Beyond the Surface: Evaluating the Impacts of Fukushima Nuclear Wastewater Release

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Abstract: Following the 2011 Fukushima nuclear power plant accident in Japan, managing contaminated water became a long-term challenge. In August 2023, Japan began discharging treated atomic wastewater into the Pacific Ocean, sparking global concern. Since nuclear wastewater discharge involves environmental safety, public health, and international relations, understanding various perspectives and presenting scientific data is crucial for formulating reasonable policies. This study aims to analyse the attitudes of different countries towards the Fukushima nuclear wastewater discharge, assess its scientific basis, and explore its economic impact on Japan's fishing industry. The results show that Japan's wastewater discharge complies with international safety standards, based on an evaluation of publicly available data from the Tokyo Electric Power Company and the International Atomic Energy Agency. The analysis encompassed both safety measures and environmental impacts of this specific nuclear wastewater release. Despite scientific studies confirming that the treated nuclear wastewater meets safety standards, ongoing public concerns and geopolitical tensions have caused significant economic impacts on Japan's fishing industry. Therefore, enhanced scientific dialogue and research are needed to effectively address the potential long-term challenges that nuclear wastewater discharge may pose to marine ecosystems and global food safety.

Keywords: Fukushima Wastewater, Nuclear Accident, Environmental Evaluation

1. Introduction

After a 9.1-magnitude earthquake struck off the east coast of Japan's main island on March 11, 2011, two tsunami waves hit the nuclear plant. As three reactors experienced meltdowns, operators started injecting seawater to cool the melted fuel. Over 12 years later, this continuous cooling process generates over 130 tons of contaminated water each day. Eventually, the wastewater was too much that it exceeded the maximum storage capacity.

In 2013, Tokyo Electric Power Company (TEPCO) introduced the Advanced Liquid Processing System (ALPS) to treat stored radioactive water, aiming to remove most radioactive nuclides, although tritium cannot be removed. In April 2021, the Japanese government approved TEPCO's plan to discharge ALPS-treated water containing tritium into the ocean, with a gradual implementation over the next 30 years. Finally, on August 24, 2023, the Fukushima Daiichi Nuclear Power Plant officially began discharging treated nuclear wastewater into the Pacific Ocean, a decision that sparked widespread concern and opposition both domestically and internationally, as of the most recent

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discharge on August 24, 2024, which marks the eighth round of discharges, over 60,000 tons of treated water have been released. The event has drawn widespread attention around the world, with many scientists and the public expressing concerns about the radioactive substances carried by nuclear wastewater, such as tritium, cesium-134, cesium-137, and carbon-14. At the same time, some individuals support Japan's approach.

With the ongoing debate on the Fukushima wastewater release, along with its potentially profound impacts, this paper will discuss the perspectives on the discharge of nuclear wastewater, both for and against it, as well as the presentation of facts regarding the discharge of atomic wastewater through the collection of publicly available data and information from Tokyo Electric Power Company, provide readers with a comprehensive understanding of the event [1-2].

2. Viewpoints from different nations and scientists

2.1. National viewpoint

2.1.1. Neutral Stance

Thailand

The Food and Drug Administration of Thailand has stated that if seafood imported from Japan exceeds radiation standards and other relevant criteria, the country is prepared to order a recall and suspend imports, as reported by Thai media outlet PPTV. According to Singapore's zaobao.com, Thailand, being in a high-risk area due to Japan's discharge of nuclear-contaminated water, held an emergency meeting involving government departments related to fisheries, food and drug administration, and nuclear energy. During this meeting, they decided to enhance supervision measures. Thai officials indicated that customs and relevant departments responsible for inspecting imported seafood are currently preparing for increased scrutiny [3].

Laos

In Laos, on April 6, 2023, Deputy Foreign Minister Thongphan stated that Japan's treatment of nuclear wastewater should comply with the standards set by the IAEA. He highlighted the importance of consulting fully with neighbouring countries and other stakeholders, inviting international experts to jointly sample and test the wastewater, and ensuring timely and transparent disclosure of the results [4].

Malaysia

In Malaysia, on August 27, 2023, Minister of Science, Technology, and Innovation Chang Lih Kang expressed concern via Facebook regarding Japan's decision to discharge nuclear wastewater into the sea. The Malaysian government has installed a nuclear radiation detection device off the coast of Sabah and plans to add four more radiation detectors in its territorial waters to monitor radiation levels in the sea [4].

2.1.2. Opposition Stance

China

A spokesperson for the Chinese Ministry of Commerce condemned the discharge as "extremely selfish and irresponsible," cautioning that it could lead to unpredictable harm to the global marine environment. On August 24, 2023, the General Administration of Customs of China announced a suspension of all imports of Japanese aquatic products to safeguard the health of Chinese consumers and ensure the safety of imported food [5].

Russia

In Russia, on October 16, 2023, the government declared that it would follow China's example by suspending imports of seafood from Japan. The Federal Service for Veterinary and Phytosanitary

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Surveillance (Rosselkhoznadzor) stated that as a "preventive measure," it would "join China's temporary restrictions on the import of fish and seafood products from Japan starting from October 16, 2023." The agency also noted that these restrictions would remain in place "until necessary detailed information is obtained to confirm the safety of the seafood products [6]."

North Korea

On April 16, 2021, the Korean Central News Agency published a commentary demanding that the Japanese government revoke its decision to discharge Fukushima's nuclear wastewater into the sea, criticising Japan's actions as "selfish, indifferent to the threat to humanity, and destructive to the global ecological environment [7]."

The Prime Minister of the Solomon Islands, Manasseh Sogavare, the Deputy Prime Minister and Minister of Foreign Affairs of Vanuatu, Matai Seremaiah, and the Deputy Prime Minister of Kiribati, Teuea Toatu, have all expressed serious concerns and opposition to Japan's decision to discharge nuclear wastewater, calling for strong actions to resist this decision and urging Japan to reconsider its approach unless the safety of the treated water can be indisputably proven [4].

2.1.3. Supporting Stance

United States

In August 2023, Secretary of State Antony Blinken expressed at a press conference that he was "satisfied with the safety of Japan's discharge plan, confirming that it aligns with international standards, including those set by the International Atomic Energy Agency (IAEA)." On August 24, U.S. Ambassador to Japan Rahm Emanuel, in a media interview, characterised Japan's decision to release treated water into the ocean as "the right path [8]."

South Korean

The South Korean government has endorsed Japan's discharge plan, referencing studies and assessments conducted by the IAEA and Japanese authorities. These assessments suggest that the treated water will present minimal risks to both human health and marine ecosystems. Supporting Japan's initiative is also viewed as a means to enhance diplomatic relations between South Korea and Japan, with cooperation on this matter seen as a step toward strengthening bilateral ties [9].

United Kingdom

On August 31, 2023, the UK Foreign, Commonwealth & Development Office released a statement expressing support for Japan's plan to discharge treated water from the Fukushima Daiichi Nuclear Power Plant. The UK government emphasised that it is "fully satisfied with the monitoring results and assessments provided by the International Atomic Energy Agency (IAEA)," confirming that the treated water being discharged is safe [10].

Fijian Prime Minister Sitiveni Rabuka, New Zealand Foreign Minister Nanaia Mahuta, the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), and other countries have all expressed support for the conclusions of the International Atomic Energy Agency. They are confident in the Agency's independent, impartial, and science-based technical recommendations [4].

2.2. Science Communication

2.2.1. Opposing stance

Potential Risks Brought by the Transition of Radioactive Materials

"It's a transboundary and trans-generational event," says Robert Richmond, a scientific adviser on the discharge plan to the Pacific Islands Forum. "Anything released into the ocean off of Fukushima is not going to stay in one place." Richmond references studies indicating that radionuclides and debris released during the initial Fukushima disaster were quickly detected nearly 5,500 miles away off the coast of California. He warns that radioactive elements from the planned wastewater discharges could similarly disperse across the ocean. These radionuclides may be transported by ocean currents, particularly the Kuroshio current, and migratory marine animals could also contribute to their spread. A study from 2012 provides "unequivocal evidence" that Pacific bluefin tuna containing Fukushima-derived radionuclides reached the San Diego coast within six months of the 2011 accident [11,12]

The study presented by Liu et al. [13] can further support previous evidence and points. They analysed both the macroscopic and microscopic diffusion of nuclear pollutants in the ocean. These processes were divided into several sub-processes, each analysed separately and then combined to create an overall diffusion simulation with the help of Fick's law[14] and Einstein's mean squared displacement theory [15].

The group simulated tritium with suitable parameters for its diffusion by considering the three stages of water movement: migration, dispersion, and attenuation. Specifically, migration refers to the process of pollutants moving with ocean currents, only changing the positions but not the concentrations. The dispersion process involves the redistribution of pollutant concentrations. Due to concentration differences, pollutants diffuse from areas of high concentration to areas of low concentration. Finally, the attenuation process refers to the phenomenon of pollutant concentrations gradually decreasing over time due to the chemical decomposition of the pollutants [13].

The results from the macro simulation indicated that during the initial stages of pollutant discharge, the affected area expands rapidly, reaching approximately 30° latitude and 40° longitude within 120 days. Due to the presence of West Wind Drift, the speed of pollutant diffusion is significantly greater in the latitude direction compared to the longitude direction [16], leaving a high-concentration area remaining around 35°N. After 1200 days, pollutants reach the coasts of North America and Australia, effectively covering most of the North Pacific region. Subsequently, these pollutants flow through the Panama Canal, driven by the equatorial current, swiftly spreading into the South Pacific Ocean. Within 2400 days, while continuing to diffuse into the Pacific, a small portion of the pollutants also reaches the Indian Ocean via waters north of Australia. By 3600 days, pollutants occupy nearly the entire Pacific Ocean, as shown in Figures 1a and 1b.

Figure. 1c illustrates the changes in pollutant concentrations in the waters adjacent to three coastal cities located near 30°N over 4000 days. Pollutants first appear near Miyazaki, followed by Shanghai and San Diego, with this order primarily influenced by their distances from Fukushima. Notably, while pollutants reach San Diego last, the steady-state (final state) concentration in its adjacent waters is greater than that near the other two cities. This phenomenon is attributed to the strong ocean currents near Japan, where Fukushima is situated at the convergence of the Kuroshio (flowing northward) and Oyashio (flowing southward) [17,18], as shown in Figure 2. [19]

Consequently, most pollutants do not migrate north or south along the coastlines but instead spread eastward with the North Pacific west wind drift. This also indicates that although North America appears to be at a considerable distance from Japan, we should consider the impact of nuclear wastewater on it, especially in the long term.

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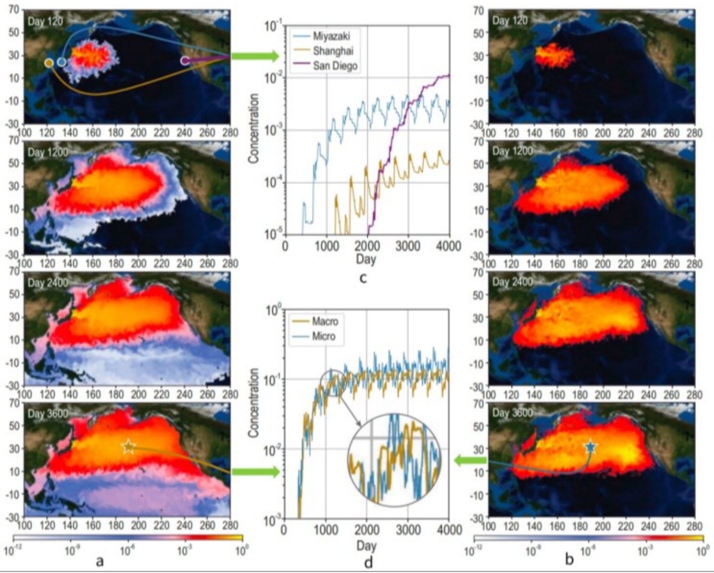

Figure 1: (a) Macroscopic and(b)microscopic diffusion analyses. (c)Variations in the pollutant concentration in the waters near the three coastal cities. (d) Comparison of the pollutant concentration curves by macro and micro methods. [13]

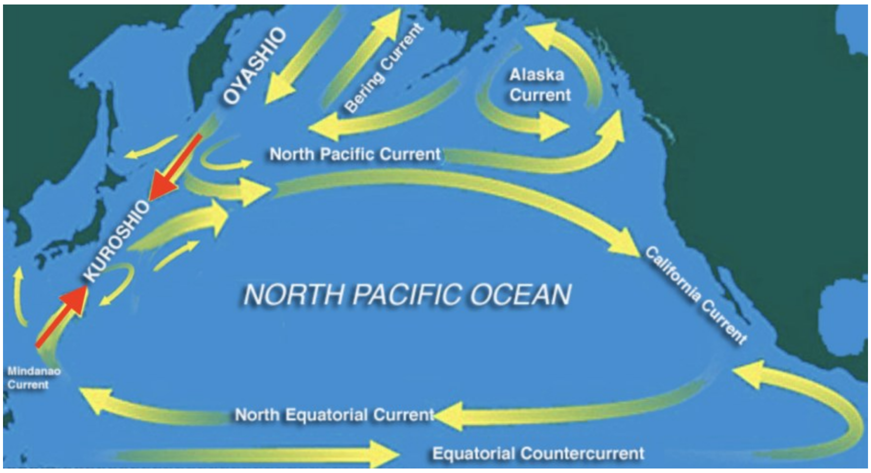

Figure 2: The North Pacific Ocean Currents Map [19]

The lower red arrow represents Kuroshio Current; the upper red arrow represents Oyashio Current.

Doubts about Cleaning System

Meanwhile, Ken Buesseler cautions that the filtration system for nuclear waste has not been proven effective at all times and highlights the presence of other concerning elements, such as caesium, which can lead to serious health issues like nausea, vomiting, diarrhoea, bleeding, coma, and even death. Both short-lived radioactive elements like iodine and longer-lived elements such as caesium, with a half-life of around thirty years, are likely to be absorbed by a wide range of marine organisms. As radiation passes up the food chain, it can concentrate depending on the type of radiation and the organisms involved [20].

Thus, he believed that the weight and value of marine products in Fukushima caught after the nuclear accident from 2011 to 2018 dropped more than seven times the previous value (based on figure. 2), which was mainly attributed to the wastewater release.

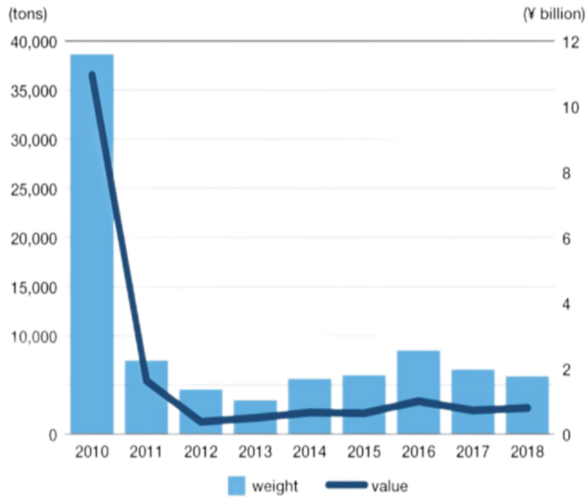

Figure 3: Weight and value of Fukushima prefecture catch [21].

2.2.2. Supporting stance

But the reality(opposing Ken Buesseler) is that the earthquake and tsunami caused extensive damage to fishing boats, gear, and aquarium facilities, directly impacting the production and catching capacity of the fishing industry. Many fishermen lost their livelihoods, and fisheries-related businesses suffered severe losses. The nuclear power plant accident led to the leakage of radioactive materials. Although it did not significantly affect living organisms, food safety came under scrutiny from consumers, leading to a decline in public confidence in the fishing industry, which in turn affected sales and exports[22,23]. Additionally, many countries imposed import bans on Japanese seafood[24]. For instance, “Meat, poultry and seafood will be banned unless first given safety clearance from Japanese officials”, the Hong Kong government has said. Besides Hong Kong, the United States, Canada and Australia are among the leading markets to ban certain Japanese seaweed and seafood. This further struck the fishing economy, resulting in a situation where demand was far less than supply and forcing fishermen to reduce their catch to minimise losses.

Low Impacts to Human Health

TPCO has mentioned that [25] tritium, which emits weak radiation energy, cannot penetrate the skin and is thus regarded as having almost no external radiation effect. It primarily exists as water and does not accumulate or concentrate within the body. Approximately half of its radioactive activity is expelled within about ten days, and it is mostly eliminated within 40 days. The weak beta radiation emitted by tritium has a minimal impact on human health, estimated to be around 1/700th that of radioactive cesium-137 [26].

A range of different radioactive isotopes can be present in nuclear wastewater before it’s treated, but after treatment, the ultimate risk posed by the tritium that remains is not affected by how the water was originally contaminated, says Jim Smith, a professor of environmental science at the University of Portsmouth who has extensively studied the impact of radioactive pollutants on the environment [27].

The common actions for some countries

Smith points out that [27] releasing tritium-contaminated water is part of the usual operating procedure for nuclear power plants. He says that both the Heysham nuclear power station and the Sellafield nuclear fuel processing plant in the United Kingdom release between 400 and 2,000 terabecquerels of tritium into the ocean each year. “Overall, because it’s such a weak β-emitter, it’s not that radiotoxic,” Smith says.

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3. Truth of wastewater

3.1. ALPS

ALPS is a pumping and filtration system that uses chemical reactions to remove 62 radionuclides from contaminated water [27]. TEPCO mentioned, "Before the diluted discharge, measurements were taken of the radioactive substances in the ALPS-treated water to confirm that the concentrations of radioactive materials, other than tritium, were below the relevant regulatory standards for release into the environment. For the tritium that could not be cleaned out, the water is diluted with seawater at a ratio of over 100 times, ensuring that the diluted tritium concentration is below 1,500 becquerels per litre. Additionally, the annual discharge limit for tritium is set to be below 22 terabecquerels. [28]"

Regarding the water intake system, to avoid the influence of radioactive materials within the harbour, water is drawn from outside the harbour. For the discharge system, to prevent the released water from re-entering the seawater that is being collected, the discharge is conducted through an underwater tunnel (approximately 1 km long) [28].

Since September 2020, Tokyo Electric Power Company has been conducting secondary treatment performance confirmation tests for the multi-nuclide removal system. The results show that, compared to before and after the secondary treatment, the concentration of radioactive substances has decreased, with the concentration of nuclides other than tritium reduced to below 1 in total. Effective removal of 63 nuclides, excluding tritium (including Cs-134, Cs-137, C-14, etc.), has been achieved (shown in the figure. 3).

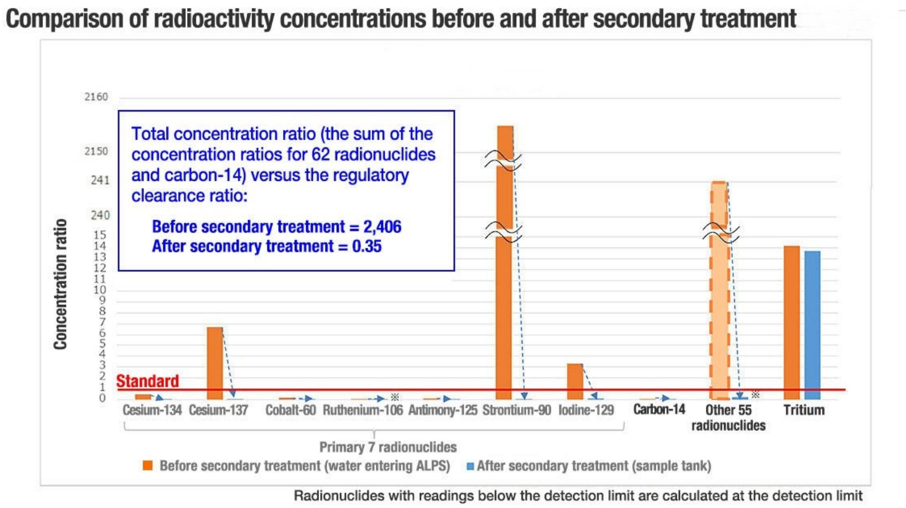

Figure 4: Comparison of radioactivity concentrations before and after secondary treatment [28].

3.2. Emission Standard

Before Emission: Tritium will be diluted with a substantial volume of seawater to ensure that its concentration is below 1,500 Bq/L before being released into the ocean. This concentration is one-fourth of the legal limit (60,000 Bq/L) and approximately one-seventh of the WHO's drinking water standard (10,000 Bq/L).

After Emission: ALPS-treated water will be discharged into the sea after dilution with seawater, and the surrounding marine area will be monitored to ensure adequate dispersion of the discharged water. The "discharge suspension level" has been established to determine if discharge should be halted based on monitoring results. In the vicinity of the discharge outlet (within 3 km of the power station), the index has been set at 700 Bq/L, reflecting the maximum management value for tritium concentration during sea discharge as outlined in the implementation plan. For areas outside the discharge outlet (within a 10 km square in front of the power station), the index is set at 30 Bq/L. If concentrations are detected at approximately half of the index value, an immediate inspection of the facilities, their operational status, and procedures will be conducted. Seawater will be resampled, and monitoring frequency may be increased based on the findings. Additionally, if any anomalies are identified during detailed monitoring by various agencies as part of the comprehensive monitoring plan, appropriate responses will be evaluated and implemented [29]

3.3. Data analysis (Cs-134, Cs-137, H-3)

Cs-134 and Cs-137 Concentration

Although TEPCO has stated that the levels of Cs134 and Cs137 in the nuclear wastewater have been controlled to below safe levels before discharge into the ocean, some scientists remain concerned about these two radioactive elements. The data of Cs134 and Cs137 presented by TEPCO from April 1, 2023, to September 30, 2024, can address those concerns by showing that the concentration for Cs-134 and Cs-137 are both around 1 Bq/L, which is below the WHO indicator of drinking water quality level of 10 Bq/L [30].

H-3 Concentration within 3km and 10km

By organising data from 28 sampling points within 3km of the discharge outlet, I have plotted the change in tritium content from August 24, 2023, to September 30, 2024. On August 24, September 20, and around February 28, during the phase of Japan's nuclear wastewater discharge, the concentration of tritium (H-3) did not show any sharp increases or fluctuations, and the overall trend remained relatively stable. Furthermore, the concentration consistently stayed below 10 Bq/L, which is far below the international reference standards, discharge suspension level, and investigation level. At the same time, this concentration was also below the H-3 concentration standards within 10 kilometres of the discharge point, even though the data collected came from within 3 kilometres. Therefore, it can be reasonably inferred that Japan has met the discharge standards in the waters within 10 kilometres of the discharge point, making it very safe.

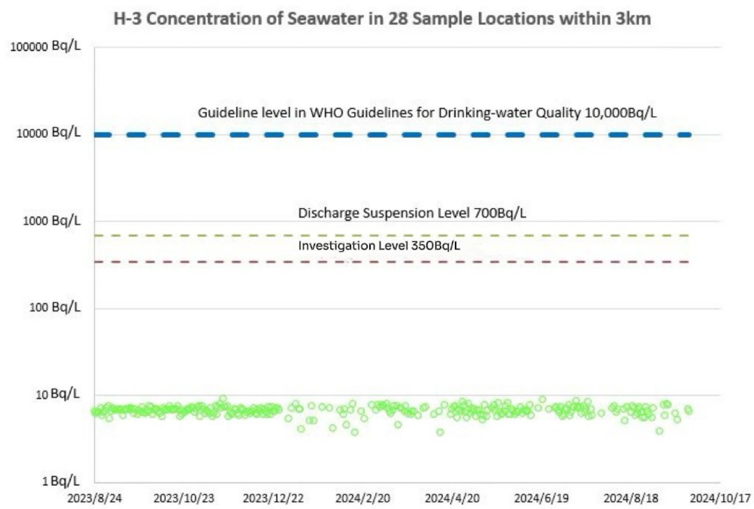

Figure 5: H-3 Concentration of Seawater in 28 Sample Locations within 3km

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4. Economic effects on Japan's fishery

4.1. Nations' Policies Effects

Taking China as an example, the Chinese government maintains last year's import ban, making it the only neighbouring country to comprehensively prohibit all Japanese seafood imports. According to data from Japan's Ministry of Agriculture, Forestry and Fisheries, Japan's total seafood export value in 2022 was 387.3 billion yen, with China accounting for 20%, totaling 87.1 billion yen (approximately 590 million USD), making it the largest export market. After the ban was implemented, the overall export value of Japanese agricultural and seafood products fell by 1.8% year-on-year in the first half of 2024, marking the first decline since the pandemic began in 2020, with exports to China plummeting by 43.8%, and scallops being particularly hard hit [31,32].

4.2. Psychological Effects

Although some experts believe that the hazards of marine contamination are negligible, consumer perceptions of the risk may change their dietary habits, leading them to refuse to purchase seafood from Fukushima and its surrounding areas. This behaviour change directly affects market demand for seafood, prompting many consumers to seek alternative foods to supplement their protein intake, including freshwater aquaculture products, pork, lamb, and other terrestrial foods, as well as plant-based foods. The sharp decline in consumer demand has severely impacted Japan's fishing economy [26,33].

5. Conclusion

The issue of Fukushima's nuclear wastewater discharge is a complex and multifaceted topic that involves environmental safety, public health, and international relations. The Japanese government has implemented transparent monitoring measures in the handling of nuclear wastewater to ensure environmental and public safety. Although scientific research indicates that the treated nuclear wastewater meets international safety standards before discharge and poses relatively low risks to human health, public fear and sensitivity to nuclear contamination persist. The varied responses from different governments and international organisations reflect differing views on nuclear safety and concerns about marine ecology. This suggests that further scientific research and international cooperation are needed to address this issue. In the future, balancing the demands of nuclear energy development with environmental protection will be a significant challenge faced globally.

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