver disease, thyroid issues, and abnormalities related to reproduction and growth. There is widespread human exposure to PFAS in China, Japan, and Korea, where more than 80% of studies originated. Blood and breast milk in several Asian countries are contaminated with a range of PFAS, which is a cause of major concern. Different types of PFAS (PFSAs, PFCAs, FOSA, PFBS, PFOA, PFOS) contamination in various aquatic matrices such as surface water, groundwater, sediments and biota across India have recently been reported (Gautam *et al*., 2025). There are a few reports on occurrences of PFASs in Indian riverine waters and fish in nanogram levels; however, there are no occurrences of PFASs in farmed Fish and shrimp harvested from aquaculture and culture-based fisheries and aquatic products in India.

According to one estimate, more than 5,000 chemicals fall into the PFAS category, although all may not be toxic or detrimental to fish. PFAS compounds, specifically PFOS and PFOA, have been studied more extensively. Some priority PFASs are currently being regulated under "the Stockholm Treaty for persistent organic chemicals". The USEPA lists nine PFAS chemicals for monitoring. Studies have detected PFAS in rivers and estuaries in different parts of India (Koulini *et al*., 2024), including the Ganges, and predictive modelling shows PFAS levels will exceed safe limits in Indian states by 2054 (Gautam *et al*., 2025).

2.5. Status of Microplastics (MPs)

MPs with a size range of < 5 mm and their impacts on natural ecosystems have garnered considerable attention lately, as they are one of the major emerging contaminants. Primary MPs are directly introduced into the environment through anthropogenic activities, while secondary MPs are formed from larger plastic particles via environmental breakdown. They can take many forms in nature, such as pieces, fibers, pellets, films, beads, and foams, etc., and are particularly common in both inland and marineaquatic environments. Gaining a greater understanding of how plastic trash behaves in river systems is essential, given the well-established detrimental effects of plastic debris on ecological habitats and biodiversity. The diminishing size of plastic waste is a major problem for environmental health because tiny plastic bits can travel up the food chain and become bioaccumulated in various aquatic food web species when they ingest these particles.

Major sources of MPs include car tyres, paint-based markings, plastic resins and synthetic clothing, environmental inflow from water, wind, and sediments. Biomagnification occurs as lower-trophic organisms ingest particles, which then accumulate in the tissues of predators across the food chain. MPs are ubiquitous in nature and stay dispersed throughout the water column according to their density and form, which is further accessible by the aquatic biota of several trophic levels, because of their extremely small sizes and other morphometric characteristics. MPs in several major rivers around the world have been reported with over 2 million tons transported by rivers each year (Lebreton *et al*., 2017), with almost 80% of the plastic debris entering marine habitats from the land. Research has shown that while bottom-dwelling species like mollusks, echinoderms, amphipods, and polychaete worms are more likely to encounter denser MPs, smaller organisms like phytoplankton and zooplankton are more likely to absorb lighter, floating MPs. Because of the natural predator-prey dynamics in aquatic environments, larger animals like fish eventually consume MPs. Furthermore, MPs can absorb organic pollutants that are water-repellent, such as persistent organic pollutants (POPs), polycyclic aromatic hydrocarbons (PAHs), and polychlorinated biphenyls (PCBs), besides flame retardants, additives, and plasticizers, integrated into their structure. PE, PP, and PET materials are the most often and extensively available plastic ingredients/pieces in river sediments worldwide. Research models show India's ganges river system carries the second highest plastic waste at 0.12 million tons per year (Lebreton *et al*., 2017). Researchers have consistently found these same types of plastics dominating the waterways throughout Asia and Southeast Asia (Sarkar *et al*., 2019; 2021). Microplastic pollution is also extensively reported in the the ganges river which carries inland trash along its path, including waste from the paint and rayon industries as well as dairy and milk processing facilities and the fibers from washing clothes (Sarkar *et al*., 2019). ICAR-CIFRI quantified the abundance of MPs ranging from 11.48 to 63.79 ng/g. The most prevalent types are polyethylene, polypropylene, and polyethylene terephthalate in the sediments of the lower stretch of the ganges at different locations in Bihar and West Bengal (Sarkar *et al*., 2019). Even major tributaries and distributaries of the river ganges were found to be contaminated with MPs at the lower estuarine stretch (Das *et al*., 2026). Levels of MPs in sediments and water of Indian rivers (Ganges, Mahanadi, Alaknanda, Netravathi, Hooghly, Cooum, Brahmaputra, Indus, Kaveri, Adyar, Kosasthalaiyar, Multhirappuzhayar, Kharkai, Godavari and Chalakudy) have been reported in the different levels (Kumar *et al*., 2025).

MPs are reported in East Kolkata Wetland (EKW), a wastewater-fed aquaculture system (Sarkar *et al*., 2021a), which is an ecologically significant aquatic body and Ramsar wetland. Different water treatment plants are also being assessed to screen the MPs removal efficiency. It was reported that the existing technologies in Indian water treatment plants are moderately efficient for removing MPs from water (Sarkar *et al*., 2021b). The momentum of MPs investigation in the Indian inland aquatic system has just taken pace. However, a more extensive effort is required for proper monitoring of MPs in Indian river systems. Several institutions have just begun assessing MPs pollution in the inland freshwater system.

The harmful effects of plastic waste, particularly MPs, fibers, threads, beads, and films, have been shown to harm fish. In the aquatic environment, larger species, including fish, birds, and mammals, have also been seen to absorb a considerable quantity of MPs through prey-predation relationships. When minuscule plastic particles suspended in water are consumed by plankton and small invertebrates, the biomagnification of MPs starts. Because small fish eat these contaminated creatures, MPs can move across trophic levels through predation. The cumulative burden of MPs in the digestive tracts and tissues of larger predatory fish rises as they ingest more contaminated prey. Additionally, harmful compounds that have been absorbed by MPs may concentrate in higher trophic creatures, increasing the dangers to human health and the environment along the aquatic food chain. A few instances of the harmful effects of MPs on the marine mussel were observed, which include oxidative stress and genotoxicity after being exposed to MPs.

There are limited reports on the occurrence of MPs in aquaculture facilities. However, deterioration of plastic-based equipment such as nets, ropes, cages, liners, and feed bags subjected to mechanical wear and sunlight is postulated as a major reason of MPs occurrence in aquaculture. Additionally, tainted raw materials or particles from packaging may introduce MPs into commercial aquafeeds. Microplastics and other CECs like pharmaceutical residues typically coexist in aquatic ecosystems, where plastic particles serve as carriers for adsorbed antibiotics and other medications. Their vast surface area and hydrophobic qualities aid in the concentration and transfer of pollutants across water bodies and food webs. This combined exposure results in localized "hotspots" of selection pressure that promote the spread of antimicrobial-resistant (AMR) bacteria. Furthermore, biofilms formed on microplastic surfaces, known as plastispheres, include varied microbial communities that enable horizontal transfer of resistance genes. As a result, the interaction of MPs and pharmaceuticals intensifies AMR reservoirs in the environment, endangering fisheries, aquaculture systems, and human health.

3. CHALLENGES

3.1. Recalcitrance, Persistence and Bioaccumulative Nature of CECs

Most of the CECs meet persistent, bioaccumulative, toxicants criteria that raise genuine concerns about food safety and long-term exposure (Jacob and Krishnani, 2024). Our ability to boost the yields and nutritional content of food to meet future demand may be impacted by the presence of CECs in crops and fish. The presence of CECs in humans can potentially cause reproductive and neurological disorders. They may also induce antimicrobial resistance in humans and other animals, cause chronic toxicity, and estrogenicity.

3.2. Challenges Associated with PFASs (Per- and poly-Fluoro Alkyl Substances)

PFAS is a very large family of more than 5,000 substances, which and can find their way into aquatic ecosystems through runoff, where they persist and do not break down. They contaminate the environment, bioaccumulate in fish and wildlife, and some can remain in human bodies for years. Compounds encompassing a variety of chemical classes and belonging to CECs, and endocrine-disrupting chemicals (EDCs), which in many cases, pose a threat to fish and other aquatic organisms through oxygen depletion and can also interfere with the hormonal system, and adversely affect fish reproduction. The USEPA/FDA Centres for Disease Control and Prevention's (CDC)/National Health and Nutrition Examination Survey (NHANES) reported presence of PFAS in the blood of 97% of the U.S. population (Tokranov *et al*., 2024). PFASs have been reported in some of the Indian River waters, but not in the farmed fish and shrimp harvested from aquaculture and culture-based fisheries. A critical factor identified is regulatory gaps for PFAS usage and disposal within the Indian environment, inadequate monitoring, and technological barriers that hinder addressing PFAS contamination effectively.

3.3. Challenges Associated with MPs

MPs are reported to leach various harmful chemicals, including plasticizer, dyes, flame-retardants, etc., and act as a vector for several contaminants, viz., heavy metals, AMR genes, PAH, etc. Packaging (plastics, etc.) and storing (formalin, etc.) materials are also contributing to fish pollution. Heavy metals are potential hazards to aquatic, animal, and human life because of their toxicity and bioaccumulative and nonbiodegradable nature (Krishnani and Ayyappan, 2006). The fish's normal development and reproductive behaviour are reportedly affected by these leached compounds, which are well-known endocrine disruptors. Currently, there is no practical way to address the global microplastic contamination problem. Micro- and nano-plastics originating from the widespread use of plastics have been raised increasingly alarming concerns worldwide. However, a fundamental knowledge gap in nanoplastics remains due to the lack of effective analytical techniques. Multidimensional profiling/quantification suggests a litre of bottled water contains about 240,000 tiny pieces of micro-nano plastics, the majority (90%) of which are nanoplastics (Quian *et al*., 2024). According to the Federation of Indian Chambers of Commerce and Industry (FICCI), even though India's per capita plastic usage is modest (11 kg annually) compared to America's (109 kg annually), this figure is estimated to rise in the coming years, which may be concerning for aquatic creatures in the future. Strict implementation of the ban on single-use plastics is a challenging task.

3.4. Challenges Associated with Pathogens

The reuse of wastewater for aquaculture is being pursued as a means of increasing aquaculture production, which is known to affect the environment and the emergence of new diseases. Perhaps pathogens that have been present in the environment or in other aquatic organisms may transfer to aquaculture species through wastewater reuse. The outbreak of white spot syndrome virus (WSSV) is an example. This virus has a wide host range and can be present in aquatic organisms, such as crabs, where it does not cause significant mortalities in the natural environment. This virus affected cultured shrimp, causing mass mortalities in 1992 in Taiwan and has spread all over the globe. Another example is AHPND (acute hepatopancreatic necrosis disease) caused by *Vibrio parahaemolyticus* that has acquired a mobile genetic element - a plasmid carrying Photorhabdus Insect-Related (PIR) toxin genes. High-density farming would facilitate horizontal gene transfer and acquisition of plasmids carrying virulence genes or genes conferring resistance to antibiotics (Bright and Yadava, 2005). In China, there is an emergence of another disease, translucent larval disease (TLD) caused by hypervirulent *Vibrio parahaemolyticus* carrying virulence genes. *V. parahaemolyticus* is known as a common estuarine organism all over the world, but this common organism has become a serious pathogen due to the acquisition of mobile genetic elements.

3.5. Knowledge Gaps in Formulating Policy related to Managing CECs

Developing and implementing definite aquaculture wastewater treatment processes and systems for the different categories of culture operations require a holistic approach. The lack of clear guidelines poses a major challenge in preparing the necessary dossiers for regulating the approval of using wastewater contaminated with CECs in irrigation and aquaculture.

4. RECOMMENDATIONS

4.1. Regulatory Measures for Monitoring and Management of CECs in Wastewater

Wastewater used for irrigation and aquaculture needs to be regulated. Efficient effluent treatment processes based on fundamental principles, such as adsorption, biodegradation, photocatalysis, filtration, activated sludge, sedimentation, and constructed wetlands, shall be implemented by industries at locations specific to water bodies and aquaculture and culture-based fisheries. Recirculating aquaculture systems (RAS) using biofloc technology should be used in traditional pond-based aquaculture. The algal and heterotrophic microbial biomass generated in biofloc systems can also serve as renewable feedstock for biofuels, bioplastics, and animal feed supplements, thus promoting a circular economy through waste reduction and nutrient recycling, ultimately enhancing the sustainability of aquaculture operations.

Mass awareness on the improved understanding of the risks and cumulative impacts of different forms of CECs on the health of inland and marine organisms, ecosystems, human health and other living beings and a harmonised integrated monitoring are required to identify and assess CECs. Efficient state-of-the-art industrial wastewater treatment process; proper disposal mechanisms for waste, unused and expired products using strict regulatory measures and reusing wastewater for crop irrigation and aquaculture by adopting a One Health approach could be some of the ways and means to manage the menace of CECs. This transition not only minimizes pollutant discharge but also boosts productivity.

4.2. Regulations for Coastal Aquaculture and Marine Fisheries

Regulations for coastal aquaculture and marine fisheries require strict compliance on product/aqua-inputs, environmental safety, and public health standards to combat antimicrobial resistance and environmental contamination. Every product used in aquaculture must have clear information on its chemical name and other details viz. trade names; target organism; mode of action; mode of application; shelf life and storage; recommended dosage; metabolism of the drug in animal body; retentivity and mode of excretion; residues in host species; host species safety; environmental safety, and operator safety.

Systematic surveillance programs for antimicrobial usage and residue monitoring to ensure compliance with international guidelines should be done by government departments. To lessen the potential of CEC contamination in aquatic systems in the future, policy makers, stakeholders, and the general public must become more aware on the regulatory framework.

4.3. Regulations for Freshwater Aquaculture and Inland Fisheries

There is a need to examine the feasibility of extending the Coastal Aquaculture Act 2005 rules and regulations to Freshwater Aquaculture wherever applicable. An expert committee may be constituted to investigate all aspects and suggest a suitable action plan. This matter may be addressed with the NFDB, the Food Safety and Standards Authority of India (FSSAI), and the respective states. FSSAI & Export Inspection Council (EIC) are two Indian government regulatory bodies that work together to ensure food safety and are responsible for setting regulatory limits for various contaminants. These regulatory authorities, in coordination with research institutions, may coordinate cluster-wise unified approach in monitoring of Environmental Contaminants, in collaboration with FSSAI focusing on setting regulatory limits for domestic as well as imported products. The EIC is focusing on quality and safety certifications for food exports. Data shall be maintained to carry out the risk assessment by the regulatory authority to substantiate the documentary evidence for the WTO on SPS matters. FSSAI has launched initiatives to empower consumers to check for illegally added formaldehyde, and also warned that such practices are illegal and punishable. CAA in coordination with the NFDB, FSSAI, and State governments ensures safe practices, sustainable environments, and robust WTO/SPS compliance.

4.4. Examining Gaps in the Existing Policy Framework

The management of aquatic resources holding fisheries is dependent on different policies/laws, viz., Environmental Protection, National Water Policy and Act, Water Pollution Rules, Forest and wildlife conservation regulations, National Policy on Marine Fisheries (NPMF), and similar other rules in operation both at the Centre and State levels. Like a carbon credit, a water credit system can incentivise and foster the conservation of water and sustainable water use, aligning with the SDGs. The amount of fresh water used to produce goods and services in an organisation needs documentation. Efforts should be made by the Fisheries Division in coordination with the NRM Division of ICAR to examine any gaps/bottlenecks in regulations that can be further amended for the management of contaminants and enhancement of sustainable fish production. Developing a water credit framework/mechanism to incentivize fisheries to adopt water-saving technologies, reduce discharge, and document freshwater usage will streamline how environmental and pollution control rules apply to fresh water fish farms and marine ecosystems.

4.5. Creation of Central Data Bank and Awareness among Stakeholders/Farmers

There is a paucity of primary data on various issues related to CECs, with a focus on wastewater-fed aquaculture activities and fisheries in the Country. Secondary information is available, that too very limited. Therefore, it is recommended that existing information on contaminants with respect to fisheries and aquaculture be documented with existing national fisheries databases maintained by the Fishery Survey of India as a priority. Mapping and monitoring major wastewater-fed aquaculture sites and conduct routine sampling for CECs to understand bioaccumulation in fish tissue will help document baseline contaminant levels and support safe, sustainable practices.

4.6. Licensing Regulations

Today, there is a licensing pattern for the aquaculture medicines by CAA, but that is restricted to the checking of antibiotic residues alone. This must be expanded to the other criteria of merit, such as the aquaculture and aquatic animal health management products. Evaluating health management products must include comprehensive product-safety profiles to prevent bioaccumulation or degradation of the local aquatic environment. The thumb rule is that any material applied in aquaculture at any stage of the operation shall not leave any residue either in the animal body or the environment, which is a core principle of sustainable aquaculture and Good Aquaculture Practices (GAPs), as mandated by the National Residue Control Plan (NRCP) for monitoring and control of residues in aquaculture products, covering substances like antibiotics, dyes, and environmental contaminants. Guidelines issued by CAA for regulating coastal aquaculture, including antibiotic-free inputs and monitoring effluent water quality and Guidelines for Sustainable Aquaculture (GSA) by the FAO for a comprehensive framework that addresses environmental, social, and economic factors need to be implemented. The NRCP and CAA can advise manufacturers to comply and ensure that all inputs meet these safety thresholds prior to commercial distribution. By harmonizing CAA regulations with the FAO comprehensive frameworks for sustainable aquaculture and NRCP monitoring capabilities, the Indian aquaculture sector can maintain its global competitive edge and food safety guarantees.

4.7. Resolving Market-related Issues

All aqua inputs must be recorded, maintained, and retained by the primary production facilities, such as farms. There is a need for Eco-labelling and traceability - chain of custody verification, indicating packing, storage, transport condition, specific standards by Fish farm owners/producers, enabling end-to-end transparency from farm to consumer. Data shall be maintained to facilitate the risk assessment by the regulatory authority, substantiating the documentary evidence for WTO/SPS matters. Safe seafood for both domestic and international markets can be substantiated and market-related issues in aquaculture can be resolved by framing uniform regulations and mandatory safety standards applicable at both levels, ensuring that producers do not face trade barriers.

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