Received: 26 January 2022 | Revised: 27 January 2023 | Accepted: 4 February 2023
DOI: 10.1111/raq.12801

REVIEW

REVIEWS IN Aquaculture

A systematic review of fish adulteration and contamination in Bangladesh: A way forward to food safety

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Funding information
Food Safety Innovation Lab, Feed the Future, USAID, Grant/Award Number: 7200AA19LE00003

Abstract

For decades, the world has been plagued by widespread food adulteration, and Bangladesh is no exception. Dishonest business people and fish farmers unlawfully utilize various preservatives to avoid rotting and extend the shelf life of fish. Although previous research has examined the level of formalin use in fish bodies, no studies focusing on all aspects of fish adulteration and contamination in Bangladesh have been carried out. In this context, the aim of this review is to explore the extent and magnitude of illegal fish adulteration and contamination in Bangladesh. Among the 37 reviewed studies, 11 of them highlighted formalin adulteration in fish samples and fish feed. The extent of formalin use varied between local and imported fish, and between large and small fish. Imported and large fish were substantially more formalin-contaminated. Several investigations have discovered that antibiotic levels in farm water and fish feed exceed the permitted level. Farmers have used growth promoters incautiously. This study also identifies that certain metal substances, such as chromium, lead, arsenic, cadmium, iron, mercury and cobalt, have been frequently found in fish bodies and feed samples. Furthermore, a distinct type of fish adulteration caused by aromatic compounds has emerged recently. The findings and their ramifications are extremely concerning for human lives. However, since each study employed a different testing kit, the results were quite distinct. Thus, the adoption of a precise and sensitive kit is strongly recommended. The government should make it a top priority to solve the problem of fish adulteration by implementing appropriate food safety laws and policies.

KEYWORDS
antibiotics, fish adulteration, food safety, formalin contamination, growth promotor, metal use

1 | INTRODUCTION

The current use of the words ‘adulteration’ and ‘contamination’ is widespread. Were we to ask whether, 50 or 100 years ago, our predecessor often heard these words, the answer would most likely be ‘No’. However, in the 21st century, these two words have become so widely used that the effect of these hazards on our lives cannot be ignored. The world is facing a crisis regarding the adulteration and contamination of various food items,[1,2] and fish is no exception. In recent ages, fish have frequently been found to be adulterated with formalin across the globe, mainly for preservation purposes. In food, formalin (a 37% formaldehyde solution) poses a significant danger to the human body.[3] Prolonged consumption of fish containing formalin may increase the risk of serious health hazards, such as cancer.[4] Some fishermen and fish traders immorally use formaldehyde to preserve fish and seafood from spoilage organisms.[5] Besides formalin, natural and synthetic agents, such as antibiotics, water and soil treatment compounds, disinfectants, fertilizers, pesticides, probiotics and other dietary supplements have become regular inputs for the treatment and prevention of bacterial and parasitic diseases, water quality improvement and natural productivity growth in ponds.[6–8]

However, the extensive use of these substances in aquaculture can result in the emergence of harmful bacteria that are resistant to antibiotics both inside and outside of aquaculture systems.[9–11] Highly toxic substances' residues, such as pesticides or treated animals' antimicrobials, are resulting in a possible risk for fish value chain actors.[12,13] Furthermore, contamination from heavy metals poses a considerable problem, as these metals are notorious for their bioaccumulation and bio-magnification, posing various threats to human health.[14] Fish bioaccumulate contaminants directly from contaminated water by diffusion through the gills and skin or food intake.[15,16] On the other hand, contaminated solid wastes from tanneries are often used as a protein source in fish feed.[17] Since the heavy metal contamination of fish feed results in biomagnifications and bio-concentrations at various points throughout the food chain, it, therefore, affects the human body, causing multiple detrimental and toxic effects. Further, polycyclic aromatic hydrocarbons (PAHs) are pervasive chemical contaminants that occur during the industrial processing of fish feed and various human activities from the incomplete combustion or pyrolysis of organic matter.[18]

Fortunately, Bangladesh, with the world's largest flooded wetlands and the third-largest marine biodiversity in Asia, following China and India, is considered among the most suitable regions for fishing on the globe. Farmers in rural areas are attracting interest regarding fish production, as aquaculture is becoming increasingly economically viable[19]; thus, commercial aquaculture is replacing subsistence aquaculture.[20–23] Bangladesh possesses significantly diversified fishing stock, variously classified as marine fisheries and inland fisheries. However, with the increase in fish production, the use of health-hazardous substances, such as formalin, antibiotics and chemicals, has increased substantially. However, despite notable progress and increased self-sufficiency in fish production, Bangladesh requires a large quantity of imported fish to meet the overwhelming domestic demand for fish, especially carp.[24] Two-thirds of imported rohu has been found to be preserved using formalin.[24] Moreover, rotenone, various forms of inorganic and organic fertilizers, salt, dipterex, antimicrobials, phostoxin, copper sulphate, potassium permanganate, malathion, sumithion and so forth are the most frequently used chemicals in preserving fish in Bangladesh.[25–28]

Undoubtedly, Bangladesh has achieved food security in the modern age. Now, however, greater emphasis should be placed on addressing the food safety issue. Hence, the question arises of whether the large amount of fish produced is safe for consumption and whether it is free from contamination and adulteration. To answer this question, this paper aims to reveal the existing scenario of adulteration and contamination in the overall fish value chain of Bangladesh. There are several reviews of the overall fisheries sector in Bangladesh[29–32] and the use of formalin,[4,33] but no comprehensive review study has been conducted on the different forms of adulteration and contamination in the fish value chain in Bangladesh. Therefore, this is a pivotal study carried out to assess fish adulteration and determine a way forward to food safety in Bangladesh. This article also provides a guide for relevant policymakers and the government to understand the current food safety concerns regarding fisheries sectors in Bangladesh. Although this study considers Bangladesh as a case study, the findings regarding food safety concerns may be relevant to other countries with a similar background.

2 | METHOD AND PROCEDURE FOR THE LITERATURE SELECTION

The preferred reporting items for systematic reviews and meta-analyses (PRISMA) model was used to perform a systematic review of the literature for this investigation.[34] This method entails a series of steps for compiling and scrutinizing the literature. To identify the existing literature regarding fish adulteration and contamination in Bangladesh, we searched online sources, including Google Scholar, Web of Science, Scopus and Science Direct. Nevertheless, it should be noted that no database, including Scopus and Web of Science, is entirely comprehensive or faultless.[35] As a result, this study utilized a manual search of various well-known sources, including Science Direct, PubMed and Springer Link, as electronic databases, as well as Google Scholar, as a search engine, to find papers related to fish adulteration and food safety in Bangladesh. The language was limited to English. However, the search covered both scholarly and grey literature connected with the research topic. The grey literature is comprised of organizational and governmental reports, whereas the scholarly literature includes peer-reviewed and non-peer-reviewed articles.[36] The keywords used in this study to search the literature are presented in Figure 1.

The six main keywords utilized to find relevant studies were 'formalin', 'adulteration', 'antibiotics', 'metals and aromatics', 'food safety' and 'Bangladesh'. Food poisoning, food safety and food hygiene are all used interchangeably in this study, as are adulteration and contamination. To find relevant papers connected to the topic, any research that addressed any of these terms or a combination of two or more terms was included. The exclusion criteria included publications in the form of conference proceedings, book chapters, books, book series, meta-analyses, reviews and systematic reviews. In the first step of the systematic literature review procedure, 192 articles were retrieved through database searching. Following the removal of duplicate articles, a total of 128 articles remained. Among these 128 papers, we found 55 previous studies most relevant to our study based on the following inclusion criteria:

- Is the paper written in English?
- Is the paper written from Bangladesh's perspective?
- Is the paper published in a journal that is not in Bell's list of predatory journals?
- Is the paper published between 2005 and 2020?
- Does the paper cover the topic of adulteration and contamination in fish?

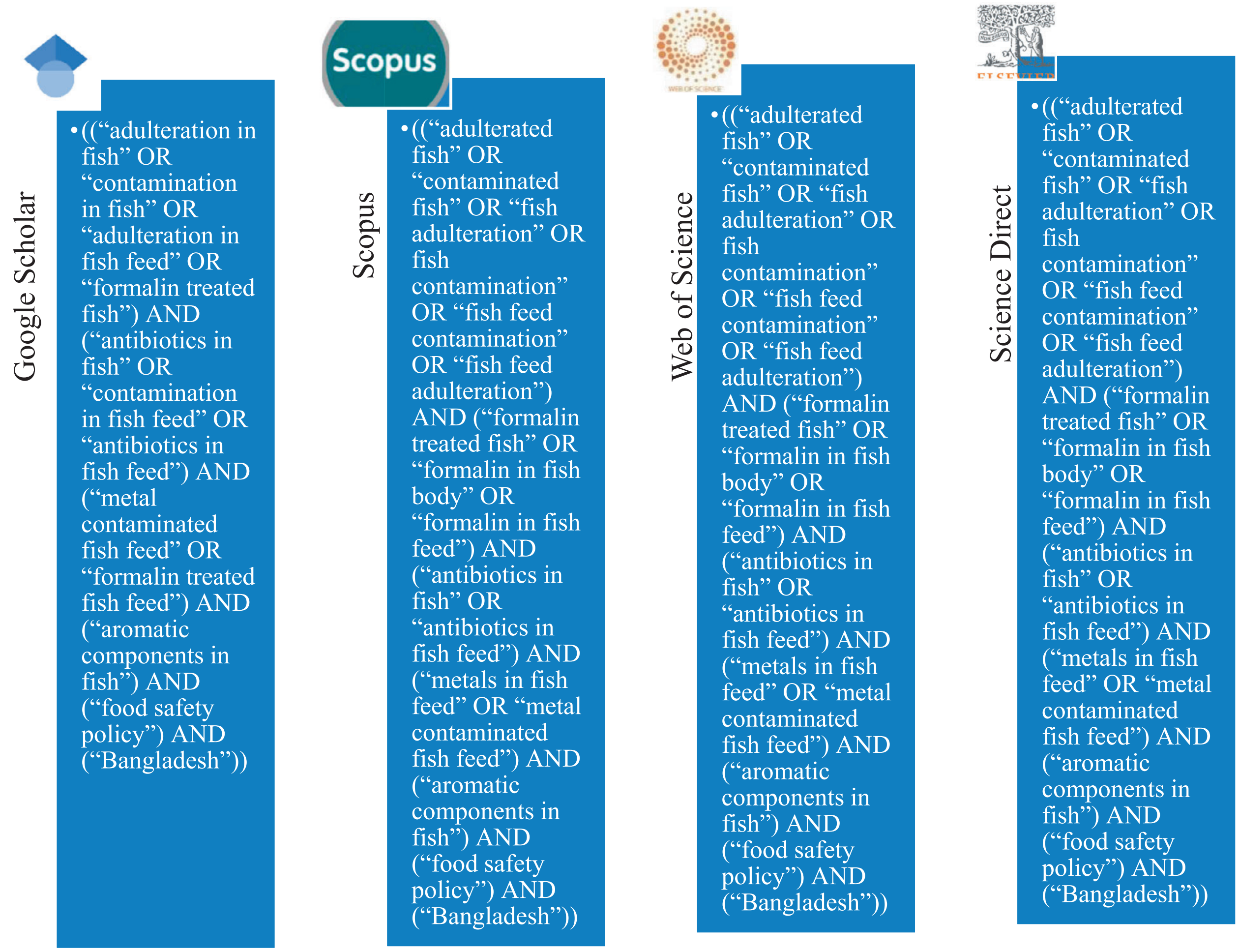

FIGURE 1 Database search string.

- Are the statistical analysis, tools and overall methodology substantive?
- Are the conclusions of the paper relevant?

The principal purpose of the screening process was to eliminate duplicate articles and research that did not meet the inclusion requirements. As a consequence, a total of 55 articles were retrieved for the eligibility stage of the systematic literature review. The abstracts and content of all the papers were thoroughly scrutinized at this stage in order to ensure that they met the study's objectives. After examining the abstracts and content, 18 papers were eliminated; thus, a total of 37 articles was chosen for this review. Figure 2 depicts the article selection procedure of this study.

3 | FINDINGS FROM PRIOR LITERATURE

3.1 | Formalin in fish bodies

To prevent the fish from decaying, formalin, a preservative, is injected into its body. According to experts, this chemical cannot be utilized to preserve fish intended for human consumption. Although formalin can prolong the shelf life of fish, the excessive use (more than the recommended level) can pose a threat to life. This chemical's ability to extend shelf life has made it extremely popular in the fish market. However, widespread usage of this method to preserve fish must come to an end, otherwise, the country is at risk of a serious health problems. There is much literature demonstrating the extent and effect of using formalin in fish bodies. Among the 37 reviewed studies, 11 of them highlighted formalin adulteration in fish samples and fish feed (Table 1). Of these 11 articles, 10 investigated formalin adulteration in fish samples or fish bodies. Only one study attempted to trace formalin in the fish feed. The findings from these studies are grouped in the following subsections.

3.1.1 | Formalin in local and imported fish

Since imported fish has to travel a long distance to reach consumers' doorsteps, the extent of formalin use differs significantly between local and imported fish owing to the need to extend the longevity of the fish. Haq et al.,[44] using a formalin testing kit, investigated probable

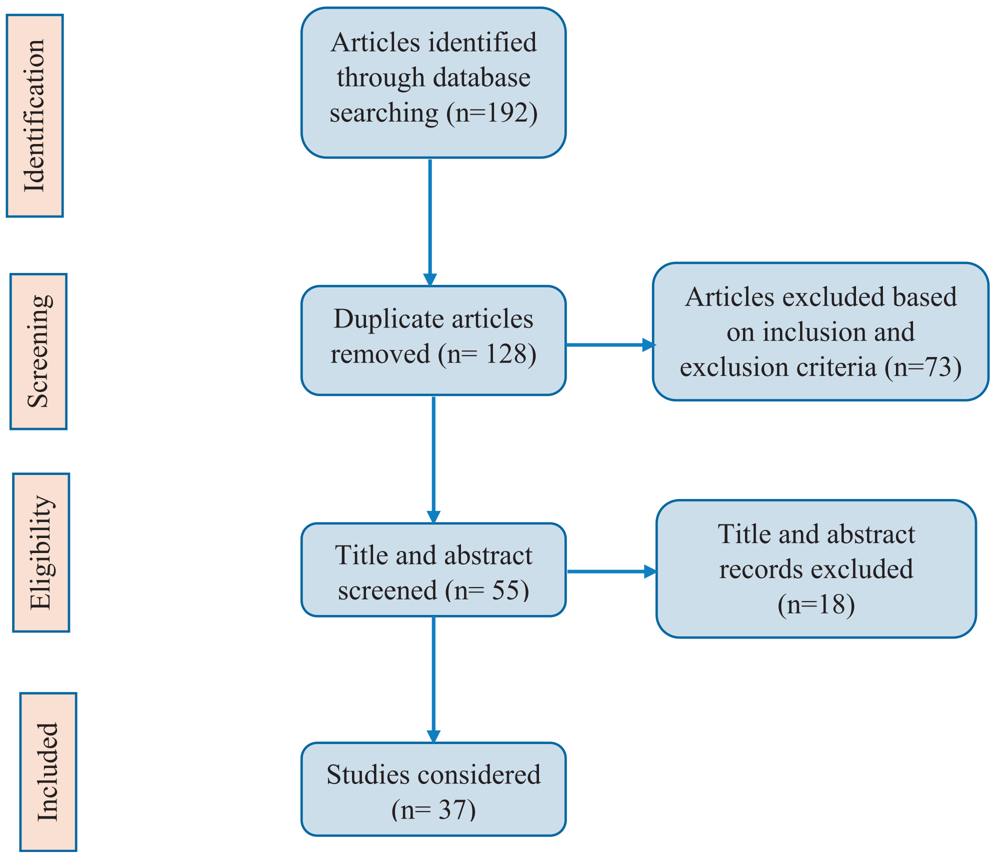

FIGURE 2 PRISMA diagram of study selection procedure.

formalin existence in fish samples collected from various markets in Sylhet. Small indigenous fish, namely kachki, mola, chapila, tengra and tit punti, were sampled in their study. They collected their samples in two different seasons, that is, summer and winter. Analysing the fish samples, they concluded that fish in the summer season were more adulterated than those in the winter season. They argued that farmers and vendors applied formalin more frequently in the summer to keep the fish fresh. However, due to cold weather in the winter, fish are naturally preserved longer, and thus formalin is rarely used. Yeasmin et al.[40] investigated the existence of formalin in imported fish. Using organoleptic quality assessment and physical and chemical analysis methods, they found that imported fish (rohu) were heavily contaminated with formalin.

Eight studies attempted to detect formalin both in local and imported fish. This kind of approach helped the researchers compare the extent and magnitude of formalin used in local and imported fish. Rahman et al.,[43] using a formalin detection kit to examine the fish samples collected from several markets in Sylhet, found that local fish were free of formalin. However, samples of imported fish were found to be adulterated with formalin. The same findings have been revealed in other studies.[37,39] Further, Yeasmin et al.[37] reported that the fish in the local markets in Mymensingh city were adulterated to a small extent. However, 0.5% to 1% of imported fish showed evidence of formalin preservation, while no presence of formalin was reported in the local fish. Paul et al.,[39] using a formalin detection kit, confirmed that 4.2% of fish in their samples collected from several markets in Jashore were contaminated with formalin. All the formalin-adulterated fish were imported, while local fish showed no evidence of formalin use. Hossain et al.[42] found that imported fish had a formalin level 3.4 times higher than fresh rohu from local ponds.

Some studies have also provided evidence of formalin adulteration in local fish. Islam et al.,[45] in their investigation of myriad markets covering Dhaka, Tangail, Mymensingh, Sherpur, Jamalpur and Manikganj districts, utilizing 939 samples of local and imported fish, ascertained that both local and imported fish were adulterated with formalin. Similar findings to this can be seen in the study of Sumon et al.,[24] who investigated the presence of formalin in 100 samples collected from markets in the Sylhet and Molovibazar districts. Based on formalin detection kit results, they stated that imported fish were more adulterated than local fish, except for catla fish.

3.1.2 | Formalin in large and small fish

Little research has been undertaken to detect differences in formalin adulteration between big fish and small fish. Islam et al.[47] reported that big fish in samples collected from Dhaka, Mymensingh, Manikganj, Tangail, Sherpur and Jamalpur districts were more adulterated in comparison to small fish. However, Paul et al.[39] found different evidence. Testing the samples sourced from markets in Jashore, they

TABLE 1 Review of studies related to formalin in the fish body.

Study	Methodology	Studied species	Findings
Yeasmin et al.[37]	Formalin detection kit	Rohu, Catla, Mrigal, Hilsha, Sarputi	No formalin in local fish. 0.5% to 1% of imported fish were contained with formalin.
Uddin et al.[38]	Formalin Detection Kit in fish	Rui, Catla, Mrigal, Ilish, Sarputi	70% of Rui fish were adulterated. Overall 50% of fish were adulterated.
Paul et al.[39]	Formalin Detection Kit	Rui, Catla, India Rui, Indian catla, Barmij Rui, Barmij catla, Ilish, Kachki, Mola, Mrigal, Kalbaus, Tilapia, Bata, Carpio, Parse, Bighead Carp, Silver Carp	4.2% of total sampled fish were found adulterated. Freshwater fish were more adulterated than marine fish. Imported fish were adulterated. No adulteration is found in local fish. Small fish were more adulterated than big fish.
Yeasmin et al.[40]	Organoleptic Quality Assessment, Physical and Chemical Analysis	Rohu	Adulterated
Sumon et al.[24]	Formalin detection kit	Rohu, Catla, Mrigal, Hilsa	All kinds of fish contained formalin. Local fish found less adulterated, except the case of Catla.
Jaman et al.[41]	Spectrophotometric method	Rohu fish, Mrigal, Shrimp, Hilsha, Catla	No formalin in local fish. Formalin was found in imported fish to various extents.
Hossain et al.[42]	Spectrophotometric method	Rohu fish	Imported fish had much greater formalin levels (3.4 times) than fresh rohu from local ponds.
Rahman et al.[43]	Formalin detection kit	Rohu fish, Mrigal, Shrimp, Hilsha, Catla	Local fish were formalin-free. Imported fish were adulterated with formalin to some extent.
Haq et al.[44]	Formalin detection kit	Local. Small fish. Summer and winter season	Fish of the summer season contained more formalin compared to fish of winter.
Islam et al.[45]	Formalin detection kit	939 samples including Mrigal, Rui, Kal Baous, Catla, Silver carp, Boal, Elish (*Tenualosa ilisha*), Tilapia, Aaeer, Baeen, Chitol, Foli, Koi, Sorpunti	Greater adulteration in imported fish than local fish. Big species were more adulterated compared to small fish.
Wahed et al.[46]	In-house validated HPLC method	Did not mention	Formalin was found within the permitted threshold by the United States Environmental Protection Agency (2010).

found that big fish contained less formalin than small fish. However, this does not represent the whole picture, as the study only investigated Jashore. In contrast, the findings of Islam et al.[45] seem to be more comprehensive, as they covered about six districts in their study.

3.1.3 | Formalin in fish feed

In the literature, almost all the articles investigated formalin adulteration in the fish body or fish organs. The only exception is the study by Wahed et al.,[46] who aimed to disclose whether fish feed contains formalin. Through inspection by adopting an in-house validated HPLC method, they claimed that some fish feed sold in the market contained formalin, although the amount of formalin was within the permissible range. However, this finding reveals how formalin is being used, surreptitiously, in fish feed.

3.2 | Antibiotics and growth promoters

Antibiotics are used to prevent and treat infectious diseases both in humans and animals around the world.[48] Antibiotics are also employed by fish farmers to keep fish free from microbial diseases, while growth promoters are utilized to accelerate the growth of the fish within the quickest time. The imprudent usage of these antibiotics contributes to the formation and spread of antimicrobial resistance (AMR). AMR's widespread prevalence is regarded as posing a serious public health danger.[49] Hossain et al.[50] and Shamsuzzaman and Biswas[51] found several antibiotic levels exceeding the permissible level in the farm water of hatcheries and shrimp farms. Conversely, Islam et al.[52] found that hatcheries were free from antibiotics, while growth promoters were indiscriminately applied in farms by farmers without having appropriate knowledge. The authors reported that, out of 11 fish feed samples, 10 were contaminated with antibiotics. Many local fish companies encourage and pressurize poor farmers to buy

TABLE 2 Relevant studies related to the use of antibiotics and growth promoters in fish.

Study	Studied elements	Results	Reason
Shamsuzzaman and Biswas[51]	Chemicals, antibiotics, Growth promoter	Farmers used antibiotics for disease treatment and rapid production.	Lack of knowledge and lack of awareness.
Hossain et al.[50]	Chemicals, antibiotics and growth promoters.	Three out of nine antibiotics were found overused. Immunity enhance Vitex C and Aqua C were found to be deviated from the standard dose of use. Oxyflow, Oxylife and Oxy-Gold, applied for increasing dissolved oxygen were found overdosed.	Influence from the companies induce farmers to use growth promoters, antibiotics and chemicals.
Islam et al.[52]	Antibiotics	Hatcheries were free from contamination. 11 shrimp feed and 10 fish feed samples contaminated with antibiotics.	–

and use their products without providing proper guidelines. Table 2 summarizes the findings of previous studies conducted in Bangladesh focusing on the use of antibiotics and growth promoters in fish farms.

3.3 | Metals used in fish feed

Several studies have detected the existence of hazardous metals in fish bodies (Table 3). Raknuzzaman et al.[53] revealed that fish at Cox's Bazar were contaminated with harmful metals. This contamination was linked with industrial waste and the mismanagement of the hatcheries. Shovon et al.[54] showed that the level of lead far exceeded tolerable levels in fish organs. Reviewing all the studies related to metal contamination, we identified several metals that were frequently found in the fish feed samples, most notably chromium (Cr), lead (Pb), cadmium (Cd), iron (Fe), cobalt (Co), arsenic (As) and mercury (Hg). Sabbir et al.[55] reported that lead and chromium levels surpassed the standard limits. Sultana et al.[56] found that chromium and cadmium levels were also worryingly high. Saha et al.[57] found excessive levels of iron, lead, cobalt and chromium in fish feed. Islam et al.[58] reported that mercury, cobalt and lead exceeded the permissible limit in prawn feed. Conversely, Shamshad et al.[59] Ullah et al.[60] and Tithi et al.[61] claimed that metals were within the safety range.

3.3.1 | Chromium contamination in fish feed

Sabbir et al.[55] and Saha et al.[57] reported an excessive level of chromium contamination in the fish feed made by various companies and collected from different markets. They highlighted that local feed companies supply poor-quality feed to the farmers. Impoverished farmers are inclined to purchase these low-quality feeds at a cheap price. The study also asserted that low efficiency and inadequate knowledge of manufacturing the fish feed were the main reasons for such contamination. If guidelines are ignored in making fish feed, hazardous elements can enter into the value chain through the feed. Sultana et al.[56] examined the farm water of several selected fish farms in Mymensingh district, finding that they were contaminated with a higher level of chromium than the acceptable threshold. They also indicated that industrial waste was a probable reason behind this contamination. Farm mismanagement and the lack of knowledge of proper farming practices were also reported. A parallel finding to this was illustrated in the study of Saha et al.[57] who showed that high levels of various hazardous chemicals existed in fish feed. In contrast, Quader et al.[71] found that the concentration of chromium in the fish feed sampled was not hazardous.

3.3.2 | Lead and iron in the fish sample and fish feed

A notable number of studies have shed light on the lead contamination in the fish feeds of different companies available in the local markets of different regions in Bangladesh. Kundu et al.[64] conducted their investigation on the fish feed of the most well-known companies in Bangladesh. Inspecting the samples, they revealed that the lead concentration was far higher than the maximum permissible limit. Saha et al.[57] examined multiple locally made fish feeds. Testing the samples with an atomic absorption spectrometer, they came to the conclusion that the lead concentration surpassed the acceptable limit. However, they did not mention in which place(s) they had carried out their study. Sabbir et al.[55] also claimed that locally produced fish feed sampled from the markets in Satkhira and Bagerhat districts contained alarming levels of lead. In line with these findings, Islam et al.[58] found lead contamination in the local fish feed collected from Satkhira and Bagerhat. Their report underscored that the lead concentration was remarkably higher in the fish feed of Satkhira and Bagerhat compared to that of Dhaka city. However, Quader et al.[71] showed that the lead detected in *Harpadon nehereus*, *Pistacia chinensis* and *H. ilisha* was not dangerous, while Baki et al.[65] reported that lead concentrations in the species *Rastrelliger kanagurta*, *Hosta nigresceus* and *Sargocentron rubrum* were greater than the recommended limit for food safety. The feed samples of the 10 largest feed companies in Bangladesh have also been reported to be contaminated with an excessive level of iron.[57]

TABLE 3 Findings of previous studies concentrating on the metal used in fish production.

Study	Method/Tool	Studied elements	Result	Reason
Shamshad et al.[59]	FAAS, CV-AAS and HG-AAS.	As, Cd, Pb, Hg and Cr	The concentration of the metals found within the permissible level	–
Ahmed et al.[62]	Inductively coupled plasma mass spectrometry (ICP–MS)	As, Cd, Pb, Cr, Ni, zinc (Zn), Selenium (Se), Copper (Cu) and Molybdenum (Mo)	Among the three researched fish species *O. mossambicus* showed higher content of As.	–
Fatema et al.[63]	Atomic Absorption Spectrometry	Pb, Cd, As, Cr and Hg	As and Hg concentration in the Gher and river shrimp samples is below the acceptable level.	–
Islam et al.[47]	Inductively coupled plasma mass spectrometer (ICP-MS)	Cr, nickel (Ni), Cu, As, Cd, Pb	Fish species have Ni, Cd and Pb metal concentrations over their respective maximum permissible levels.	–
Sultana et al.[56]	Atomic Absorption Spectrophotometer	Cu, Zn, Pb, Cd and Cr.	Excessive level of Cr found; Cd level was slightly greater than the standard level.	Excessive Cr may be a result of waste materials of land or indiscriminate use of fertilizer and Cd comes from contaminated fish feed
Raknuzzaman et al.[53]	Trace metal concentration	Trace metals	In fish and crabs harvested from Cox's Bazar, As and Zn concentrations were extremely high.	Buoyant industrial activities around the area and mismanagement of hatcheries.
Kundu et al.[64]	Atomic Absorption Spectrometer	Cu, Fe, Pb, Cd, Sodium (Na), Cr, Ni	The concentration of Fe, Cd, Pb and Na found in fish muscles and fish feed exceeded the recommender level.	Improper management and lack of integrity of the fish feed companies.
Islam et al.[58]	Energy Dispersive X-ray Fluorescence (EDXRF), Spectrometry (Epsilon 5, PANalytical, Australia)	Materials including As, Cd, Cr, Pb, Co, Hg	Higher Hg, Co and Pb reported in the prawn feed. Cd exceeded the permissible limit for half the examined feed brands.	Fish samples are contaminated via contaminated feed.
Ullah et al.[60]	GF-AAS	Pb, Cd and Cr	Metal levels satisfied the standard level.	–
Shovon et al.[54]	Atomic Absorption Spectrophotometer	Pb, Ni and Cd.	The level of Pb and Cd was exceedingly higher across the fish organs samples while Ni was within the standard limit.	Did not mention
Saha et al.[57]	Atomic Absorption Spectrometer	Cd, Pb, Ni, Fe, Cr, Co, Cu and Zn	Fe, Pb, Co and Cr concentrations in the various fish feed brands surpassed the permissible limits suggested by the FAO/WHO.	Ignorance and aloofness of the fish feed producers.
Baki et al.[65]	Atomic absorption spectrometer	Cr, manganese (Mn), Cu, Zn, As, Cd, Pb, Hg and Fe	The marine fish's heavy metal hierarchy is Fe > Cd > Zn > Pb > Cu > Cr > Mn > Hg	–
Sabbir et al.[55]	Atomic Absorption Spectrometer	Pb, Cd, Cr, As and Hg	Pb and Cr exceeded the standard limit.	Improper production practices by the local feed companies and small farmers.
Rahman et al.[5]	Energy dispersive X-ray fluorescence (EDXRF)	Cr, Cu, Pb, Mn and As	There is no danger of adulteration with the examined fish samples.	–
Tithi et al.[61]	Atomic Absorption Spectrophotometer	Cd, Pb and Cr	All the metals were found within the standard level. Feed samples were safe.	–

(Continues)

TABLE 3 (Continued)

Study	Method/Tool	Studied elements	Result	Reason
Alam and Haque[66]	LC–MS/MS, GC–MS and AAS	Antibacterial substances, nitrofuran metabolites and other chemicals (ANCs)	Pangasius and tilapia contained Pb and Cr. Old tilapia ponds contained much greater levels of As but no Hg.	–
Maruf et al.[67]	Atomic absorption spectrometer	Ni, Cu, Pb, Cd and Cr	In pangasius tissues, there was noticeably higher Cd, Pb, Ni and Cu deposition.	–
Saha et al.[68]	ICP-OES (Optima-7000DV)	Pd, Cd, Cr, Cu, As, Hg in different commercial fish feeds and fish samples	The concentration of As is within the safe level, but Pb, Cr and Hg in the tested feeds and fish samples were greater than the allowed limit.	Accumulate metals from the diet, water and sediment
Moxness Reksten et al.[69]	Certified Reference Materials (CRM)	As, Cd, Hg and Pb	All tested species did not have Hg and Pb concentrations that exceeded the upper limits	–
Shorna et al.[70]	Atomic absorption spectrometer (AAS)	As, Cd, Cr, Hg, Ni and Pb	Despite the presence of heavy metals in the fish sample, the concentration did not exceed the standards for food safety	Feeding habits and living habitats
Quader et al.[71]	Atomic Absorption Spectrophotometer	As, Pb and Cr	As accumulation value was deemed critical while Pb and Cr were not harmful.	Effluent discharges from industrial and siderurgical plant.

3.3.3 | Cadmium and cobalt contamination

Cadmium contamination both in the fish feed of various brands (such as Quality, Mega and Rupshi) and in tilapia fish muscles collected from different fish farms was recorded in the study of Kundu et al.[64] Similarly, Islam et al.[58] reported that most of the fish feed produced by companies contained higher cadmium concentrations than the permissible limit. Meanwhile, apart from the contamination in fish feed, Sultana et al.[56] using an atomic absorption spectrophotometer to examine farm water, also found cadmium at a slightly higher level than the standard threshold. In the Mymensingh district of Bangladesh, Maruf et al.[67] examined pangasius fish samples and various marketed feed samples and discovered that cadmium deposition was considerably greater in the studied fish tissues and feed samples. Notably, the study of Islam et al.[58] traced the potential health risks regarding cobalt contamination to the fish feed made available by companies in Bangladesh. Similarly, Saha et al.[57] found that most of the fish feed sold by companies contained cobalt concentrations surpassing the tolerable threshold.

3.3.4 | Arsenic compounds in fish bodies and fish feed

In aquatic ecosystems, such as ponds, streams, canals, lakes and groundwater, arsenic, a hazardous element, is prevalent.[72] However, arsenic has also been identified in fish bodies, similar to the presence of other metals, in various regions of Bangladesh. In several organs (gill, liver, muscle and kidney) of three fish species (*H. nehereus*, *P. chinensis* and *H. ilisha*) caught off Chattogram coast of Bay of Bengal, Quader et al.[71] found that the concentration of arsenic was excessive, that is, higher than the WHO/FAO recommended level. Ahmed et al.[62] gathered three fish samples (*Labeo rohita*, *Pangasius* and *Oreochromis mossambicus*) from 30 distinct agroecological zones of Bangladesh. They discovered that the fish samples had greater levels of arsenic contamination than the maximum recommended level. Similarly, extremely high levels of arsenic concentration were discovered in fish samples taken from the Bangladeshi Cox's Bazar region in the study of Raknuzzaman et al.[53] However, Alam and Haque[66] found higher levels of arsenic concentration in tilapia ponds, while Saha et al.[68] and Fatema et al.[63] revealed that the mean concentration of arsenic in the tested feeds and fish samples were within the safe limit. Further, Rahman et al.[5] gathered five economically significant marine fish from Bangladesh's northern Bay of Bengal (*Sillaginopsis panijus*, *Trichiurus lepturus*, *Harpadon nehereus*, *Rita rita* and *Coilia dussumieri*) and discovered that the designated tropical marine fish species were safe since they were free from excessive arsenic contamination.

3.3.5 | Mercury concentration

Several studies have also identified excessive levels of mercury in tested fish samples and fish feeds. For instance, Islam et al.[58] reported

TABLE 4 Previous studies related to the aromatic contamination.

Study	Method	Studied element	Results	Reason
Tareq et al.[18]	Gas Chromatography–Mass Spectrometric (GC–MS)	Polycyclic aromatic hydrocarbons (PAHs) (naphthalene, fluorene, phenanthrene, anthracene, pyrene, benzo(a)anthracene, chrycene and benzo(a)pyrene)	Naphthelene, benzo(a)pyrene exceeded the recommended level (5.0 mg/kg)	Did not mention
Hossain[32]	Spectrometric (GC–MS)	Naphthalene	Naphthalene was found greater than the tolerable level	Industrial wastages and tannery wastages caused contamination

TABLE 5 Existing important legal framework of food safety and fish adulteration.

Important acts, ordinances and rules	Description	Gaps and deficiencies
Pure Food Ordinance, 1959	This ordinance provides insight into food adulteration, the formation of the National Food Safety Advisory Council (NFASC) to control the manufacturer and safe food sale for human consumption.	Some definitions, such as additives, adulteration, container, contaminant, contamination, Council and so forth, are not exhaustive and do not meet international standards. The NFASC merely serves as a consultant and has no administrative power. The Ordinance does not specify any qualifications for Inspectors to be appointed and it does not clearly provide information on penalties for making, selling or storing tainted, unsanitary or health-harming food.
Pure Food Rules, 1967	This rule provides a detailed description of standards, food preservatives, the colour used in food, labelling of food additives.	These rules did not entirely consider Codex standards, protocol and practices including Hazard Analysis and Critical Control Point (HACCP).
Fish and Fish Products (Inspection and Quality Control) Ordinance, 1983	The Ordinance provides the Government the power to set grades, quality and standards of fish and fish products for ensuring nutrition security. Penalties for violations have also been specified. It has received due importance of HACCP principles.	The sampling criteria are not in accordance with international standards.
Fish and Fish Products (Inspection and Quality Control) Rules' 1997	In these rules, a clear indication of the provisions to be pursued in fish processing, export, chemical use in fish culture, the operational procedure of processing plants and implementing quality assurance programs based on HACCP principles were provided.	The number of representative samples for testing is not determined according to Codex or international norms. The traceability issue does not include a mass balance check. The competency-based accredited criteria for inspectors need to be upgraded even more.
The Bangladesh Standards and Testing Institution Ordinance, 1985 and BSTI Act, 2003	The purpose of this Ordinance is to create an institution for standardization, testing, quality control, grading, metrology and labelling of food items.	BSTI likes to focus on inspection services, quality control and punishment concerns rather than investing more work into standardizing different food items and establishing grading of fresh produce and processed products.
Food Safety Act, 2013	This act regulates and supervises the food sale activities linked with production, processing, storage, distribution and import; thus, it ensures safe food access through applying suitable scientific methods.	According to this act, the maximum allowable limit for food additives or processing aids has yet to be released. There are no documented regulations on maximum residue limits for growth promoters, pesticides and insecticides.
Formalin Control ACT 2015	This Act provides information on the definition, licensing, investigation, formalin control committee and offences and punishment of illegal formalin use.	There is a lack of cooperation among the regulators who are responsible for formalin regulation. Investigations are not carried out properly under this Act due to a shortage of human resources.

a higher level of mercury in the prawn feed in Bangladesh. Saha et al.[68] found that, while the mean concentration of arsenic was within the safe level, the concentrations of mercury in the tested feeds and fish samples were greater than the allowed limit. Fatema et al.[63] found that the mercury concentration in the Gher and river shrimp samples was below the acceptable level. Using samples taken from Bangladeshi maritime waters, Moxness Reksten et al.[69] examined the levels of arsenic, cadmium, mercury and lead in 24 distinct marine fish species from the Bay of Bengal. They discovered that mercury levels in fish of all species were significantly lower than the EU regulatory limits. Meanwhile, Islam et al.[47] found higher levels of mercury than the permissible limit in fish samples collected from the Paira River of the Patuakhali district located in the southern part of Bangladesh. However, Shorna et al.[70] found that mercury in fish samples collected from the Old Brahmaputra River in Bangladesh did not exceed the standards for food safety. Alam and Haque[66] also found no level of mercury concentration in tilapia and pangasius ponds.

3.4 | Aromatic contamination

Recently, a new sort of contamination, caused by aromatic elements, has emerged. Like formalin, antibiotics, metals and different types of chemicals, aromatic substances pose a threat to mankind. Table 4 summarizes the studies related to aromatic contamination in fish bodies. The first study in this context, by Hossain,[32] revealed the presence of a greater level of naphthalene than the maximum limit in the Bangshi river. Digging deeper into that issue, it should be noted that, if the water becomes polluted, its inhabitants will also become vulnerable to contamination. This study noted that the source of the contamination was waste from industries and tanneries operating in the surrounded area. Not only is the water quality deteriorating, but also the fish living there are being harmed, and this contamination, in turn, is entering the human body through fish intake. However, the study of Tareq et al.[18] reported another startling fact regarding some restaurants in Dhaka city. They revealed that the smoked fish collected from various restaurants contained aromatic contamination, which may cause a serious risk to the human body.

3.5 | Existing legal issues and future policy framework

Food safety is regarded as a critical issue in Bangladesh, as the country's customers have been harmed by major food adulteration. Bangladesh's constitution places a considerable emphasis on food safety, such as Article 15, which states that 'It is a fundamental responsibility of the state to secure provisions of the basic necessities of life including food'. According to Article 18 of the constitution, 'States shall raise the level of nutrition and improve public health as its primary duties'. Both Articles imply that consumer and state food safety requirements must be met through the implementation of suitable legislation. Bangladesh has a number of laws and regulations in place to ensure health and safety standards. Multiple ministries are associated with food control initiatives in Bangladesh; however, their roles and responsibilities are not always well delineated, resulting in gaps and overlaps. Food safety was previously governed by the Bangladesh Pure Food Ordinance 1959 and the Bangladesh Pure Food Rules 1967.

Table 5 provides insights into some important food safety ordinances, acts and rules in Bangladesh, as well as gaps and deficiencies. For instance, Bangladesh Pure Food Ordinance 1959 has some limitations, although it was amended in 2005. These deficiencies should be rectified in a future amendment to ensure proper food safety. If some definitions need to be revised, modified or added in the light of international standards, then establishing a food safety authority with subsidiary entities, such as scientific committees and panels under the executive body, would be a more effective method. Bangladesh, in this context, could build a model for a food safety authority that is more similar to the Indian model. The recommendation for the Indian model is appropriate because of the parallels in the socio-cultural origins and legislative frameworks of the two countries. Under the provision of Section 8 of the present Ordinance, it is the local authority that determines the standard of food purity. However, local governments lack the necessary technical skills and logistical assistance to establish such a standard.

The Bangladesh Pure Food Rules 1967 were enacted by the government in accordance with Section 49 of the Bangladesh Pure Food Ordinance 1959; however, there have been no amendments to the Rules since then. Furthermore, the Ordinance was passed in 1959, long before the Codex Alimentarius Commission, of which Bangladesh is a member. As a result, the Rules do not use Codex standards for a number of issues. Food labelling, food additives, pollutants in foods, food hygiene, techniques of analysis and sampling, risk evaluation procedures for assessing chemical and microbiological safety of food products and so forth, are not covered in this law. This Rule needs to be updated to reflect the current state of the country and international standards.

Bangladesh passed the Fish and Fish Products (Inspection and Quality Control) Ordinance in 1983 to regulate the inspection and quality of fish and fish products. A licence is required to operate a fish processing and packing facility under this Ordinance. It mandates that fish must be processed in compliance with sanitary norms and conditions. The Ordinance also makes it illegal to export fish or fisheries products without obtaining a health certificate. The Department of Fisheries (DOF) has full responsibility for fish inspection and quality control. Under this Ordinance, a traceability system based on EU requirements was implemented, as well as Hazard Analysis and Critical Control Point (HACCP) standards, in some selected export-oriented fish farms. The Fish and Fish Product (Inspection and Quality Control) Rules 1997, which contains HACCP standards for shrimp processing factories, further implements this Ordinance.

The Bangladesh Standards and Testing Institution (BSTI) has been established to standardize, test and quality control fresh and processed food items through the BSTI Ordinance 1985 and BSTI Act 2003. However, the BSTI's functionalities and this Ordinance suffer from a number of flaws. Rather than focusing on the standardization of various fresh and processed food items, the BSTI prefers to focus on inspection services and penalty issues. There are no defined inspection, criteria, or sampling methods for individual products. Furthermore, this Ordinance does not effectively address qualification and training in the field of food safety inspection. Every 5 years, the good practice standards of these institutions should be amended to ensure effective policy.

The Food Safety Act 2013 repealed the Pure Food Ordinance 1959 (as amended in 2005). A food safety rule was also issued by the government in 2014. Since 1 February 2015, the Food Safety Act has been in effect. Provision has been made in this Act to establish a single agency, the Bangladesh Food Safety Authority (BFSA), to combat rampant food adulteration and to safeguard food safety in the country. Despite being entrusted with a wide range of responsibilities, the BFSA lacks the necessary human resources to combat adulteration effectively. It is unclear how the BFSA will coordinate actions with other ministries and the BSTI. Although outlined in the Act, the National Food Safety Management Advisory Council has yet to be formed. However, it is critical to provide the BFSA with the necessary trained/skilled staff, infrastructure and financial backing if it is to succeed in its duty as the 'watchdog' for food safety standards.

4 | DISCUSSION

There was a time when billions of people used to starve, and many lost their lives to famine. But times have changed, with food security being effectively achieved by many nations, including Bangladesh. Achieving food security, however, does not yield any benefits if food safety is not ensured. In light of this, the modern world is making efforts to tackle the problem of the adulteration and contamination of food to ensure a healthy and prosperous future. Accordingly, fish, as one of the most popular consumed foods and an important source of protein in dietary requirements, needs to be safeguarded from adulteration and contamination. Among all the hazardous elements, the unlawful use of formalin is becoming a widespread phenomenon throughout the world. Even developed nations are facing this issue.[73–80]

As clearly highlighted in the literature, formalin is deliberately applied in fish preservation in many cases. Formalin has been found to be relatively more prevalent in imported and big fish in Bangladesh.[40,47] In Hossain et al.'s[42] study, the mean level of formalin was found to be 402.35 mg/kg in imported fish, substantially greater than local fish (118.60 mg/kg). Formalin is thought to be added to imported fish anywhere along the marketing chain once they enter Bangladesh from neighbouring nations.[37,39] Further, some studies have claimed that fish marketed in Dhaka city are more formalin-adulterated than in other markets.[4,38] According to the World Health Organization (WHO), natural levels of formaldehyde in fish range from 1 to 98 mg/kg.[81] A WHO report advised that fish have a natural formaldehyde concentration of 6–20 mg/kg and that shellfish have a formaldehyde content of 1–100 mg/kg.[82] Similarly, the Malaysian Food Act (1985) and Malaysian Food Regulation (1985) specified a maximum limit for formalin in fish and fish products of 5 mg/kg.[79] However, the use of formalin above the recommended level as a preservative in fish and other food items by fraudulent sellers remains a source of concern. Although some of the formalin is rinsed off during shipping because of ice melting, the content in the fish tissue may still be significant.[43] Moreover, after the fish has been bathed in formalin, it cannot be entirely removed by soaking, heating or frying.

One of the drawbacks of the research examined in this review is the validity and reliability of formalin detection techniques. Only two investigations[41,42] used the spectrophotometric approach to detect formalin levels, which is a straightforward, reliable and suitable technique.[41] Other research has adopted the formalin detection kit, developed by the Bangladesh Council of Scientific and Industrial Research (BCSIR), which simply reveals the existence or absence of formalin (only qualitative) applied unlawfully to fish.[39] There have also been notable debates about the authenticity of a formalin kit (Formaldehyde Meter Z-300) imported by the Ministry of Fisheries that measures the level of formalin in the air rather than in fish.[83] The Bangladeshi High Court ordered the government to purchase new formalin detection kits in order to reliably reveal the presence of formalin in food products sold throughout the country.[84]

The perpetrators of these illicit actions not only jeopardize other lives but also put themselves at risk. Formalin accumulates in the body over a long period. The implications of formalin on one's health can indeed be chronic, meaning they appear after long periods and repeated exposure, such as severe irritation, watery eyes, gastrointestinal issues, kidney failure, liver damage and central nervous system dysfunction, while it also is suspected to cause cancer. Furthermore, the effect of formalin on human physiology can appear as diverse mucosal inflammation symptoms affecting pulmonary functioning, and dermatitis has also been well documented in recent literature.[85] When formaldehyde levels in the ambient atmosphere surpass 2 ppm, skin issues, such as eczema and skin irritation, occur.

As the aforementioned investigations have shown, a significant amount of the occurrences of antibiotic- and chemical-based fish adulteration are unintended, caused by farmers' lack of knowledge. Fish farmers lack the required knowledge regarding proper disease management and therefore misinterpret the rational doses of antibiotics and chemicals. Antibiotics are one of the most common types of feed additives used as growth promoters to enhance fish growth through the synthesis of digestive enzyme supplements.[86] Several antibiotics have been used as growth promoters in fish farms.[86] The antibiotics authorized for use in Bangladesh to treat specific diseases are tetracycline, oxytetracycline, salfomithoxin, sulfadimethoxine, sulfadiazine, amoxicillin, oxilinic acid, difloxin, chlortetracycline and sulfanilamide and chelinos. These antibiotics have been marketed under several brand names and have various active ingredients. Among the different ingredients, three active ingredients (doxycycline, colistine sulphate + vitamin premix + mineral, oxytetracycline HCl 200 mg and oxytetracycline 200 mg) are overused by fish farmers.[50] Farmers indiscriminately add these antibiotics to the supplemental feed to avoid diseases before they even have an issue. The majority of studies on the benefits of antibiotics and growth promoters on cultured aquatic animals have focused on reduced mortality or, conversely, higher survival and disease resistance.[87] Contrarily, the overuse of antibiotics and growth promoters can cause low disease resistance in the fish, as well as posing a danger for human consumption. Veterinary and livestock education could serve to minimize the threat of antibiotics in the fisheries sector, particularly in aquaculture. Instead of antibiotics, probiotics, vaccinations, phage therapy and essential oil products may be prudent alternatives for disease control. Farmers can use a traditional feeding system along with the proper fingerling stocking density to enhance the fish growth instead of using growth promoters at excessive levels.

It is worth mentioning that irrational antibiotic use in the food chain is associated with resistant diseases in human health caused by antibiotic-resistant strains. What is particularly concerning is the fact that the agricultural application of antibiotics is showing a worrying impact on children's health, threatening their growth and development. Indiscriminate antibiotic use in farming practices, including fisheries, has negative effects on the human body in three distinct ways. First, humans can be afflicted by a resistant pathogen of farming origin by exposure to animals or bacteria ingestion from contaminated fish, meat or water, but the pathogen is not spread from person to person. Second, humans can be infected or colonized with a resistant bacterium, which leads to continued transmission among humans, with many of these individuals falling sick. This scenario involves a microorganism that may be inherently lethal to people or a commensal with the propensity to trigger bacterial infections breaking through the 'species barrier'. Third, horizontal gene transfer introduces resistance genes originating in the farming context into human diseases. Antibiotics absorbed in humans ultimately select the ensuing resistant lineages.[88] Thus, protecting human health from the overuse of antibiotics is a vital issue, with particular focus required on fishing practices.

Another worrying finding is that metal used in fish feed is posing a deadly threat to human lives. Heavy metal contamination in aquatic ecosystems is increasing at an alarming rate and has become a major global issue.[89] After evaluating several studies, the present paper discovered that fish samples and fish feed contain various harmful trace heavy metals, such as lead, cadmium, chromium, cobalt, iron, arsenic, mercury and so forth. These substances are being found at much higher levels than the recommended standards. To obtain greater profits, dishonest feed millers are contaminating fish feed with heavy metals. Trace metals are necessary for human health and help to avoid diseases, but when they are in high concentrations, they can have a carcinogenic effect on humans.[90] When metals enter living beings, they mix with enzymes, DNA molecules and proteins to produce highly stable bio-toxic substances, leading to malfunctioning and impeding bioreactions. Notably, allergies, hyperpigmentation and other side effects are caused by metals.

For instance, lead damages both the respiratory and digestive systems, as well as suppressing the immune system. Furthermore, children's intelligence and neurological systems are particularly vulnerable to this metal.[91,92] Arsenic exposure has both carcinogenic and non-carcinogenic consequences over time.[62] Moreover, arsenic and cadmium can promote cancer induction as a result of the gastrointestinal absorption system. They invade the liver, placenta, lungs, kidneys, brain and bones once absorbed. Chromium can occur in a variety of oxidation states.[93,94] Hexavalent chromium (VI) is extremely soluble and mobile and is toxic to the skin, liver, kidneys and respiratory organs, causing dermatitis, renal tubular necrosis, nasal septum perforation and lung cancer, among other disorders. Therefore, chromium is classified as a group-1 carcinogen.[89] Furthermore, cadmium, lead and nickel ingestion also impairs human organs.

Surprisingly, our study found aromatic contamination in fish served in one of the restaurants in Dhaka city. Restaurant owners are prone to mixing aromatic substances to improve the food taste. This finding suggests that fish meals sold in restaurants in Bangladesh need to be investigated further for possible aromatic substances. Food processing (such as drying and smoking) and high-temperature cooking (roasting, grilling and frying) are key sources of PAHs.[25] Aromatic substance ingestion entails both acute and chronic hazards for human health. The acute impacts may include diarrhoea, vomiting, nausea, eye irritation and skin irritation, while the chronic effects may lead to liver and kidney damage, coupled with asthma and immune dysfunction.[95]

Although concerted and combined toward food safety by the WHO, FAO and other national and international organizations are helping to change the scenario, adulteration and contamination in the fish supply chain requires further surveillance. Since fish products serve as a prime protein source for a significant portion of Bangladeshi people, their supply chains should be devoid of improper cultural practices, ensuring eco-friendly management and proper public health awareness. Perpetrators engaged in adulteration should be targeted by the law and regulations. Otherwise, Bangladesh will likely suffer serious public health hazards, which in turn will hinder the economy's sustainable development due to unhealthy manpower. Furthermore, fish exports will likely shrink if exporters fail to provide international-grade fish products. To ensure food safety standards, the government of Bangladesh has passed several Acts, Ordinances, Rules and Laws. However, most of the rules and regulations are not in accordance with international standards. Based on the gap analysis of food safety-related policies and Acts, it is clear that Bangladesh's current food safety regulations do not cover critical aspects of food safety and require urgent modernization. Bangladesh, in particular, lacks a consolidated food safety law, as well as comprehensive regulations and standards to assure food safety that is commensurate with modern Codex standards, guidelines and codes of practices. Food safety policies should be reformed to encompass safety throughout the entire food supply chain based on the FAO New Model Food Law and backed up by current food safety norms and regulations.

5 | CONCLUDING REMARKS AND FUTURE RESEARCH DIRECTION

Food adulteration with poisonous substances that are harmful to human health has become an epidemic in Bangladesh, and fish is no exception. The adulteration of fish in Bangladesh takes several forms, including the use of formalin both in the fish body and fish feed, antibiotics and growth promoters, metal in the fish feed and aromatic substances in the fish body. The current study has discovered that fish in Bangladeshi marketplaces were mostly contaminated by formalin, with large and imported fish being the most impacted. However, there are discrepancies concerning the testing tools used to identify formalin in fish and other foods, with most of the studies using formalin detection kits developed by the BCSIR. This research has shown revealed that several previous studies have identified metals in fish and feed samples, including chromium (Cr), lead (Pb), cadmium (Cd), cobalt (Co), iron (Fe), arsenic (As) and mercury (Hg). Additionally, fish farmers and feed millers are utilizing antibiotics and growth promoters in excess of the permitted levels. Aromatic compounds, formalin, metals, antibiotics and other forms of chemicals are harmful to humans and have recently been detected in fish. The long-term consumption of adulterated fish may increase the population's risk of major health problems, such as cancer. This will lead to an increase in morbidity and mortality, as well as a surge in the country's healthcare costs.

Since the application of formalin testing techniques is controversial, the use of precise, cutting-edge and sensitive techniques is required. Furthermore, strong laws/policies are urgently needed to prevent fish adulteration and ultimately ensure food safety across the country. Several Laws and Acts have been enacted by the Bangladeshi government in order to address the root cause of the problem. For example, the government passed a new 'Safe Food Law 2013' that came into effect in February 2015. However, the majority of laws and rules are out-of-date and must be reframed immediately in accordance with international standards. The relevant authorities should prioritize adulteration as a public health issue, and they should effectively implement laws to combat it. Academics and researchers should perform extensive and follow-up studies to look into the long-term health consequences (carcinogenic risk assessment) of adulteration on human lives.

Although this study has attempted to demonstrate the existing fish adulteration situation in Bangladesh, there is a room for improvement in research activities regarding this issue that may be addressed in future studies. A comprehensive nationwide study should be performed regarding the heavy metal and aromatic substances used in the fish production process. Fish adulteration in different stages of the supply chain should be examined to detect at which stage fish are being adulterated most. A major constraint of existing research regarding detecting the active ingredients in antibiotics is the unavailability of well-accepted and error-free kits. Thus, to ensure the right antibiotic is used in the recommended quantity, the causative agent of a certain disease must be identified using a sensitivity test at a sophisticated diagnostic laboratory. Moreover, there are no substantial studies on the effect of organic and inorganic compounds of Cr(II), or Cr(III), or Cr(VI) and their different oxidation states on fish bodies. More importantly, future studies should also be directed toward the detection of toxic elements in the fish bodies of conventional recirculating aquaculture systems, which is an excellent strategy for developing the aquaculture industry because of their potential widespread use in Bangladesh.

AUTHOR CONTRIBUTIONS

Md. Akhtaruzzaman Khan: Conceptualization; funding acquisition; investigation; project administration; supervision; writing – review and editing. **Md. Emran Hossain:** Formal analysis; methodology; writing – original draft. **Md. Sayemul Islam:** Data curation; formal analysis; investigation; writing – original draft. **Mohammad Saidur Rahman:** Funding acquisition; project administration; resources; writing – review and editing. **Pratheesh Omana Sudhakaran:** Project administration; resources; validation; writing – review and editing. **Madan Mohan Dey:** Conceptualization; funding acquisition; project administration; supervision; writing – original draft; writing – review and editing.

ACKNOWLEDGEMENT

None to acknowledge.

FUNDING INFORMATION

This study is made possible by the generous support of the American people provided by the Feed the Future Innovation Lab for Food Safety through the United States Agency for International Development (USAID). The contents are the responsibility of the authors and do not necessarily reflect the views of USAID or the United States Government. The Feed the Future Innovation Lab for Food Safety is managed by Purdue and Cornell Universities through an award from USAID (Award No. 7200AA19LE00003; Madan Mohan Dey, PI).

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest for submission and publication of this article.

DATA AVAILABILITY STATEMENT

This work was based on previously published research; no primary data was used.

ETHICS STATEMENT

Not applicable.

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How to cite this article: Khan MA, Hossain ME, Islam MS, Rahman MS, Sudhakaran PO, Dey MM. A systematic review of fish adulteration and contamination in Bangladesh: A way forward to food safety. *Rev Aquac*. 2023;1-16. doi:10.1111/raq.12801