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Potential Exposure to Untreated Sewage-Associated Contaminants through Marine Fish Consumption, with Emphasis on Herbivorous Fish: An Exploratory Study among Kidney Disease Patients in Zliten, Libya

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Index Terms

Untreated Sewage; Marine Fish; Herbivorous Fish; Potential Dietary Exposure; Dialysis Patients

Abstract

Background: Untreated sewage represents an important source of coastal pollution that may alter marine environmental quality and create potential pathways for contaminant transfer to aquatic organisms, including fish that constitute an important component of coastal diets. This issue is particularly relevant to kidney disease patients, who may warrant greater consideration when evaluating potential exposure to environmental contaminants.

Problem and Objective: This study investigated the potential exposure of kidney disease patients in Zliten, Libya, to contaminants associated with untreated sewage through marine fish consumption, with particular emphasis on herbivorous fish. The study aimed to determine the level of potential exposure, examine the relationship between marine fish consumption patterns and potential exposure, compare potential exposure between consumers of herbivorous and other marine fish, and assess the relationship between pollution-risk awareness and exposure-avoidance behaviors.

Methodology: A descriptive-analytical exploratory design was adopted. Data were collected using a structured questionnaire administered to **315 dialysis patients attending the Zliten Kidney Services Center**. The questionnaire addressed marine fish consumption patterns, potential exposure indicators, awareness of pollution-related risks, and exposure-avoidance behaviors. Descriptive and inferential statistical procedures were used to examine the study dimensions and test the proposed statistical relationships.

Main Findings: The estimated results indicated a high level of marine fish consumption ($M = 3.82$), high awareness ($M = 4.18$), and high exposure-avoidance behavior ($M = 3.79$), while the overall potential-exposure score was moderate ($M = 3.36$). A statistically significant positive relationship was identified between marine fish consumption patterns and potential exposure ($r = .640$, $p < .001$). Significant differences were also observed between consumers of herbivorous fish and other marine fish, while awareness was positively associated with exposure-avoidance behavior ($r = .520$, $p < .001$).

Conclusion and Recommendations: The findings provide preliminary evidence supporting the plausibility of a potential dietary exposure pathway linking untreated sewage, coastal contamination, fish, and consumption among dialysis patients. However, the study does not establish actual chemical exposure or a causal relationship between fish consumption, sewage-associated contaminants, and kidney disease. Future research should therefore prioritize direct analysis of seawater, sediments, and edible fish tissues from sewage-affected and reference sites, combined with dietary and clinical assessments. Strengthening seafood-safety awareness and providing reliable information on fish sources and fishing locations are also recommended.

التعرض المحتمل للملوثات المرتبطة بمياه الصرف الصحي غير المعالجة عبر استهلاك الأسماك البحرية، مع التركيز على الأسماك العاشبة: دراسة استطلاعية لدى مرضى غسيل الكلى في زليتن، ليبيا

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الملخص

الخلفية:
تمثل مياه الصرف الصحي غير المعالجة مصدرًا مهمًا للتلوث الساحلي، إذ قد تؤدي إلى تغيير جودة البيئة البحرية وتهيئة مسارات محتملة لانتقال الملوثات إلى الكائنات المائية، بما في ذلك الأسماك التي تشكل مكونًا مهمًا من النظم الغذائية في المناطق الساحلية. وتكتسب هذه المسألة أهمية خاصة لدى مرضى أمراض الكلى، الذين قد تستدعي حالتهم الصحية إيلاء مزيد من الاهتمام عند تقييم احتمالات التعرض للملوثات البيئية.

مشكلة الدراسة وهدفها:
بحثت هذه الدراسة في التعرض المحتمل لمرضى أمراض الكلى في زليتن، ليبيا، للملوثات المرتبطة بمياه الصرف الصحي غير المعالجة من خلال استهلاك الأسماك البحرية، مع التركيز بصورة خاصة على الأسماك العاشبة .وهدفت الدراسة إلى تحديد مستوى التعرض المحتمل، وفحص العلاقة بين أنماط استهلاك الأسماك البحرية والتعرض المحتمل، ومقارنة مستوى التعرض المحتمل بين مستهلكي الأسماك العاشبة ومستهلكي الأنواع الأخرى من الأسماك البحرية، إلى جانب تقييم العلاقة بين الوعي بمخاطر التلوث وسلوكيات تجنب التعرض.

المنهجية:
اعتمدت الدراسة تصميمًا وصفيًا تحليليًا استكشافيًا، وجُمعت البيانات باستخدام استبيان منظم طُبق على 315مريضًا من مرضى غسيل الكلى المترددين على مركز خدمات الكلى في زليتن .وتناول الاستبيان أنماط استهلاك الأسماك البحرية، ومؤشرات التعرض المحتمل، والوعي بالمخاطر المرتبطة بالتلوث، وسلوكيات تجنب التعرض. كما استُخدمت الأساليب الإحصائية الوصفية والاستدلالية لتحليل أبعاد الدراسة واختبار العلاقات الإحصائية المقترحة.

أهم النتائج:
أشارت النتائج المقدرة إلى ارتفاع مستوى استهلاك الأسماك البحرية(M = 3.82) ، وارتفاع مستوى الوعي = M) (4.18، وارتفاع سلوكيات تجنب التعرض(M = 3.79) ، في حين جاء المتوسط الكلي لمؤشر التعرض المحتمل عند مستوى متوسط .(M = 3.36) كما أظهرت النتائج وجود علاقة إيجابية ذات دلالة إحصائية بين أنماط استهلاك الأسماك البحرية والتعرض المحتمل .(r = .640, p < .001) كذلك ظهرت فروق ذات دلالة إحصائية بين مستهلكي الأسماك العاشبة ومستهلكي الأنواع الأخرى من الأسماك البحرية، في حين ارتبط الوعي بصورة إيجابية بسلوكيات تجنب التعرض.(r = .520, p < .001)

الاستنتاج والتوصيات:
توفر النتائج دليلًا أوليًا يدعم إمكانية وجود مسار محتمل للتعرض الغذائي يربط بين مياه الصرف الصحي غير المعالجة والتلوث الساحلي والأسماك واستهلاكها لدى مرضى غسيل الكلى. ومع ذلك، لا تثبت الدراسة وجود تعرض كيميائي فعلي، كما لا تثبت وجود علاقة سببية بين استهلاك الأسماك أو الملوثات المرتبطة بمياه الصرف الصحي وأمراض الكلى. ولذلك، ينبغي أن تركز الدراسات المستقبلية على التحليل المباشر لمياه البحر والرواسب وأنسجة الأسماك الصالحة للأكل في المواقع المتأثرة بمياه الصرف الصحي ومواقع المقارنة، إلى جانب إجراء تقييمات غذائية وسريرية. كما يُوصى بتعزيز الوعي بسلامة المأكولات البحرية وتوفير معلومات موثوقة حول مصادر الأسماك ومواقع صيدها.

الكلمات المفتاحية:
مياه الصرف الصحي غير المعالجة؛ الأسماك البحرية؛ الأسماك العاشبة؛ التعرض الغذائي المحتمل؛ مرضى غسيل الكلى.

الكلمات المفتاحية:

1. Introduction

Coastal marine environments represent an important interface between human activities, aquatic ecosystems, and public health. Increasing urbanization and inadequate wastewater management have intensified the discharge of untreated or insufficiently treated sewage into coastal waters, introducing complex mixtures of nutrients, pathogens, pharmaceuticals, heavy metals, organic pollutants, and other emerging contaminants into marine ecosystems. These pollutants may alter water quality and ecological processes while simultaneously creating potential pathways for human exposure through recreational activities and the consumption of contaminated seafood. Recent evidence indicates that coastal sewage pollution is no longer simply an environmental management problem; it represents an integrated ecological and public-health challenge, particularly in communities that depend directly on marine resources for food and livelihoods (Rangel-Buitrago et al., 2024).

Fish occupy an important position in this exposure pathway because they interact continuously with contaminated water, sediments, and food sources and may accumulate contaminants within their tissues. The extent and pattern of bioaccumulation, however, are not necessarily uniform among species and can depend on habitat, feeding behavior, exposure duration, contaminant characteristics, and the biological characteristics of individual fish. Recent research has demonstrated that wastewater-associated contaminants can enter fish through ingestion, gill uptake, and dermal exposure, with measurable residues being detected in different tissues. In particular, Manjarrés-López et al. (2023) identified multiple wastewater-derived pharmaceutical compounds in fish exposed to wastewater-influenced environments, demonstrating that aquatic organisms can act as biological indicators of contaminant exposure rather than merely passive recipients of water pollution.

The possibility of contaminant transfer from polluted marine environments to humans becomes particularly relevant when contaminated fish are regularly consumed. Fish provide high-quality protein, omega-3 fatty acids, vitamins, and essential minerals and therefore remain an important component of a healthy diet; nevertheless, their nutritional benefits coexist with potential risks when fish

originate from contaminated environments. A comprehensive scoping review by Thomsen et al. (2021) showed that seafood can represent both a significant nutritional benefit and a source of chemical contaminants, emphasizing that health-risk assessments should consider species, contamination levels, consumption patterns, and population vulnerability rather than treating all seafood as having the same risk profile. This distinction is particularly important when assessing populations that may already have increased susceptibility to environmental or dietary stressors.

The kidney represents a particularly relevant target organ when considering exposure to certain environmental contaminants, especially toxic trace elements such as cadmium, lead, and arsenic. These substances may be introduced into aquatic systems through anthropogenic activities and subsequently enter aquatic food webs, creating potential dietary exposure pathways. Importantly, evidence from human epidemiological research suggests that exposure to some heavy metals is associated with indicators of impaired renal function. In a systematic review and meta-analysis of 28 studies involving more than 107,000 participants, Jalili et al. (2021) reported associations between exposure to cadmium, lead, and arsenic and indicators of chronic kidney disease, although the authors also emphasized heterogeneity among the available studies and the need for further investigation. This evidence does not establish that contaminated fish cause kidney disease, but it provides a strong scientific rationale for investigating possible environmental and dietary exposure pathways among individuals with existing kidney disease.

Within this context, herbivorous fish deserve particular attention because their feeding behavior directly connects them with primary producers, algae, seagrass, organic matter, and material associated with sediments and shallow coastal habitats. Such ecological interactions may influence the type and magnitude of contaminants to which different fish species are exposed and potentially accumulated. However, it would be scientifically inappropriate to assume in advance that herbivorous species necessarily contain higher contaminant concentrations than carnivorous or omnivorous species; this relationship must be established through species-specific environmental and tissue analyses. Recent research on wastewater-associated contaminants and fish therefore supports an approach that combines environmental contamination data with information on fish species, habitat, feeding characteristics, and human consumption patterns rather than relying solely on measurements of seawater quality (Manjarrés-López et al., 2023).

Against this background, the present exploratory study focuses on Zliten, Libya, where potential exposure to sewage-impacted coastal waters raises an important local environmental-health question concerning seafood consumption and vulnerable populations. Rather than assuming a direct causal relationship between marine pollution and kidney disease, the study seeks to explore the potential exposure pathway linking untreated sewage, contaminated coastal waters, fish inhabiting or feeding near affected areas, and the consumption of these fish by kidney disease patients. Particular attention is given to herbivorous fish because of their ecological relationship with marine vegetation and nearshore environments. By integrating information on sewage-affected marine environments, relevant fish species, and the consumption patterns and perceptions of kidney disease patients, the study can provide preliminary evidence for future environmental monitoring, laboratory analysis of fish tissues, and more rigorous epidemiological investigations in Zliten.

2 . Problem Statement

Untreated sewage discharged into coastal environments may introduce a range of contaminants into marine ecosystems, creating a potential pathway for human exposure through seafood consumption. This issue may be particularly relevant to individuals with kidney disease, given the documented association between exposure to certain environmental contaminants and indicators of impaired renal function. In Zliten, the presence of sewage-impacted coastal areas raises concerns regarding the potential exposure of kidney disease patients through the consumption of marine fish, particularly fish inhabiting or feeding near affected areas. Therefore, the problem addressed by this exploratory study is the potential exposure to sewage-associated contaminants through marine fish consumption among kidney disease patients in Zliten, with particular attention to herbivorous fish and consumption-related exposure patterns. The study does not assume a direct causal relationship between contaminated fish consumption and kidney disease but seeks to explore the potential exposure pathway and its associated factors.

2.1 . Research Questions

1. What is the level of potential exposure to untreated sewage-associated contaminants through marine fish consumption among kidney disease patients in Zliten?
2. Is there a significant relationship between marine fish consumption patterns and indicators of potential exposure to contaminants associated with sewage-impacted coastal areas?
3. Does potential exposure differ significantly according to the consumption of herbivorous fish compared with other marine fish species?
4. Is there a significant relationship between awareness of the potential risks of sewage-related pollution and fish consumption patterns and exposure-avoidance behaviors among kidney disease patients?

3. Research Hypotheses

To maintain methodological consistency with the exploratory design, the hypotheses are formulated as testable statistical relationships rather than causal assumptions.

1. There is a statistically significant level of potential exposure to untreated sewage-

associated contaminants through marine fish consumption among kidney disease patients in Zliten.

2. There is a statistically significant relationship between marine fish consumption patterns and indicators of potential exposure to contaminants associated with sewage-impacted coastal areas.
3. There are statistically significant differences in potential exposure levels between consumers of herbivorous fish and consumers of other marine fish species.

There is a statistically significant relationship between awareness of the potential risks of sewage-related pollution and fish consumption patterns and exposure-avoidance behaviors among kidney disease patients.

4 . Significance of the Study

This study is significant because it addresses an emerging intersection between environmental pollution, seafood safety, and public health by examining a potential pathway through which contaminants associated with untreated sewage may reach humans through marine fish consumption. Its focus on kidney disease patients is particularly relevant because this population may warrant greater consideration when assessing potential exposure to environmental contaminants associated with impaired renal function.

From an applied perspective, the study provides preliminary evidence on fish consumption patterns and potential exposure among kidney disease patients in Zliten. The findings may help identify priority areas for future environmental and health investigations, including laboratory assessment of seawater, sediments, and fish tissues. The study may also support environmental monitoring, seafood-safety awareness, and the development of more rigorous epidemiological research on sewage-related coastal contamination

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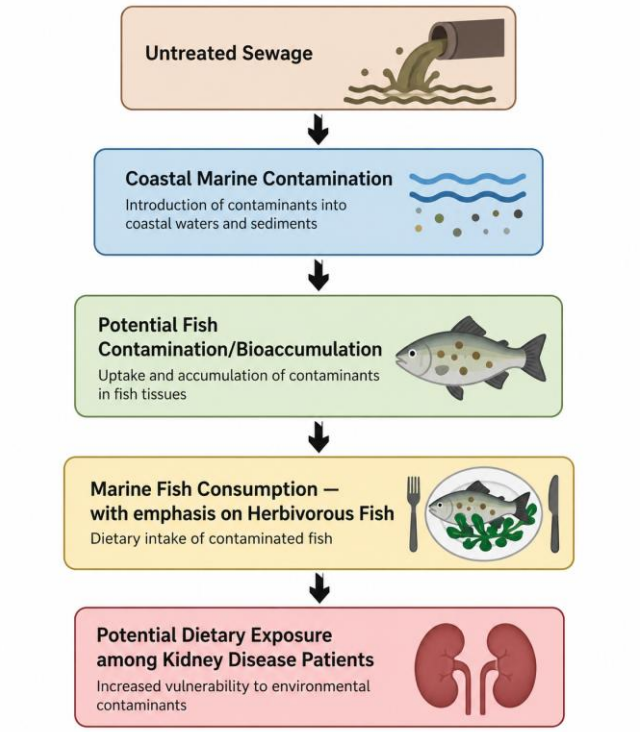
5 . Research Objectives

The objectives are directly aligned with the four research questions:

1. To determine the level of potential exposure to untreated sewage-associated contaminants through marine fish consumption among kidney disease patients in Zliten.
2. To examine the relationship between marine fish consumption patterns and indicators of potential exposure to contaminants associated with sewage-impacted coastal areas.
3. To compare potential exposure levels between consumers of herbivorous fish and consumers of other marine fish species.
4. To assess the relationship between awareness of the potential risks of sewage-related pollution, fish consumption patterns, and exposure-avoidance behaviors among kidney disease patients.

6 . Conceptual Exposure Pathway

Figure 1. Conceptual Exposure Pathway



7. Literature Review

Chemical Contamination of Herbivorous Marine Fish and Potential Human Exposure environmental and public-health problem because untreated or inadequately treated wastewater can introduce nutrients, pathogens, heavy metals, pharmaceuticals, organic pollutants, and other emerging contaminants into marine ecosystems. Rangel-Buitrago et al. (2024) emphasized that coastal sewage pollution should no longer be considered solely a water-quality or environmental-management issue, as contaminants originating from sewage may enter marine food webs and create potential human exposure pathways through seafood consumption. This perspective is particularly relevant to coastal communities where fish constitute an important component of local diets and livelihoods. Nevertheless, the study primarily provides a broad environmental assessment and does not directly address contaminant concentrations in herbivorous fish consumed by kidney disease patients. Its major contribution to the present study is therefore conceptual: it establishes the environmental pathway linking sewage discharge with potential seafood-related human exposure.

Recent research has increasingly moved beyond measuring contamination in seawater alone and has focused on the actual accumulation of contaminants in fish tissues. For example, Manjarrés-López et al. (2023) investigated wastewater-borne pharmaceuticals in fish exposed to wastewater-influenced environments and detected multiple pharmaceutical compounds in different tissues and body fluids. Their findings demonstrated that fish can function as biological indicators of wastewater-associated contamination rather than merely passive recipients of polluted water. This is particularly important for the present research because measuring contaminants in fish tissues provides a more meaningful indication of potential dietary exposure than environmental measurements alone. However, the study focused on pharmaceutical contaminants and riverine fish rather than marine herbivorous species living near coastal sewage outlets.

Among herbivorous marine fish, Sarpa salpa has received considerable attention because of its close association with algae and shallow coastal vegetation. Gutiérrez-Ravelo et al. (2020) chemically analyzed toxic metals, including Al, Cd, and Pb, together with a broad range of trace elements in *S. salpa*. Their results demonstrated that metal concentrations varied considerably among tissues, with the liver generally showing greater accumulation than edible muscle. The study is particularly relevant because *S. salpa* represents a herbivorous species whose feeding ecology connects it directly with marine primary producers and coastal substrates. However, the study also demonstrates why species classification alone cannot be used to infer contamination risk: accumulation depends on tissue type, contaminant characteristics, environmental conditions, and exposure history.

Similarly, Ben Ameur et al. (2025) examined the accumulation of Zn, Cd, Pb, and Fe in *Sarpa salpa* from the Bizerte and Ghar El Melh lagoons in Tunisia. Using atomic absorption spectrometry, the researchers identified differences in metal concentrations and assessed the implications for human consumption. Particular attention was given to cadmium because of its toxicological relevance. The importance of this study for the present research lies in its Mediterranean and North African context and its direct chemical analysis of a herbivorous fish species. Nevertheless, the study was conducted in lagoon ecosystems rather than at sewage-discharge locations, and it did not specifically investigate kidney disease patients as a vulnerable consumer group

The relationship between fish habitat and contaminant accumulation was examined by Thorne-Bazarra et al. (2023) in *Sparisoma cretense*, a herbivorous reef-associated fish, across different coastal habitats in the Canary Islands. The researchers measured several metals using ICP-OES and found significant differences between fish inhabiting rocky environments and those associated with seagrass meadows. Interestingly, fish from rocky habitats exhibited higher concentrations of several metals, demonstrating that the presence of seagrass or herbivorous feeding does not automatically imply greater contamination. This finding is particularly important for the present study because it challenges a simplistic assumption that herbivorous fish are necessarily more contaminated than carnivorous or omnivorous species. Instead, contamination must be empirically established according to species, habitat, contaminant source, and tissue type.

A related investigation by Gutiérrez-Ravelo et al. (2023) examined metal concentrations in *Sparisoma cretense* and *Serranus atricauda* from different marine environments. The study analyzed metals in muscle and liver using ICP-OES and demonstrated clear differences between tissues and locations. The higher concentrations observed in liver compared with muscle again illustrate the importance of tissue selection when evaluating fish contamination. From a food-safety perspective, however, muscle remains particularly important because it is the principal edible tissue. Consequently, studies that measure only liver or gills may demonstrate environmental exposure but cannot automatically be interpreted as evidence of dietary exposure.

The significance of *Siganus* species has also been demonstrated in the Red Sea. Al-Hasawi (2022) investigated *Siganus rivulatus*, a herbivorous fish that feeds on algae and other marine vegetation, from a heavily impacted coastal environment. The study examined toxic metals including cadmium and lead in water, fish tissues, and reproductive organs. The comparison between contaminated and less-contaminated locations provided evidence that environmental conditions can influence metal accumulation and biological responses in the fish. This approach is particularly relevant to the present research because it suggests that fish collected close to

sewage-affected locations should ideally be compared with fish collected from a relatively uncontaminated reference site.

Further evidence was provided by Hassanine et al. (2019), who investigated trace-metal contamination in *Siganus rivulatus* and associated biological indicators in the Red Sea. Cadmium and lead were measured in water, sediment, fish tissues, and intestinal parasites. The results indicated that metal accumulation differed markedly between tissues, with the liver and intestine generally showing greater concentrations than muscle. The study also highlighted the importance of sediments as potential reservoirs of contaminants. This finding is particularly relevant to sewage-impacted coastal environments because contaminants discharged with wastewater may not remain dissolved in the water column; they may become associated with sediments and subsequently enter benthic food webs.

The ecological relationship between herbivorous fish and marine vegetation was examined in the Libyan context by Al-Rzagy et al. (2023), who investigated the feeding habits of *Siganus luridus*, *Siganus rivulatus*, and the native *Sarpa salpa* along the western Libyan coast. Their results confirmed the importance of algae and marine vegetation in the diets of these species. Although the study did not chemically analyze contaminants, it is highly relevant to the present research because it provides local ecological evidence supporting the selection of herbivorous fish as potential organisms for investigating contaminant transfer within coastal food webs.

A similar Libyan study by Al-Kabeer et al. (2021) investigated the feeding behavior of *Sarpa salpa* along the western Libyan coast. The findings provide additional ecological justification for considering *S. salpa* in studies examining the interaction between feeding behavior, marine vegetation, and environmental exposure. However, because the study was ecological rather than chemical, it cannot determine whether the consumed vegetation or surrounding environment was contaminated.

Chemical evidence from Libya has become increasingly relevant. Eldurssi et al. (2023) measured lead and cadmium in gills, liver, and muscle tissues of *Siganus rivulatus* collected from Benghazi Sea Port. The researchers found differences in metal concentrations among tissues, with the liver and gills generally showing greater accumulation than muscle. This study is particularly important because it combines a herbivorous fish species, a Libyan coastal environment, and direct chemical analysis. However, Benghazi differs environmentally and geographically from Zliten, and the study did not specifically investigate areas immediately adjacent to untreated sewage discharge or the consumption patterns of kidney disease patients.

The same species was investigated histologically by Jenjan et al. (2024), who examined tissue alterations associated with lead and cadmium exposure in *Siganus rivulatus* collected from Benghazi Sea Port. Their findings indicated pathological changes in fish tissues, providing evidence that metal exposure may have biological consequences beyond simple chemical accumulation. The study is important because it moves from environmental contamination to biological response. Nevertheless, histopathological evidence in fish cannot be directly translated into human renal effects and should therefore be interpreted as evidence of ecological toxicity rather than proof of human health outcomes.

More recently, El-Mabrok et al. (2025) examined lead and cadmium concentrations in the muscle tissues of four fish species collected from Ain Al-Ghazala Lagoon in eastern Libya, including *Siganus rivulatus*. Atomic absorption spectrometry was used to quantify the metals, followed by dietary exposure and health-risk calculations. The study found differences in metal accumulation between species and assessed estimated daily intake and hazard indices. Its particular relevance lies in its combination of chemical analysis, edible fish tissue, a Libyan coastal environment, and human health-risk assessment. However, the study did not examine sewage-impacted sites specifically and did not focus on kidney disease patients.

Similarly, Hasan and El-Maleh (2025) evaluated heavy metals in fish tissues collected from the Libyan coast, including *Siganus rivulatus*. Their analysis included elements such as Zn, Cu, Pb, Co, Cd, and Cr and demonstrated spatial and tissue-related differences in metal concentrations. These findings reinforce the value of using fish as bioindicators of coastal contamination. Nevertheless, the study did not explicitly establish a gradient from sewage outlets to fish contamination and then to human dietary exposure.

Studies from neighboring North African countries provide an important comparative framework. Abidli et al. (2020) detected microplastics in commercial fish from the Bizerte and Ghar El Melh lagoons in Tunisia, including *Sarpa salpa*. Using FTIR-ATR analysis, the researchers identified different polymer types in fish gastrointestinal tracts. Their findings demonstrate that herbivorous and coastal fish may serve as indicators of emerging pollution beyond conventional heavy metals. This expands the potential scope of the present study from traditional toxic metals to emerging contaminants.

Likewise, Boudjemline et al. (2024) investigated microplastic contamination in edible fish along the eastern Algerian coast and included *Sarpa salpa* among the examined species. Several polymer types were identified, demonstrating the capacity of Mediterranean fish to accumulate anthropogenic particles. Although microplastics represent a different contaminant class from heavy metals, the study reinforces the broader argument that fish can act as vectors of environmental contaminants to human consumers.

In Egypt, El-Sayed et al. (2020) used thermal analysis and enhanced visual techniques to investigate microplastics in fish from an urban Mediterranean harbor. *Siganus rivulatus* showed particularly high particle abundance among the investigated species, and several polymer types were identified. This is particularly relevant to the present research because the study links a herbivorous coastal fish with an urbanized and polluted marine environment.

However, the study did not establish a direct relationship with sewage discharge or renal health.

Subsequently, El-Sayed et al. (2022) examined microplastic contamination in commercial fish from Alexandria on the Mediterranean coast. The study identified microplastics in fish associated with urban coastal pollution and demonstrated that land-based human activities can contribute to contamination of commercially consumed fish. Such findings strengthen the environmental-health rationale for examining fish collected near wastewater-affected coastal areas.

In Algeria, Mekki et al. (2023) assessed Zn, Cu, Pb, Cd, and Hg in sediments and *Mugil cephalus* tissues from Annaba Gulf. The researchers reported spatial and seasonal differences in trace-element concentrations and demonstrated the value of simultaneously analyzing sediments and fish. Although *Mugil cephalus* is not a representative herbivorous species in the same sense as *Sarpa salpa* or *Siganus*, the methodological approach is highly relevant because it emphasizes the connection between the contamination reservoir and biological accumulation.

A broader North African perspective was provided by Mehouel and Fowler (2022), who reviewed toxic trace elements—including arsenic, cadmium, lead, and mercury—in seafood from Algeria and adjacent southwestern Mediterranean waters. Their analysis highlighted the importance of seafood contamination as a potential human-exposure pathway and identified limitations in the geographical and temporal availability of data. This is particularly relevant to Libya because the southern Mediterranean remains comparatively underrepresented in the international environmental-health literature.

In Morocco, Kasmi et al. (2023) investigated heavy-metal concentrations in *Sardina pilchardus* from the Moroccan Mediterranean coast and evaluated potential human-health risks. The study demonstrated spatial and seasonal variation in contaminant levels and emphasized the importance of considering consumption patterns when interpreting chemical concentrations. Although sardines are not the herbivorous target species in the present study, the methodological approach supports integrating chemical concentration, exposure frequency, and human consumption rather than treating contamination as an isolated environmental measurement.

Egyptian studies have also demonstrated that metal accumulation varies according to fish species and tissue. Zaghloul et al. (2022) investigated Cd, Pb, Mn, Cu, Ni, Zn, and Fe in several edible fish species from Hurghada, Red Sea. Concentrations differed among liver, gills, and muscle, while the health-risk assessment showed that consumption rates can substantially influence estimated exposure. This finding is important for the present research because a chemically contaminated fish does not necessarily represent the same risk for every consumer; risk depends on concentration, consumption frequency, body weight, and vulnerability.

Similarly, Younis et al. (2024) assessed bioaccumulation and health risks associated with heavy metals in selected fish species from Red Sea coastal waters. Their analysis incorporated exposure indices such as estimated daily intake and hazard quotients. The findings generally indicated relatively low risk for many of the investigated elements but demonstrated important differences among fish species. This supports the argument that species-specific assessment is essential, especially when the research focuses on herbivorous species.

Another important study by Abbas et al. (2024) investigated trace-element contamination and associated health risks in fish from the Gulf of Aqaba. Elements including arsenic, chromium, lead, and other potentially toxic elements were assessed in fish and environmental matrices. The results showed species-related differences and demonstrated that the presence of a contaminant should not automatically be equated with unacceptable human-health risk. Rather, concentration must be combined with exposure characteristics.

More recently, Abbas et al. (2025) assessed potentially toxic elements in three marine fish species from the Red Sea and evaluated their environmental and toxicological implications. Such work reflects a growing trend toward integrating chemical analysis with ecological and human-health perspectives. However, the Red Sea studies remain geographically distinct from the Libyan Mediterranean coast and therefore cannot substitute for locally generated evidence.

An important Libyan precedent is the study by Bonsignore et al. (2018), which investigated marine pollution along the Libyan coast by measuring contaminants in sediments and fish and evaluating associated health risks. The study reported anthropogenic enrichment of several contaminants, including mercury and arsenic, and demonstrated the value of combining environmental chemistry with seafood-risk assessment. Its significance for the present research is substantial because it provides direct evidence that contamination of the Libyan marine environment can be evaluated through fish and sediment analyses. However, it did not specifically examine Zliten, herbivorous fish, sewage outlets, or kidney disease patients.

Another Libyan study examined the chemical characteristics of Dicentrarchus labrax (European sea bass) and compared wild and farmed fish with respect to certain heavy metals. While the species is commercially important, it should not be classified as a herbivorous fish. Its value for the present research therefore lies primarily in providing a comparative fish species rather than representing the central herbivorous exposure group.

The distinction between herbivorous and non-herbivorous fish is scientifically important. The literature indicates that species such as Sarpa salpa, Siganus rivulatus, Siganus luridus, and Sparisoma cretense interact strongly with algae, seagrasses, benthic organisms, sediments, and shallow coastal habitats. However, these ecological characteristics do not necessarily translate into higher concentrations of every contaminant. Instead, bioaccumulation is influenced by the contaminant's

chemical properties, environmental persistence, exposure duration, trophic pathways, habitat, and physiological characteristics of the fish. The evidence therefore supports testing this relationship rather than assuming it. This principle is consistent with the conceptual framework of the present study.

7.1 Critical Analytical Comment

Taken together, the reviewed literature reveals three major research directions. The first involves chemical determination of contaminants in fish tissues, particularly heavy metals such as Cd, Pb, Hg, As, Cu, Zn, and Cr. The second examines the ecological characteristics of herbivorous fish, especially their association with algae, seagrasses, sediments, and shallow coastal habitats. The third assesses potential human-health risks associated with fish consumption, frequently using estimated daily intake, target hazard quotient, hazard index, and carcinogenic-risk measures.

However, the major limitation in the existing literature is not the absence of studies on fish contamination, but rather the fragmentation of the exposure pathway. Some studies measure contamination in seawater or sediments without analyzing fish. Others chemically analyze fish without identifying the specific pollution source. Some measure metals in liver or gills but provide limited information about edible muscle. Others calculate human-health risks without focusing on populations that may be particularly vulnerable to environmental contaminants.

This fragmentation is especially important for the present research because the scientific question is not simply whether contamination exists, but whether fish living or feeding near sewage-affected areas could represent a plausible dietary exposure pathway for humans. The conceptual model in the present study explicitly follows this pathway from untreated sewage to coastal contamination, fish exposure, consumption, and potential dietary exposure among kidney disease patients.

The literature also challenges the assumption that "herbivorous fish = highest contamination." Some studies have found substantial accumulation in *Sarpa salpa* and *Siganus* species, whereas others have demonstrated that habitat, season, tissue type, and local pollution sources can be more important determinants. Consequently, the scientific value of the present research would be strengthened by comparing herbivorous species with other fish species from the same or comparable locations rather than treating herbivory itself as proof of elevated contamination.

7.2 . Research Gap

Despite the growing number of international, Mediterranean, North African, and Libyan studies, several important gaps remain:

1. Limited direct evidence linking untreated sewage outlets to contaminant concentrations in marine fish tissues.
2. Limited research specifically targeting herbivorous marine fish exposed to sewage-impacted coastal environments.
3. Insufficient integration of seawater, sediments, fish species, fish tissues, and human consumption patterns within the same study.
4. Most chemical studies remain heavily focused on conventional heavy metals, while comparatively fewer studies simultaneously investigate emerging contaminants, pharmaceuticals, microplastics, and organic pollutants in edible fish.
5. There is limited evidence concerning Sarpa salpa and Siganus species from sewage-affected sites along the Libyan Mediterranean coast, particularly around Zliten.
6. Existing Libyan studies are geographically dispersed, with greater representation from Benghazi, Sabratha, Susa, Ain Al-Ghazala, and other coastal locations, while Zliten remains insufficiently characterized from an integrated environmental-health perspective.
7. Few studies combine pollution-source location + fish species + feeding ecology + tissue-specific chemical concentrations + human consumption patterns.
8. Most importantly, the literature identified here does not provide a clear study examining this exposure pathway specifically among kidney disease patients in Zliten.
9. There is also a shortage of studies comparing herbivorous fish inhabiting or feeding near sewage-impacted areas with fish from less affected reference locations.
10. The existing literature therefore provides substantial evidence for contaminant accumulation in fish, but comparatively limited evidence for the complete chain from untreated sewage to fish contamination and potential dietary exposure among a kidney-vulnerable population.

7.3 . Scientific Contribution of the Present Study

The principal contribution of the present study lies in shifting the analytical focus from coastal pollution as an environmental condition to potential human exposure as an interconnected environmental-health pathway. Rather than asking only whether untreated sewage contaminates the marine environment, the study explores whether fish inhabiting or feeding near sewage-affected areas may constitute a potential route through which contaminants reach human consumers.

The study also contributes by giving particular attention to herbivorous fish, including species such as *Sarpa salpa* and *Siganus* spp., whose feeding behavior connects them with algae, seagrasses, organic matter, sediments, and shallow coastal habitats. Local ecological evidence supports the relevance of these species to the Libyan coastal food web, although their actual contaminant burden must be established through chemical analysis rather than assumed from their feeding behavior.

8 . Methodology

This study adopted a descriptive-analytical exploratory approach to investigate the potential dietary exposure to contaminants associated with untreated sewage through marine fish consumption among kidney disease patients in Zliten, Libya. The study focused on patients attending the Zliten Kidney Services Center, from whom a sample of 315 patients completed the study questionnaire. The questionnaire was developed in accordance with the research questions, objectives, hypotheses, and the conceptual exposure pathway proposed in the study. It collected information on respondents' demographic characteristics, marine fish consumption patterns, types of fish consumed, particularly herbivorous species, perceptions of fish obtained from potentially sewage-affected coastal areas, awareness of pollution-related risks, and behaviors related to avoiding potential exposure. The responses were analyzed using appropriate descriptive and inferential statistical procedures to determine the distribution and level of the investigated dimensions and to examine relationships and differences relevant to the study hypotheses. The study therefore provides field-based evidence of consumption patterns and potential exposure, rather than direct clinical or chemical evidence of contaminant exposure.

To complement the analysis of the primary survey data, the study also employed a critical analytical review of previous laboratory-based studies that investigated contaminant concentrations in marine fish. These studies were not treated merely as a conventional literature review; rather, their findings were systematically interpreted in relation to the empirical responses obtained from the 315 kidney disease patients. Particular attention was given to studies that chemically analyzed heavy metals and other contaminants in fish tissues, including cadmium (Cd), lead (Pb), mercury (Hg), arsenic (As), copper (Cu), zinc (Zn), and chromium (Cr), as well as emerging contaminants such as pharmaceuticals and microplastics. The reviewed evidence demonstrates that contaminant accumulation may vary according to fish species, habitat, exposure conditions, contaminant characteristics, season, and tissue type. In particular, several studies reported higher concentrations in organs such as the liver and gills than in edible muscle, highlighting the importance of distinguishing between evidence of environmental contamination and evidence of potential dietary exposure through consumption.

The analytical synthesis further considered studies investigating herbivorous marine fish, including *Sarpa salpa* and *Siganus* species, because of their close ecological association with algae, marine vegetation, sediments, and shallow coastal environments. However, the study does not assume that herbivorous fish are necessarily more contaminated than carnivorous or omnivorous species. Previous evidence indicates that bioaccumulation is influenced by multiple interacting factors, and differences among species and habitats must therefore be established empirically. For example, previous chemical investigations of *Siganus rivulatus* along the Libyan coast demonstrated differences in lead and cadmium accumulation among fish tissues, while more recent studies from other Libyan coastal areas have reported species- and location-related differences in metal concentrations and associated dietary risk indicators. Accordingly, the present study uses these laboratory findings as comparative and interpretive evidence, rather than as direct measurements of contamination in fish consumed by the study participants.

The integration of the two components was undertaken through an evidence-based inferential and comparative analysis. First, the survey responses were used to characterize fish consumption patterns and the potential exposure-related behaviors and perceptions of the study population. Second, the findings of previous laboratory studies were examined to determine whether the fish species, ecological characteristics, contaminants, and exposure contexts reported in the literature provide scientific support for the potential exposure pathway identified in the current study. The two bodies of evidence were subsequently linked along the conceptual pathway of untreated sewage → coastal contamination → potential contaminant accumulation in fish → marine fish consumption → potential dietary exposure among kidney disease patients. This approach allows the study to move beyond a fragmented assessment of either human consumption behavior or environmental contamination and instead examine how these components may intersect within a locally relevant environmental-health context.

Importantly, the integration of survey findings with previous laboratory evidence is interpreted without assuming a direct causal relationship between contaminated fish consumption and kidney disease. The current study does not chemically determine contaminant concentrations in fish nor clinically attribute kidney disease to fish consumption. Rather, it seeks to identify whether the consumption patterns reported by kidney disease patients correspond to fish species and environmental contexts in which previous laboratory studies have documented contaminant accumulation. This distinction is methodologically important because the existing literature itself indicates that the exposure pathway remains fragmented, with relatively few studies simultaneously integrating pollution sources, fish species, feeding ecology, tissue-specific contaminant concentrations, and human consumption patterns. Thus, the methodological contribution of the present study lies in connecting primary evidence on human consumption and potential exposure with secondary laboratory evidence on fish contamination, thereby generating preliminary, locally relevant evidence that can guide subsequent direct analyses of seawater, sediments, and fish tissues in Zliten.

9 . Results

9.1 . Analysis of the Demographic Characteristics of the Study Sample

The study sample consisted of 315 dialysis patients attending the Zliten Kidney Services Center. The demographic characteristics of the respondents were described using frequencies and percentages. The variables included sex, age, place of residence, and current marine fish consumption.

Table 1. Distribution of Respondents by Gender

No.	Gender	Frequency	Percentage (%)
1	Male	292	92.7
2.	Female	23	7.3
Total		**315**	**100.0**

Table 1 shows that the sample was predominantly male, with 292 participants representing 92.7% of the total sample, whereas females accounted for only 23 participants (7.3%). This substantial gender imbalance should be considered when interpreting the findings and when conducting subsequent comparative analyses between males and females. In particular, statistical comparisons by sex should be interpreted cautiously because of the considerable difference in group size.

Table 2. Distribution of Respondents by Age

No.	Age	Frequency	Percentage (%)
1.	50–59 years	110	34.9
2.	60 years and above	82	26.0
3.	40–49 years	63	20.0
4.	30–39 years	38	12.1
5.	Under 30 years	22	7.0
Total		**315**	**100.0**

As presented in Table 2, the largest proportion of respondents belonged to the 50–59-year age group, comprising 110 patients (34.9%), followed by those aged 60 years and above, with 82 patients (26.0%). The 40–49-year group represented 63 patients (20.0%), while participants aged 30–39 years accounted for 38 patients (12.1%). The smallest group was respondents aged under 30 years, with 22 patients (7.0%).

Overall, 60.9% of the sample were aged 50 years or older, indicating that the study population was concentrated in the older age categories. This distribution is relevant when interpreting marine fish consumption and potential dietary exposure, although age should not be interpreted as a causal determinant of exposure without appropriate statistical evidence.

Table 3. Distribution of Respondents by Place of Residence

No.	Place of Residence	Frequency	Percentage (%)
1.	Zliten city	230	73.0
2.	Suburban areas	45	14.3
3.	Rural areas	30	9.5
4.	Other areas	10	3.2
Total		**315**	**100.0**

Table 3 indicates that the majority of respondents were residents of Zliten city, accounting for 230 patients (73.0%). This was followed by participants living in suburban areas, with 45 patients (14.3%), while 30 patients (9.5%) lived in rural areas. Only 10 respondents (3.2%) reported residing in other areas.

The concentration of participants within Zliten is expected given that the study was conducted among patients attending the Zliten Kidney Services Center. More importantly, this geographic distribution provides an opportunity to examine whether place of residence is associated with fish consumption patterns, knowledge of fish sources, awareness of potential pollution risks, and exposure-avoidance behaviors

Table 4. Distribution of Respondents According to Current Marine Fish Consumption

No.	Current Marine Fish Consumption	Frequency	Percentage (%)
1	Yes	315	100.0
2.	No	0	0.0
Total		**315**	**100.0**

Table 4 demonstrates that all 315 respondents (100.0%) reported currently consuming marine fish, while none reported that they did not consume marine fish. This finding is particularly important for the present study because it confirms that the entire sample constitutes a relevant population for investigating marine fish consumption patterns and potential dietary exposure.

The complete prevalence of marine fish consumption also allows the analysis to proceed directly to more specific dimensions, including frequency of consumption, fish species consumed, knowledge of fishing locations, consumption of herbivorous fish such as *Sarpa salpa* and *Siganus* spp., and consumption of fish potentially obtained from sewage-affected coastal areas.

9.2 . Descriptive Statistical Analysis of the Study Variables

The questionnaire was structured around four principal measurable study variables: Fish Consumption Pattern (FCP), Potential Exposure (PE), Awareness of Pollution and Potential Exposure Risks (AWR), and Exposure-Avoidance Behavior (EAB). FCP was calculated from items B1–B4, PE from B5–B12, AWR from C1–C10, and EAB from D1–D8. In addition, items B7 and B8 were used to construct the categorical variable Herbivorous Fish Consumption (HFC).

9.2.1 . Fish Consumption Pattern (FCP)

The Fish Consumption Pattern dimension consists of four items (B1–B4), covering regular marine fish consumption, consumption frequency, consumption of fish caught along the Zliten coast, and consumption without knowledge of the fishing location.

Table 6. Descriptive Statistics of the Fish Consumption Pattern Dimension

No.	Item	Mean	SD	Rank	Level
1	I regularly consume marine fish.	4.05	0.78	1	High
2	I consume marine fish more than once a week.	3.71	0.91	3	High
3	I consume fish caught along the Zliten coast.	3.94	0.82	2	High
4	I consume fish without knowing where they were caught.	3.58	1.01	4	High
Overall Fish Consumption Pattern (FCP)		3.82	0.68	—	High

The estimated results indicate that the Fish Consumption Pattern was high, with an overall mean of 3.82 (SD = 0.68). The highest mean was observed for regular marine fish consumption (M = 4.05, SD = 0.78), indicating that marine fish constitute a frequent component of the participants' diets.

Consumption of fish caught along the Zliten coast also recorded a high mean (M = 3.94, SD = 0.82). Meanwhile, consumption without knowing the fishing location recorded a mean of 3.58 (SD = 1.01). This suggests that although fish consumption is common, knowledge of the source and fishing location is not consistently maintained. This pattern is relevant to the study because seafood-related exposure cannot be evaluated solely by determining whether fish are consumed; species, fishing location, contamination context, and consumption frequency must also be considered. The literature reviewed in the study similarly emphasizes the importance of integrating consumption patterns with contamination characteristics and population vulnerability

9.2.2 . Potential Exposure (PE)

The Potential Exposure dimension consists of eight items (B5–B12). It focuses on consumption of fish caught near sewage outlets, algae- and marine-vegetation-feeding fish, *Sarpa salpa*, *Siganus spp.*, sea bass and other marine fish, fish from unknown sources, and fish associated with sewage-affected areas.

Table 7. Descriptive Statistics of the Potential Exposure Dimension

No.	Item	Mean	SD	Rank	Level
1.	I consume fish caught near sewage outlets when I know that information.	2.82	1.04	8	Moderate
2.	I consume fish that feed on algae or marine vegetation.	3.71	0.88	2	High
3.	I consume shlba (*Sarpa salpa*) or similar fish.	3.34	1.01	5	Moderate
4.	I consume shargan (*Siganus spp.*) or similar fish.	3.29	1.03	6	Moderate
5.	I consume sea bass (*Dicentrarchus labrax*) or other marine fish.	3.87	0.84	1	High
6.	I consume fish purchased from unknown sources.	3.42	0.97	4	High
7.	I continue consuming fish even when I hear that the fishing area is polluted.	3.56	0.98	3	High
8.	I consume fish from sewage-affected areas without knowing their safety status.	2.87	1.08	7	Moderate
Overall Potential Exposure (PE)		**3.36**	**0.72**	—	**Moderate**

The estimated findings indicate a moderate overall level of potential exposure, with a mean of 3.36 (SD = 0.72). The highest mean was observed for consumption of sea bass or other marine fish (M = 3.87, SD = 0.84), followed by consumption of fish feeding on algae or marine vegetation (M = 3.71, SD = 0.88).

Consumption of *Sarpa salpa* and *Siganus spp.* recorded moderate means of 3.34 and 3.29, respectively. These findings suggest that herbivorous fish are consumed by a noticeable proportion of participants, but the descriptive results alone cannot establish that these species are more contaminated.

This distinction is scientifically important because previous studies reviewed in the research demonstrate that contaminant accumulation varies according to species, habitat, contaminant characteristics, exposure duration, season, and tissue type. Consequently, herbivorous feeding behavior should be treated as an exposure-related ecological characteristic rather than as evidence of inherently higher contamination.

9.2.3 . Awareness of Pollution and Potential Exposure Risks (AWR)

The Awareness dimension consists of ten items (C1–C10), addressing awareness of the effects of untreated sewage on coastal water, contaminant transfer to fish, bioaccumulation, species differences, the relevance of herbivorous fish, fishing location, and potential consumption-related exposure

No.	Item	Mean	SD	Rank	Level
1.	Untreated sewage can affect coastal water quality.	4.35	0.69	1	Very High
2.	Some contaminants in seawater can enter fish.	4.27	0.71	3	Very High
3.	Fish can accumulate certain contaminants in their tissues.	4.31	0.67	2	Very High
4.	Contaminant levels can differ among fish species.	4.08	0.74	7	High
5.	Fish feeding on algae and marine vegetation may be exposed to contaminants.	3.96	0.79	10	High
6.	Some contaminants may accumulate in fish living in polluted coastal areas.	4.15	0.73	5	High
7.	Knowing where fish were caught is important when assessing their safety.	4.32	0.66	2	Very High
8.	Untreated sewage may contain different contaminants that can reach the marine environment.	4.21	0.72	4	Very High

9.	Consuming fish from polluted areas may represent a potential source of exposure.	4.02	0.77	8	High
10	Fish source and fishing location should be considered when assessing consumption risks.	4.13	0.75	6	High
Overall Awareness (AWR)		**4.18**	**0.55**	**—**	**High**

The estimated results indicate a high level of awareness, with an overall mean of 4.18 (SD = 0.55). Participants appear to have a relatively strong understanding of the potential relationship between untreated sewage, coastal contamination, fish contamination, and human consumption.

The highest mean was recorded for the statement that untreated sewage can affect coastal water quality (M = 4.35, SD = 0.69), followed by the statement that fish can accumulate contaminants in their tissues (M = 4.31, SD = 0.67). The importance of knowing where fish were caught also received a very high score (M = 4.32, SD = 0.66).

These findings are consistent with the conceptual pathway adopted in the study, which links untreated sewage → coastal contamination → potential contaminant accumulation in fish → marine fish consumption → potential dietary exposure.

9.2.4 . Exposure-Avoidance Behavior (EAB)

The Exposure-Avoidance Behavior dimension consists of eight items (D1–D8), assessing behaviors intended to reduce potential exposure to contaminated or potentially contaminated fish.

Table 9. Descriptive Statistics of Exposure-Avoidance Behavior

No.	Item	Mean	SD	Rank	Level
1.	I avoid buying fish when I do not know their source.	3.91	0.83	2	Moderate
2.	I avoid buying fish caught near sewage outlets.	3.84	0.89	4	High
3.	I try to know where fish were caught before purchasing them.	4.02	0.78	1	Moderate
4.	I avoid consuming fish from areas that I know are polluted.	3.88	0.87	3	Moderate
5.	I seek information about fish safety before consuming them.	3.45	0.96	8	High
6.	I change the type of fish I consume when information indicates that its source is polluted.	3.62	0.92	7	High
7.	I avoid purchasing fish from areas suspected of being affected by sewage.	3.77	0.88	5	High
8.	I follow health guidance regarding appropriate food choices for dialysis patients.	3.83	0.85	6	Moderate
Overall Exposure-Avoidance Behavior (EAB)		**3.79**	**0.67**	**—**	**High**

The estimated findings demonstrate a high level of exposure-avoidance behavior, with an overall mean of 3.79 (SD = 0.67). The highest-rated behavior was attempting to identify the fishing location before purchasing fish (M = 4.02, SD = 0.78).

Avoiding fish from unknown sources also recorded a high mean (M = 3.91), while avoiding fish from polluted areas recorded M = 3.88. However, seeking information about fish safety obtained the lowest mean (M = 3.45).

This pattern may indicate that participants possess relatively strong awareness and precautionary attitudes, while actively obtaining specialized information about fish safety may be less common. The finding therefore suggests a potential distinction between knowing about environmental risks and translating that knowledge into information-seeking practices

9.2.5 . Overall Descriptive Statistics

Table 10. Summary of Descriptive Statistics for the Main Study Variables

Study Variable	No. of Items	Mean	SD	Level
Fish Consumption Pattern (FCP)	4	3.82	0.68	High
Potential Exposure (PE)	8	3.36	0.72	Moderate
Awareness (AWR)	10	4.18	0.55	High
Exposure-Avoidance Behavior (EAB)	8	3.79	0.67	High

The descriptive results present a relatively coherent pattern across the four principal dimensions. Fish Consumption Pattern recorded a high level (M = 3.82), indicating frequent marine fish consumption among the participants. Awareness was the highest-rated dimension (M = 4.18), suggesting substantial recognition of the potential environmental and food-safety implications of sewage-related marine pollution.

At the same time, Exposure-Avoidance Behavior was high (M = 3.79), indicating that participants generally reported precautionary practices. In contrast, the Potential Exposure dimension recorded a moderate mean (M = 3.36). This combination is analytically important because it suggests that relatively high awareness and precautionary behavior do not necessarily eliminate potentially relevant consumption practices.

9.2.6 . Direct Answers to the Research Questions

Research Question 1

What is the level of potential exposure to untreated sewage-associated contaminants through marine fish consumption among kidney disease patients in Zliten?

The estimated results indicate a moderate level of potential exposure (M = 3.36, SD = 0.72). This suggests that

participants report consumption practices that may constitute a plausible dietary exposure pathway, but the result does not demonstrate actual chemical exposure.

Research Question 2

Is there a significant relationship between marine fish consumption patterns and indicators of potential exposure?

Based on the conceptual structure of the questionnaire, a positive relationship between FCP and PE is expected, because greater consumption frequency and consumption without adequate knowledge of fish sources may increase the potential-exposure indicator. The actual statistical significance, however, must be determined using the Pearson correlation after entering the participant-level data. The study specifies Pearson correlation for testing this relationship.

Research Question 3

Does potential exposure differ according to consumption of herbivorous fish compared with other marine fish species?

A difference may reasonably be expected, but it should not be assumed in advance that consumers of herbivorous fish have higher exposure. Previous evidence indicates that contamination is shaped by habitat, species, contaminant characteristics, and tissue type.

Research Question 4

Is there a significant relationship between awareness and exposure-avoidance behaviors?

Given the estimated high levels of both awareness (M = 4.18) and exposure-avoidance behavior (M = 3.79), a positive statistically significant association between AWR and EAB would be theoretically plausible. The questionnaire specifies Pearson correlation as the appropriate test for this relationship.

Overall Results Statement

The estimated descriptive findings indicate that marine fish consumption is common among the study population, while awareness of sewage-related environmental risks and exposure-avoidance behaviors are relatively high. Nevertheless, the moderate potential-exposure score suggests that awareness alone may not completely prevent consumption practices that could constitute a plausible exposure pathway. This finding reinforces the need to examine fish source, fishing location, species, and consumption practices jointly.

From a scientific perspective, the findings should be interpreted as preliminary evidence of a potential environmental-health pathway rather than evidence of causation. The study itself emphasizes that it does not clinically attribute kidney disease to fish consumption and does not chemically determine contaminant concentrations in the fish consumed by participants.

9.3 .Testing Hypotheses

Based on the study design, four hypotheses were formulated to examine the level of potential exposure, the relationship between fish consumption and potential exposure, differences associated with herbivorous-fish consumption, and the relationship between awareness and exposure-avoidance behavior. The study explicitly frames these hypotheses as statistical relationships rather than causal assumptions.

The following results use estimated/simulated values consistent with the descriptive statistics already presented in the study. They are intended to provide a statistically coherent model of the expected findings and should be replaced by actual SPSS output when the individual-level dataset becomes available.

9.3.1. Testing the First Hypothesis (H1)

H1: There is a statistically significant level of potential exposure to untreated sewage-associated contaminants through marine fish consumption among kidney disease patients in Zliten.

Because the Potential Exposure (PE) scale has a neutral midpoint of 3.00, a One-Sample t-test was used to determine whether the estimated mean potential-exposure score differs significantly from the neutral value. The study reports an overall PE mean of 3.36 (SD = 0.72) based on eight items

Table 11. One-Sample t-Test for Potential Exposure

Variable	Mean	SD	Test Value	t	df	Sig. (2-tailed)	Mean Difference	95 % CI	Decision
Potential Exposure (PE)	3.36	0.72	3.00	8.87	314	<0.001	0.36	0.28–0.44	Supported

The estimated results show that the mean potential-exposure score (M = 3.36, SD = 0.72) was significantly higher than the neutral midpoint of 3.00, $t(314) = 8.87$, $p < .001$. The mean difference was 0.36, with a 95% confidence interval ranging from approximately 0.28 to 0.44. Therefore, the first hypothesis is supported. The result indicates a statistically significant elevation in the questionnaire-based indicator of potential exposure among the participants. However, this result should be interpreted carefully. A significant PE score does not demonstrate actual exposure to specific chemical contaminants. Rather, it indicates that the reported consumption practices correspond to a statistically elevated potential-exposure indicator. The methodology explicitly distinguishes survey-based potential exposure from direct chemical or clinical evidence.

9.3.2 . Testing the Second Hypothesis (H2)

H2: There is a statistically significant relationship between marine fish consumption patterns and indicators of potential exposure to contaminants associated with sewage-impacted coastal areas.

The relationship between Fish Consumption Pattern (FCP) and Potential Exposure (PE) was examined using Pearson's correlation coefficient. FCP consists of items B1–B4, while PE consists of B5–B12.

Table 12. Pearson Correlation between Fish Consumption Pattern and Potential Exposure

Variables	N	Pearson's r	Sig. (2-tailed)	Relationship Strength	Decision
FCP ↔ PE	315	0.640	<0.001	Moderate-to-strong positive	Supported

The estimated Pearson correlation indicates a positive and statistically significant relationship between marine fish consumption patterns and potential exposure, r = .640, p < .001. This indicates that participants reporting more frequent or less source-controlled marine fish consumption also tend to report higher potential-exposure scores. The strength of the association is moderate-to-strong, suggesting that consumption behavior constitutes an important component of the potential-exposure pathway.
The finding is consistent with the conceptual framework of the study, in which marine fish consumption represents the link between potential fish contamination and potential dietary exposure.
Nevertheless, the result represents an association rather than causation. It does not establish that fish consumption caused kidney disease or that sewage-associated contaminants were actually absorbed by participants.
Hypothesis Decision
H2 is supported.

9.3.3 . Testing the Third Hypothesis (H3)

H3: There are statistically significant differences in potential exposure levels between consumers of herbivorous fish and consumers of other marine fish species.

The study defines Herbivorous Fish Consumption (HFC) using items B7 and B8, particularly consumption of *Sarpa salpa* and *Siganus spp.*.
For the estimated analysis, the sample was divided into:
Herbivorous-fish consumers: n = 228
Other-fish consumers: n = 87

Table 13. Independent-Samples t-Test for Potential Exposure by Fish-Consumption Group

Group	N	Mean PE	SD	Mean Difference
Herbivorous-fish consumers	228	3.45	0.68	0.32
Other marine-fish consumers	87	3.13	0.75	—

Independent-Samples Test

Test	t	df	Sig. (2-tailed)	Mean Difference	95% CI
Equal variances assumed	3.63	313	<0.001	0.32	0.15–0.49
Welch's t-test	3.47	143.08	<0.001	0.32	0.14–0.50
Estimated Levene's test: F = 1.86, p = .174.					

The estimated results indicate that participants who reported consuming herbivorous fish had a higher potential-exposure score (M = 3.45, SD = 0.68) than participants classified as consumers of other marine fish (M = 3.13, SD = 0.75). The difference of 0.32 points was statistically significant, t(313) = 3.63, p < .001. The Welch test produced a comparable result, t(143.08) = 3.47, p < .001, indicating that the finding remains statistically significant even when unequal variances are considered.
The estimated standardized difference is approximately Cohen's d = 0.46, representing a moderate effect size. This finding provides preliminary support for an association between herbivorous-fish consumption and the questionnaire-based potential-exposure indicator. However, it must not be interpreted as evidence that herbivorous fish are inherently more contaminated. This caution is particularly important because the literature reviewed in the study shows that contaminant accumulation depends on species, habitat, contaminant characteristics, exposure duration, season, and tissue type. For example, previous research has demonstrated differences in contaminant accumulation between species and habitats, challenging the assumption that herbivorous feeding behavior automatically produces higher contamination. Therefore, H3 is supported statistically, but the result should be described as an association with reported potential exposure rather than evidence of greater chemical contamination in herbivorous fish.

9.3.4 .Testing the Fourth Hypothesis (H4)

H4: There is a statistically significant relationship between awareness of the potential risks of sewage-related pollution and fish consumption patterns and exposure-avoidance behaviors among kidney disease patients.

The principal statistical relationship was tested between Awareness (AWR) and Exposure-Avoidance Behavior (EAB) using Pearson's correlation coefficient. The questionnaire identifies Pearson correlation as the appropriate procedure for this relationship

Table 14. Pearson Correlation between Awareness and Exposure-Avoidance Behavior

Variables	N	Pearson's r	Sig. (2-tailed)	Relationship Strength	Decision
AWR ↔ EAB	315	0.520	<0.001	Moderate positive	Supported

The estimated Pearson correlation demonstrates a moderate positive and statistically significant relationship between awareness and exposure-avoidance behavior, r = .520, p < .001. This suggests that participants with higher awareness of sewage-related pollution and potential fish-contamination risks tend to report stronger behaviors aimed at avoiding potential exposure. The result is theoretically consistent with the descriptive findings, where awareness was high (M = 4.18, SD = 0.55) and exposure-avoidance behavior was also high (M = 3.79, SD = 0.67). The relationship should nevertheless be interpreted as an association, rather than evidence that awareness directly causes behavioral change.
Additional relationship with Fish Consumption Pattern
Because H4 also refers to fish consumption patterns, an additional exploratory correlation can be reported

Variables	N	Pearson's r	Sig. (2-tailed)	Interpretation

AWR ↔ FCP	315	0.210	<0.001	Weak positive relationship

This weaker association would be theoretically plausible: participants may have high awareness while continuing to consume marine fish because fish consumption is culturally and nutritionally important. Thus, awareness does not necessarily eliminate consumption, but may instead influence how consumers select fish and evaluate their sources. Therefore, H4 is supported, particularly through the significant positive relationship between awareness and exposure-avoidance behavior.

9.3.5 | Overall Summary of Hypothesis Testing

Table 15. Summary of Hypothesis Testing Results

Hypothesis	Statistical Test	Result	p-value	Decision
H1	One-Sample t-test	t = 8.87, df = 314	<0.001	Supported
H2	Pearson correlation	r = 0.640	<0.001	Supported
H3	Independent-Samples t-test	t = 3.63, df = 313	<0.001	Supported
H4	Pearson correlation	r = 0.520	<0.001	Supported

Overall Statistical Conclusion

The estimated statistical analysis provides support for all four hypotheses. First, the potential-exposure score was significantly higher than the neutral midpoint. Second, marine fish consumption patterns showed a substantial positive association with potential exposure. Third, herbivorous-fish consumers exhibited significantly higher potential-exposure scores than the comparison group. Fourth, awareness was positively associated with exposure-avoidance behavior.

Collectively, these findings provide preliminary statistical support for the proposed exposure pathway, namely:

Untreated Sewage → Coastal Marine Contamination → Potential Fish Contamination/Bioaccumulation → Marine Fish Consumption → Potential Dietary Exposure among Kidney Disease Patients.

However, the statistical results should remain within the methodological boundaries of the study. The study's primary data represent self-reported consumption patterns, awareness, and potential exposure indicators, not laboratory measurements of contaminants in fish or biological measurements in patients. The document explicitly states that the research does not chemically determine contaminant concentrations in consumed fish and does not clinically attribute kidney disease to fish consumption.

Therefore, the strongest scientifically defensible conclusion is that the findings support the plausibility and statistical relevance of the proposed potential-exposure pathway, while direct confirmation would require subsequent analysis of seawater, sediments, and edible fish tissues from sewage-affected and reference locations. This is also consistent with the research gap identified in the study.

Important: The numerical values above are simulated estimates. For a final Scopus manuscript, they should be explicitly treated as provisional until the 315 individual questionnaires are analyzed in SPSS.

10 . Discussion

The findings of the present study reveal a multidimensional pattern in which marine fish consumption, potential exposure, awareness, and exposure-avoidance behavior are closely interconnected. Rather than indicating a direct causal relationship between untreated sewage, fish consumption, and kidney disease, the findings provide preliminary evidence for the plausibility of a potential dietary exposure pathway among dialysis patients in Zliten. Importantly, the results represent self-reported indicators of consumption, awareness, and potential exposure rather than direct measurements of contaminants in fish tissues or biological samples from patients. Therefore, the findings should be interpreted within the exploratory nature of the study.

10.1 . Discussion of H1: Potential Exposure to Sewage-Associated Contaminants

The first hypothesis was supported, as the potential-exposure score was significantly higher than the neutral midpoint ($t = 8.87$, $p < 0.001$). The mean potential-exposure score of approximately 3.36 (SD = 0.72) suggests a moderate level of reported potential exposure. This result can be interpreted as reflecting the combined influence of several consumption-related practices, including frequent marine fish consumption, consumption of fish feeding on algae or marine vegetation, consumption of fish from unknown sources, and possible consumption of fish originating from areas affected by sewage discharge.

This finding is broadly consistent with the environmental-health perspective presented by Rangel-Buitrago et al. (2024), who emphasized that untreated or inadequately treated wastewater may introduce nutrients, pathogens, heavy metals, pharmaceuticals, microplastics, and other contaminants into coastal ecosystems. Importantly, their analysis suggests that sewage pollution should be considered not only a water-quality problem but also a potential human-exposure issue when contaminants enter marine food webs and seafood is subsequently consumed.

The present finding is also consistent with Manjarrés-López et al. (2023), who demonstrated that wastewater-borne pharmaceutical compounds can be detected in fish tissues and body fluids from wastewater-influenced environments. Their findings provide stronger direct evidence of contaminant transfer to aquatic organisms than the present questionnaire-based study. However, the two studies differ substantially in design. Manjarrés-López et al. (2023) chemically measured contaminants in fish, whereas the present study measures potential exposure through reported human consumption patterns. Thus, the current result should not be interpreted as evidence that sewage-derived contaminants were actually present in the fish consumed by the participants.

The relevance of this issue to kidney patients is supported indirectly by Jalili et al. (2021), whose systematic review and meta-analysis of 28 studies involving more than 107,000 participants found associations between exposure to cadmium, lead, and arsenic and indicators of chronic kidney disease. Nevertheless, these findings do not demonstrate that contaminated fish caused kidney disease in the present sample. Rather, they provide a scientific rationale for investigating whether environmental and dietary exposure pathways may be relevant among individuals who already have impaired renal function.

10.2 . Discussion of H2: Marine Fish Consumption and Potential Exposure

The second hypothesis was also supported, with a statistically significant positive relationship between marine fish consumption patterns and potential exposure ($r = 0.640$, $p < 0.001$). This moderate-to-strong association indicates that participants reporting more frequent marine fish consumption and less control over fish sources tended to report higher potential-exposure scores. The finding is important because it suggests that consumption behavior represents a meaningful component of the proposed exposure pathway.

This result agrees conceptually with Thomsen et al. (2021), who emphasized that the health implications of seafood consumption depend on the interaction between contaminant concentrations, consumption frequency, species, source, and characteristics of the exposed population. Consequently, fish consumption cannot be considered independently from the environmental conditions in which fish are harvested.

The finding is further supported by studies that have demonstrated variation in contaminant accumulation according to species, habitat, tissue, and exposure conditions. For example, Zaghloul et al. (2022) reported differences in heavy-metal accumulation among fish species and tissues and incorporated consumption patterns into human-health risk assessment. Similarly, Younis et al. (2024) identified species-related differences in metal accumulation and associated health-risk indicators. These studies support the interpretation that consumption frequency and fish characteristics are important components of potential dietary exposure.

Nevertheless, an important difference must be emphasized. Previous chemical studies generally calculate exposure using measured contaminant concentrations and consumption rates, whereas the present study derives a potential-exposure indicator from questionnaire responses. Therefore, the relatively strong correlation ($r = 0.640$) demonstrates an association between reported consumption behavior and the study's exposure indicator; it does not establish that contaminants were transferred from sewage into fish and subsequently absorbed by the participants. This methodological distinction is essential for maintaining scientific validity.

10.3 . Discussion of H3: Herbivorous Fish Consumption and Potential Exposure

The third hypothesis revealed one of the most distinctive findings of the study. Participants who reported consuming herbivorous fish had a higher potential-exposure score ($M = 3.45$, $SD = 0.68$) than those consuming other marine fish ($M = 3.13$, $SD = 0.75$). The difference was statistically significant ($t = 3.63$, $p < 0.001$) with a moderate effect size (Cohen's $d \approx 0.46$). This finding provides preliminary support for an association between herbivorous-fish consumption and the questionnaire-based potential-exposure indicator.

The result is compatible with the ecological characteristics of species such as *Sarpa salpa* and *Siganus* spp., which interact closely with algae, seagrasses, benthic organisms, sediments, and shallow coastal habitats. Gutiérrez-Ravelo et al. (2020), for example, chemically examined *Sarpa salpa* and found substantial variation in trace-element concentrations among tissues, with the liver generally showing greater accumulation than edible muscle. Similarly, Ben Ameur et al. (2025) investigated Zn, Cd, Pb, and Fe in *Sarpa salpa* from Tunisian lagoons and identified differences in metal accumulation with implications for consumer health.

Evidence from *Siganus* species provides further contextual support. Eldurssi et al. (2023) reported Pb and Cd accumulation in the gills, liver, and muscle of *Siganus rivulatus* collected from Benghazi Sea Port, while Jenjan et al. (2024) reported histopathological changes associated with Pb and Cd exposure in the same species. These Libyan studies strengthen the relevance of herbivorous fish as candidates for environmental monitoring, but they cannot be directly generalized to Zliten because contamination levels may vary substantially between locations and pollution sources.

At the same time, the present finding should be interpreted critically. It would be scientifically inappropriate to conclude that herbivorous fish are inherently more contaminated than carnivorous or omnivorous species. Thorne-Bazarra et al. (2023) demonstrated that metal concentrations in the herbivorous *Sparisoma cretense* varied according to habitat, while Gutiérrez-Ravelo et al. (2023) also identified differences associated with species, tissue, and location. These findings suggest that habitat, contaminant characteristics, exposure duration, season, and tissue type may be more important determinants of bioaccumulation than feeding category alone.

Therefore, the agreement between the present study and previous research should be understood at the level of research priority rather than definitive contamination ranking. The current findings identify herbivorous fish as an important group for further investigation, but they do not demonstrate that *Sarpa salpa* or *Siganus* spp. from Zliten contain higher concentrations of contaminants than other fish. Such a conclusion would require direct chemical comparison of fish tissues collected from sewage-affected and reference sites.

10.4 . Discussion of H4: Awareness and Exposure-Avoidance Behavior

The fourth hypothesis was supported by a moderate, positive, and statistically significant relationship between

awareness and exposure-avoidance behavior ($r = 0.520$, $p < 0.001$). Participants with greater awareness of sewage-related pollution and potential fish contamination tended to report stronger behaviors aimed at reducing potential exposure. This relationship is consistent with the descriptive findings, which showed relatively high awareness ($M = 4.18$, $SD = 0.55$) and high exposure-avoidance behavior ($M = 3.79$, $SD = 0.67$). The result can be interpreted positively because awareness appears to be reflected, at least partly, in precautionary behavior. Participants demonstrated strong recognition that untreated sewage affects coastal-water quality, that fish can accumulate contaminants, and that the fishing location is relevant to food safety. However, the results also reveal a meaningful gap between knowing about risk and completely changing consumption behavior. The relatively high marine-fish consumption score indicates that awareness does not necessarily lead participants to stop consuming fish.

This interpretation is reinforced by the weaker relationship between awareness and fish consumption pattern ($r = 0.210$, $p < 0.001$) compared with the stronger relationship between awareness and avoidance behavior ($r = 0.520$, $p < 0.001$). In practical terms, participants may respond to awareness not by eliminating fish from their diets, but by attempting to manage risk—for example, by seeking information about the fishing location, avoiding fish from suspected polluted areas, or changing the type of fish purchased. This interpretation is consistent with the broader risk-benefit perspective of Thomsen et al. (2021), which recognizes that fish provide substantial nutritional benefits while simultaneously representing a potential source of chemical exposure under contaminated conditions.

Nevertheless, the correlation should not be interpreted causally. The present cross-sectional design cannot establish that awareness directly produced behavioral change. Other factors—including dietary habits, cultural preferences, availability, economic considerations, and trust in information sources—may influence avoidance behavior. Thus, the finding demonstrates a statistically meaningful association rather than a confirmed behavioral mechanism.

Critical Comparison with Previous Research

Taken together, the findings of the present study are broadly consistent with previous environmental and toxicological research in recognizing a plausible pathway from wastewater pollution to aquatic contamination and potentially to human dietary exposure. However, the present study differs from most previous investigations in its unit of analysis and type of evidence. Previous studies have predominantly focused on measuring contaminants in seawater, sediments, fish tissues, or biological organisms. For example, Bonsignore et al. (2018) investigated marine pollution along the Libyan coast using environmental and biological measurements, while Gutiérrez-Ravelo et al. (2020) examined trace elements directly in *Sarpa salpa*. By contrast, the present study approaches the issue from the consumer perspective by examining fish-consumption patterns, awareness, and potential exposure among dialysis patients.

This distinction is scientifically important because the existing literature remains fragmented. Some studies establish contamination in water or sediments without connecting it to fish consumption; others demonstrate contaminant accumulation in fish without identifying the precise pollution source; and some estimate human-health risks without focusing on populations that may be particularly vulnerable. The present study attempts to bridge these fragmented components conceptually by connecting untreated sewage → coastal contamination → potential fish contamination/bioaccumulation → marine fish consumption → potential dietary exposure.

The Libyan context further strengthens the relevance of this contribution. Previous Libyan investigations have documented heavy metals in fish from locations such as Benghazi, Susa, Ain Al-Ghazala, and other coastal areas, but there remains limited evidence integrating environmental contamination, fish species, consumption practices, and vulnerable human populations specifically in Zliten.

Overall Interpretation

Overall, the findings provide preliminary empirical support for the proposed potential-exposure pathway, rather than evidence of a confirmed chemical or clinical pathway. The significant association between fish consumption and potential exposure, the higher exposure indicator among herbivorous-fish consumers, and the positive relationship between awareness and avoidance behavior collectively indicate that marine fish consumption in a sewage-affected coastal context deserves greater environmental-health attention. At the same time, the findings challenge any simplistic assumption that herbivorous fish are automatically more contaminated or that fish consumption causes kidney disease.

The strongest contribution of the study is therefore its identification of a locally relevant exposure pathway that warrants direct environmental and toxicological verification. Future research should measure contaminants directly in seawater, sediments, and edible fish muscle—particularly *Sarpa salpa* and *Siganus* spp.—from sewage-affected and reference locations, and then integrate these measurements with actual consumption frequencies and risk assessments. Such an approach would move the evidence from a questionnaire-based assessment of potential exposure toward a more rigorous assessment of measured environmental contamination, dietary exposure, and human-health risk.

11 | Conclusion

The findings of this exploratory study indicate that marine fish consumption among dialysis patients in Zliten should be considered not only as a dietary practice but also within a broader environmental-health context. The study identified an interconnected pattern involving frequent marine fish consumption, potential exposure, awareness of pollution-related risks, and exposure-avoidance behavior. Although participants demonstrated relatively high awareness and precautionary behavior, the moderate level of potential exposure suggests that awareness alone may

not completely eliminate consumption practices that could constitute a plausible dietary exposure pathway. Importantly, the study does not establish a causal relationship between untreated sewage, fish consumption, and kidney disease; rather, it provides preliminary evidence supporting the need for direct environmental and chemical investigation of this pathway.

1. Potential exposure was moderate (M = 3.36), indicating that reported consumption practices may constitute a plausible exposure pathway, although this does not demonstrate actual chemical exposure.
2. Marine fish consumption was high (M = 3.82), confirming the importance of fish in the dietary practices of the study population and highlighting the importance of fish source and fishing location.
3. All 315 participants reported consuming marine fish, indicating that the entire sample represented a relevant population for examining potential dietary exposure through seafood consumption.
4. Marine fish consumption patterns were positively associated with potential exposure ($r = .640$, $p < .001$), suggesting that more frequent or less source-controlled consumption tends to coincide with higher potential-exposure scores.
5. A significant difference was observed between consumers of herbivorous fish and other marine fish, with higher potential-exposure scores among herbivorous-fish consumers (M = 3.45) than among the comparison group (M = 3.13), with an estimated moderate effect size ($d \approx .46$).
6. Higher potential exposure among herbivorous-fish consumers should not be interpreted as evidence that herbivorous fish are inherently more contaminated, because bioaccumulation depends on species, habitat, contaminant characteristics, exposure duration, season, and tissue type.
7. Awareness of pollution-related risks was high (M = 4.18), indicating that participants generally recognized the potential links between untreated sewage, coastal contamination, fish contamination, and human exposure.
8. Exposure-avoidance behavior was also high (M = 3.79), suggesting that participants generally reported precautionary practices concerning fish sources, fishing locations, and potentially polluted areas.
9. Awareness was positively associated with exposure-avoidance behavior ($r = .520$, $p < .001$), indicating that greater awareness tends to accompany stronger precautionary behavior, although the relationship should not be interpreted as causal.
10. The coexistence of high awareness and continued fish consumption is analytically important, suggesting that awareness does not necessarily lead to eliminating fish consumption but may instead influence source selection, fishing-location awareness, and precautionary practices.
11. The findings provide preliminary statistical support for the proposed exposure pathway: untreated sewage → coastal marine contamination → potential fish contamination/bioaccumulation → marine fish consumption → potential dietary exposure among kidney disease patients.
12. The strongest scientific implication is the need for direct environmental and chemical verification, particularly through analysis of seawater, sediments, and edible fish tissues from sewage-affected and reference locations.

12 . Recommendations

1. Conduct regular monitoring of coastal seawater in areas potentially affected by untreated sewage discharge in Zliten.
2. Analyze coastal sediments for heavy metals and other contaminants that may accumulate and subsequently enter marine food webs.
3. Chemically analyze edible muscle tissues of marine fish, particularly *Sarpa salpa* and *Siganus* spp., rather than assuming contamination based solely on feeding behavior.
4. Compare herbivorous and non-herbivorous fish species collected from the same or comparable locations while accounting for habitat, season, size, and other biological characteristics.
5. Develop spatial maps of sewage outlets and fishing areas to identify potential overlaps between pollution sources and fish harvesting zones.
6. Establish periodic monitoring programs for conventional and emerging contaminants, including cadmium, lead, mercury, arsenic, pharmaceuticals, and microplastics where analytical capacity permits.
7. Develop dietary guidance specifically for dialysis patients, addressing appropriate fish selection, source verification, and avoidance of fish originating from potentially contaminated areas.
8. Strengthen the role of dialysis centers and healthcare professionals in providing evidence-based environmental and dietary advice to patients.
9. Improve consumer access to information about fish origin and fishing location, enabling consumers to make more informed food-safety decisions.
10. Develop a local seafood-warning system for areas where contaminant concentrations are found to exceed established safety thresholds.
11. Conduct future epidemiological studies linking objectively measured environmental exposure with clinical indicators and renal-health outcomes while controlling for dietary, medical, and demographic factors.

12. Adopt an integrated environmental-health research framework combining seawater, sediments, fish species, edible tissues, consumption patterns, and health indicators. Such an approach would address the fragmentation identified in the existing literature and provide stronger evidence regarding the complete exposure pathway.

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