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Systematic Review

Systematic Review of the Impact of Natural Resource Management on Public Health Outcomes: Focus on Water Quality

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Abstract: Natural resource management (NRM) plays a pivotal role in ensuring the sustainability of ecosystems, which are essential for human health and well-being. This systematic review examines the impact of various NRM practices on water quality and their subsequent effects on public health. Specifically, it focuses on interventions such as watershed management, pollution control, land use management, water treatment, and ecosystem restoration. We conducted a comprehensive search across PubMed, Scopus, and Web of Science, supplemented by gray literature from Google Scholar, WHO reports, and government and NGO publications, covering studies published between 2014 and 2024. A total of 42 studies met the inclusion criteria, encompassing diverse geographical regions with significant representation from developing countries. The findings indicate that effective NRM practices, particularly those aimed at reducing pollutants, managing watersheds, and promoting sustainable land use, significantly improve water quality by lowering levels of chemical contaminants, microbial pathogens, and physical pollutants. Improved water quality directly correlates with reduced incidences of waterborne diseases, chronic health conditions from long-term chemical exposure, and acute health effects from immediate pollutant exposure. The review underscores the need for tailored NRM strategies that consider local environmental and socio-economic contexts. It also highlights the importance of community involvement, regulatory frameworks, and continuous monitoring to enhance the effectiveness of NRM interventions. Despite the positive impacts, barriers such as limited financial resources, technical expertise, and community engagement pose challenges to the implementation of these practices. In conclusion, the systematic review demonstrates that comprehensive and context-specific NRM practices are crucial for improving water quality and public health outcomes. Policymakers and practitioners are encouraged to adopt integrated water resource management approaches, prioritize sustainable practices, and engage local communities to achieve long-term health and environmental benefits.

Keywords: natural resources; water quality; public health; watershed management; pollution control; sustainable land use; ecosystem restoration

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1. Introduction

Natural resource management (NRM) plays a critical role in ensuring the sustainability and health of ecosystems, which are essential for human well-being [1]. Effective NRM practices are particularly crucial in managing water resources, as water is a fundamental necessity for life and a key determinant of public health [2]. The management of natural resources, including water, soil, air, minerals, and biodiversity, involves implementing practices and strategies that promote their sustainable use and conservation [3]. This ensures that these resources are available for future generations while supporting current human needs and mitigating environmental degradation [3].

Water quality, a primary focus of NRM, is determined by its physical, chemical, and biological characteristics, which must meet specific standards for various uses, such as drinking, agriculture, industry, and recreation [4]. Poor water quality can lead to numerous adverse public health outcomes, including waterborne diseases, chronic health conditions, and acute health effects [5–7]. Contaminated water is a significant vector for pathogens and pollutants, which can cause a range of health issues from gastrointestinal illnesses and skin infections to more severe conditions like cancers and neurological disorders [6,8,9].

Globally, approximately 2.2 billion people lack access to safely managed drinking water services, and an estimated 485,000 deaths each year are attributed to diarrheal diseases caused by contaminated water and poor sanitation [7,10]. In low- and middle-income countries, 70% of industrial waste is dumped untreated into waters where they pollute the usable water supply [11–13].

In Europe, drinking water quality is a critical public health issue, heavily influenced by regulatory frameworks such as the EU Drinking Water Directive (DWD). The 2020 revision of the DWD emphasizes risk assessment and consumer safety, mandating transparency in water quality communication to enhance public confidence in drinking water supplies [14,15]. Despite these advancements, significant challenges remain, particularly concerning microbiological contamination, which poses serious health risks. To address these risks, the DWD sets stringent standards for various contaminants, aligning with WHO guidelines to mitigate waterborne diseases, which continue to affect millions globally [16].

In addition to the DWD, Regulation (EU) 2020/741 establishes minimum requirements for water reuse in the European Union. Its primary objective is to protect the environment and human health by setting stringent quality standards for reclaimed water used in agricultural irrigation. This regulation promotes the safe and efficient use of treated wastewater, contributing to water conservation and sustainable water management practices, particularly in regions facing water scarcity. Key provisions include requirements for monitoring reclaimed water quality, ensuring compliance with microbiological and chemical parameters, and implementing risk management plans to address potential hazards associated with water reuse. This regulation represents a significant step toward harmonizing water reuse practices across the EU while safeguarding public health and environmental sustainability [17]. Natural resource management related to water quality in Europe is a complex challenge shaped by policy frameworks, environmental changes, and human activities. The European Union's Water Framework Directive aims to achieve sustainable water use and improve water quality by incorporating natural capital accounting, which assesses the value of ecosystem services and informs policy interventions [18].

These statistics underscore the critical need for effective NRM practices to improve water quality and public health outcomes.

This systematic review aims to examine the impact of various NRM practices on public health outcomes, specifically focusing on interventions that improve or maintain water quality. These interventions include watershed management, pollution control, land use management, water treatment, and ecosystem restoration. Each of these practices addresses different aspects of water resource management and contributes to enhancing water quality and, consequently, public health.

Watershed management involves strategies to protect and manage watershed areas to ensure the sustainable supply and quality of water resources [19]. This can include reforestation and afforestation activities to prevent soil erosion and enhance water infiltration, as well as the construction of soil and water conservation structures. Pollution control measures aim to prevent or reduce the introduction of pollutants into water bodies through regulations and policies that limit industrial discharge and agricultural runoff and the installation of wastewater treatment plants [20]. Land use management encompasses practices that influence land allocation and use in ways that protect water quality, such as sustainable agriculture, forestry, and urban planning [21]. Water treatment technologies and processes are implemented to improve the quality of water for various uses, including drinking, agriculture, and industry [22]. Ecosystem restoration activities, such as restoring wetlands and riparian buffers, aim to rehabilitate degraded water bodies and surrounding ecosystems to restore their natural functions and services [23]. Assessing the effectiveness of these NRM interventions requires a comprehensive evaluation of their impact on water quality indicators, including chemical and microbial contaminants, physical characteristics, nutrient levels, and pollution indicators [24]. The relationship between NRM practices and water quality directly influences public health outcomes. Poor water quality can lead to waterborne diseases, chronic health conditions from long-term exposure to chemical contaminants, and acute health effects from immediate exposure to pollutants [25]. Understanding this relationship is crucial for developing effective NRM strategies that can lead to significant improvements in water quality and reduce the risk of adverse health effects in human populations.

Literature Review

Before 2014, research on natural resource management (NRM) focused on the links between ecological processes, water quality, and public health. Early studies highlighted watershed management as key to controlling water pollution and protecting health. For instance, Willett and Porter (2000) [26] showed that well-managed watersheds reduce sediment and nutrient runoff, improving water quality and lowering waterborne disease rates. Global Water Partnership, Sweden (2002) [27], emphasized that practices like reforestation and managing agricultural runoff are crucial for maintaining ecological balance and clean water in less regulated areas.

A significant body of work explored the effects of land use changes on water quality. Vladimir (1999) [28] discussed how intensive agriculture leads to chemical runoff and soil erosion, harming freshwater ecosystems. The United Nations Environment Program, UNEP (2008) [29], examined how deforestation affects hydrological cycles, exacerbating soil erosion, sediment loads, and water quality, increasing waterborne disease risks.

Karin (2008) [30] linked poor water quality to adverse health outcomes, noting higher incidences of diseases like cholera in areas with inadequate water management. They stressed the need for effective NRM strategies, particularly in developing countries. Calderon (2000) [31] analyzed how pollutants in contaminated water are associated with chronic conditions such as cancer and neurological disorders, emphasizing the need for better water quality management.

Research also began to address the socio-economic aspects of NRM and water quality. Arun and Clark (1999) [32] argued that isolated interventions often failed, advocating for integrated approaches that consider ecological, economic, and social factors. They highlighted the importance of community-based management and involving local stakeholders in decision-making.

By the early 2010s, adaptive management frameworks gained attention due to challenges like climate change and urbanization. Engle et al. (2011) [33] noted that traditional NRM approaches were insufficient, recommending resilience-building strategies that combine scientific and traditional knowledge to enhance water resource management.

Overall, the pre-2014 literature underscores the importance of integrated, multidisciplinary approaches to NRM, balancing ecological health with socio-economic factors to ensure sustainable water management and protect public health.

This systematic review aimed to assess the impact of natural resource management on water quality and its subsequent effects on public health. We included studies evaluating water quality as a natural resource, considering chemical, biological, and physical indicators, and their impact on public health. The water management strategies included in the review were watershed management, pollution control, sustainable agriculture, and community education on water conservation and sanitation.

2. Materials and Methods

2.1. Search Strategy

We conducted searches in the following electronic databases for relevant studies: PubMed, Scopus, and Web of Science. Additional searches were performed on Google Scholar, World Health Organization (WHO) reports, government and non-governmental organization (NGO) publications, conference proceedings, and theses and dissertations to capture gray literature. Both electronic and manual searches were employed to identify references from included studies. The search was restricted to studies published in English from 2014 to 2024.

The search terms combined keywords related to 'natural resource management', 'water quality', and 'public health outcomes. The search strategy was developed in consultation with a librarian to ensure comprehensive coverage. This systematic review protocol was registered with the PROSPERO database (registration number: [CRD42024562179]).

2.2. Inclusion Criteria

We included studies that addressed practices for the sustainable management of water resources. Specifically, the practices included the following:

- Protecting and managing watersheds;
- Reducing pollutants in water bodies;
- Implementing sustainable land practices to protect water quality;
- Using technologies to improve water quality;
- Rehabilitating degraded water bodies.

Additionally, studies needed to report on water quality indicators, such as the following:

- Chemical Contaminants: Heavy metals, pesticides, and industrial chemicals;
- Microbial Contaminants: Pathogens including bacteria, viruses, and protozoa;
- Physical Characteristics: Turbidity, color, and temperature;
- Nutrient Levels: Nitrogen and phosphorus concentrations;
- Pollution Indicators: Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD).

Furthermore, the inclusion criteria encompassed studies reporting public health effects related to water quality, including the following:

- Waterborne Diseases: Infections from contaminated water;
- Chronic Health Conditions: Long-term effects of chemical exposure;
- Acute Health Effects: Immediate impacts from pollutants;
- Mortality and Morbidity Rates: Death and illness related to poor water quality.

2.3. Study Selection

The search results were imported into EndNote version 20.2.1 for initial de-duplication, followed by further de-duplication using Covidence, the Cochrane tool for systematic reviews. Two reviewers independently screened titles and abstracts against predefined inclusion and exclusion criteria. Full-text articles were reviewed to determine final eligibility. Disagreements between reviewers were resolved through discussion or, when necessary, consultation with a third reviewer. Covidence was utilized for all stages of the review process, including title and abstract screening, full-text screening, and data extraction.

2.4. Data Extraction

Two reviewers independently extracted data from included studies using a pre-designed extraction sheet. Extracted data included the author, year of publication, country, study aim, type of water source, main findings (including water parameters and public health implications), and study conclusions. Discrepancies were resolved through discussion to ensure consensus.

2.5. Data Synthesis

The reported data were synthesized narratively to identify themes and patterns across studies. We compared quantitative and qualitative findings to highlight points of agreement and disagreement, thereby enhancing the overall interpretation of the results. The synthesis process involved several key steps, which were as follows:

- Narrative Synthesis: We conducted a narrative synthesis of the qualitative data by systematically reviewing and summarizing findings from each study. This approach allowed us to identify and explore recurring themes, patterns, and concepts across studies. Thematic analysis was used to categorize these findings into major themes and subthemes, providing a structured overview of the data.
- Integration of Findings: To enhance interpretation, we compared qualitative findings with quantitative results. This involved assessing points of agreement and disagreement between the two types of data. For instance, we examined how qualitative insights into participants' experiences aligned with or diverged from quantitative measures of outcomes. This comparison contextualized the quantitative data and provided a more comprehensive understanding of the research questions.
- Cross-Study Comparisons: We conducted cross-study comparisons to identify consistent patterns and variations in the data. This included analyzing differences in methodologies, contexts, and populations to understand how these factors might influence results. By doing so, we highlighted key trends and inconsistencies that informed the overall synthesis.
- Contextual Analysis: Alongside thematic analysis, we incorporated a contextual analysis to evaluate the broader implications of the findings. This involved assessing the impact of external factors, such as study settings and participant demographics, on the results. This step was crucial for understanding how context might shape the data and its interpretation.
- Synthesis of Impact Chains: Specifically, we examined the chain of impact from natural resource management (NRM) to water quality and human health. We mapped out how different elements of NRM influenced water quality and, subsequently, health outcomes. This detailed synthesis provided insights into the causal relationships and pathways identified in the studies.

2.6. Reporting

The review adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. A PRISMA flow diagram was used to depict the study selection process and the flow of information through the review (Figure 1). This systematic approach ensured a transparent and reproducible synthesis of the evidence.

This systematic review maintained high standards of methodological rigor, ensuring the reliability and validity of the findings and their implications for public health and water quality management.

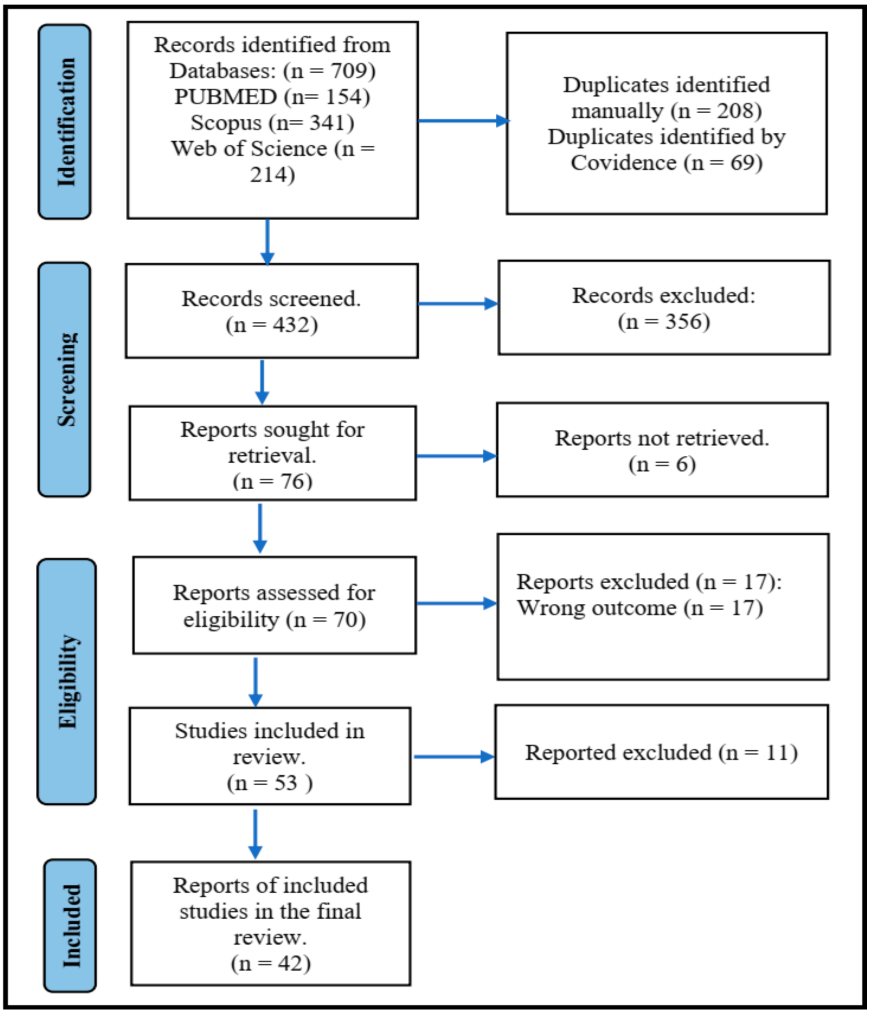

Figure 1. PRISMA flowchart illustrating the results of the literature search and screening procedure for the most recent studies on water quality management's impact on public health.

3. Results

3.1. Search Outcome

The search across PubMed, Scopus, and Web of Science databases identified 709 articles, filtered by title, abstract, publication date (2014–2024), and English language. After removing 208 duplicate articles manually using Endnote and 69 duplicates automatically with Covidence, 432 records were assessed for eligibility. Following a comprehensive peer evaluation of the search strategy, the titles and abstracts of these records were screened, leading to the exclusion of 356 articles. Subsequently, 76 articles underwent full-text review, though 6 articles were not retrievable, leaving 70 articles for full-text screening. After reviewing these articles, 17 were excluded due to having outcomes that did not align with the study's criteria. Thus, out of the initial 53 studies, 42 were incorporated into this review, while 11 were excluded due to insufficient data. The details of the included studies and the extracted data are presented in Table A1 in the Appendix A.

3.2. Study Characteristics

The studies included in this review span various geographical locations, with a majority from developing countries. Specifically, there are 13 studies from China [34–46]; 10 studies from India [47–56]; 2 each from Ethiopia [57,58], Iran [59,60], Saudi Arabia [61,62], and Ghana [63,64]; and 1 each from Algeria [65], Vietnam [66], Bangladesh [67], South Korea [68], Afghanistan [69], Kenya [70], Pakistan [71], Romania [72], the USA [73], West

Africa [74], and Serbia [75]. All the studies included in this review are single studies employing qualitative research methods. The studies collectively explore the effects of natural resource management, particularly focusing on water quality and health risks associated with poor water management.

3.3. Thematic Synthesis (Narrative)

This section explores the interconnected impacts of natural resource management (NRM) practices on water quality and public health outcomes, addressing the central aim of the study. By integrating various studies, we illustrate how specific NRM practices influence water quality and subsequently affect health outcomes across different contexts.

3.3.1. Theme 1: NRM Practices and Water Quality Improvement

Effective NRM practices, such as pollution control, watershed management, and sustainable agricultural practices, are crucial for improving water quality. Studies consistently indicate that water quality is adversely affected by industrial and agricultural activities, which contaminate both surface water and groundwater. For example, Zhao et al. (2020) in China [34] and Zhang et al. (2020) in China [35] reported poor surface water quality with elevated levels of Total Phosphorus (TP), Total Nitrogen (TN), Biological Oxygen Demand (BOD5), Chemical Oxygen Demand (COD), and heavy metals like arsenic (As) and lead (Pb) exceeding safety standards due to industrial and agricultural discharges. These findings are echoed by Ren et al. (2023) in China [40] and Cao et al. (2017) in China [46], who identified seasonal variations in water quality linked to these activities, underscoring the need for robust pollution control measures. Similarly, Zakaria et al. (2022) in Ghana [63] highlighted significant groundwater contamination by Pb and chromium (Cr), posing severe health risks to local populations. These studies collectively demonstrate the need for integrated approaches that combine watershed management, pollution control, and sustainable practices to improve water quality and reduce contamination risks.

- Surface and Groundwater Contamination

Surface Water Contamination: Surface water is particularly vulnerable to contamination from industrial, agricultural, and urban sources. Shil et al. (2019) in India [47] and Cao et al. (2017) in China [46] pointed out heavy metal pollution in rivers, necessitating ongoing monitoring and sustainable management practices to protect water quality and public health. Addressing these risks requires integrated NRM approaches that consider seasonal and land use variations, promoting sustainable practices and robust pollution control measures.

Groundwater Contamination: Groundwater contamination remains a critical issue in many regions. Wang et al. (2024) in China [37] reported significant fluoride and arsenic contamination in shallow groundwater, while Rashid et al. (2023) in Pakistan [71] found high levels of heavy metal contamination in mining areas, particularly affecting children and females. These findings emphasize the importance of comprehensive management strategies, including regular monitoring, pollution control measures, and public awareness campaigns to ensure safe drinking water.

3.3.2. Theme 2: Impact of Water Quality on Public Health Outcomes

Changes in water quality, driven by both effective and poor NRM practices, have significant public health implications. Heavy metals, such as lead and arsenic, pose severe health risks, including carcinogenic and non-carcinogenic effects. For example, Roy et al. (2023) in India [48] and Ruan et al. (2024) in China [39] identified elevated health risks due to unsafe levels of iron (Fe) and arsenic (As) in groundwater, particularly affecting children. Additionally, nitrate and fluoride contamination in groundwater were significant concerns in studies by Wang et al. (2024) in China [37] and Bisht et al. (2023) in India [55], highlighting the urgent need for remedial actions to protect public health.

- Health Risks from Contaminants

Health Risks from Heavy Metal Pollution: Heavy metal pollution, including arsenic, lead, cadmium, and chromium, is a significant concern across various studies. Vesković et al. (2024) in Serbia [75] found high cancer and non-cancer risks from heavy metals in groundwater, primarily due to smelting and mining activities. Kormoker et al. (2023) in Bangladesh [67] identified carcinogenic risks from trace metals in river water, necessitating critical environmental management strategies.

Public Health Impacts of Poor Water Quality Management: Poor water quality management can lead to significant public health impacts, such as the increased prevalence of waterborne diseases, chronic health conditions from chemical contaminants, and the greater vulnerability of specific populations. Studies like that by Tarek et al. (2023) in the USA [73] identified microbial sources of contamination contributing to high prevalence rates of waterborne diseases, while Hamidi et al. (2023) in Afghanistan [69], Opiyo et al. (2022) in Kenya [70], and Karunanidhi et al. (2021) in India [52] highlighted bacteriological contamination causing widespread waterborne illnesses.

3.3.3. Theme 3: Tailored NRM Strategies for Local Contexts

The effectiveness of NRM practices can vary significantly depending on local environmental, socio-economic, and cultural contexts. Ren et al. (2023) in China [40] showed that tailored interventions in a sub-watershed of the upper Yangtze River, which included both agricultural and industrial pollution control measures, significantly improved water quality during both warm and cold seasons. This approach led to a notable decrease in health risks related to waterborne pathogens and chemical pollutants, demonstrating the necessity of context-specific approaches to NRM. Similarly, Opiyo et al. (2022) in Kenya [70] found that community-led water quality monitoring and pollution control measures in the Migori River led to reduced microbial contamination, improving overall public health outcomes.

- Geographical Variation in Water Quality and Health Risks

Regional Differences and Customized Approaches: The studies reveal significant geographical variations in water quality and health risks, underscoring the unique environmental, industrial, and agricultural impacts on water sources. For instance, Zhao et al. (2020) in China [34] found the poorest water quality in the lower reaches of the Yellow River Basin, necessitating customized pollution control policies. In contrast, Zakaria et al. (2022) in Ghana [63] identified substantial health risks from Pb and Cr in groundwater, emphasizing the need for localized monitoring and management strategies.

Vulnerability and Targeted Interventions: Certain population groups, particularly children and infants, are more vulnerable to waterborne contaminants. Studies by Wang et al. (2024) in China [37] and Rashid et al. (2023) in Pakistan [71] highlight increased susceptibility to heavy metal toxicity among children and females. Mitigation strategies must prioritize these vulnerable populations, ensuring safe water access and targeted public health interventions.

4. Discussion

The impact of natural resource management (NRM) practices on drinking water quality and public health is complex and multifaceted, addressing both the removal of contaminants and the management of nutrient inputs while influencing waste management, health policy, and behavioral interventions. This review synthesizes the existing literature on these aspects, highlighted the critical role of effective NRM practices in enhancing water quality and public health outcomes. Consistent with previous studies, our results confirm that advanced technologies, such as nanofiltration and activated carbon adsorption, are highly effective in reducing levels of Natural Organic Matter (NOM) in drinking water. These technologies have been shown to decrease turbidity and organic carbon content by up to 90% [76], aligning with the literature that highlights their efficacy in managing NOM. The reduction in NOM is crucial as it can react with disinfectants to form harmful byproducts, complicating treatment processes and potentially compromising water safety [76]. Thus, the review findings reinforce the need to incorporate these technologies within comprehensive

NRM strategies to ensure safe drinking water. Our study emphasizes the importance of nutrient management, particularly the reduction in nitrogen (N) and phosphorus (P) inputs, in mitigating eutrophication, a significant factor in water quality degradation. Studies on reservoirs such as Hongfeng Lake demonstrate that reducing nutrient levels can substantially improve water quality by mitigating harmful algal blooms and fostering healthier aquatic ecosystems [77]. This supports the broader literature advocating for integrated approaches to nutrient management in NRM. Our findings, including the simulation of various management scenarios, further corroborate that nutrient reduction strategies are essential for enhancing water body health. This research highlights the potential of innovative treatment solutions, such as reactors designed for denitrification, which have demonstrated high efficiencies in reducing nitrate levels in drinking water. These results are consistent with existing studies emphasizing the importance of adopting novel technologies to address specific contaminants, particularly in regions facing high nitrate pollution [78]. This underscores a critical avenue for future NRM practices, focusing on the development and implementation of advanced treatment technologies tailored to local water quality challenges.

The broader impact of NRM practices on public health extends to waste management, a critical factor in urban settings. Poor waste management can lead to contaminated water and soil, increasing the risk of diseases such as cholera, especially in developing countries [79]. Effective waste management is essential to mitigate these health risks, emphasizing the need for organized and systematic approaches to manage waste and prevent exposure to hazardous substances. Health policy development is another crucial aspect influenced by NRM practices. The National Rural Health Mission (NRHM) in India exemplifies how structured health management initiatives can improve public health by training health personnel and addressing gaps between health service demand and supply [80]. Such initiatives highlight the importance of integrating NRM practices into broader health policy frameworks to enhance public health outcomes. Behavioral factors play a significant role in public health, with interventions showing promise in reducing morbidity and mortality. However, challenges remain in translating research into practice due to barriers in communication and supportive policies [81]. Effective NRM practices can support behavioral interventions by creating healthier environments and promoting public awareness, which is essential for reducing health disparities and improving overall health outcomes. While NRM practices can enhance water quality and public health, challenges remain. Adapting NRM practices to local environmental and socio-economic conditions and ensuring equitable access to their benefits are critical. As highlighted in the literature, a one-size-fits-all approach is insufficient. Tailored strategies, involving stakeholder engagement and consideration of local conditions, are essential for achieving sustainable improvements in both water quality and public health. This literature review supports the critical role of NRM practices in improving water quality and public health. Zhao et al. (2020) [34] and Zhang et al. (2017) [35] reported elevated contamination levels due to inadequate pollution control measures in China, including increased Total Phosphorus (TP), Total Nitrogen (TN), Biological Oxygen Demand (BOD5), Chemical Oxygen Demand (COD), and heavy metals like arsenic (As) and lead (Pb). Similarly, Zakaria et al. (2022) [63] highlighted severe groundwater contamination by Pb and chromium (Cr) in Ghana, posing significant health risks.

In contrast, De Wrachien et al. (2003) [21] demonstrated that integrated watershed management practices, such as reforestation and soil conservation, positively impacted water quality by reducing sedimentation and nutrient leaching. This is supported by Rashid et al. (2023) [71], who found that poor NRM practices, particularly in mining, led to high levels of heavy metal contamination in groundwater in Pakistan, exacerbating health risks. These examples underscore the need for robust NRM strategies that incorporate pollution control, sustainable practices, and equitable access to mitigate contamination risks and enhance public health. The health implications of water quality are profound and multifaceted, with varying effects across different populations due to environmental and socio-economic factors. Poor water quality, often a consequence of inadequate natural resource management (NRM) practices, is linked to a range of health issues, including gastrointestinal diseases, chronic conditions, and neurological disorders. Recent studies underscore these impacts and highlight the need for effective NRM strategies to mitigate health risks. The presence of heavy metals such as lead, arsenic, cadmium, and chromium pose severe health risks, including carcinogenic and non-carcinogenic effects. For instance, Roy et al. (2023) in India [48] and Ruan et al. (2024) in China [39] identified elevated health risks due to unsafe levels of iron (Fe) and arsenic (As) in groundwater, particularly affecting children. These findings align with studies by Vesković et al. (2024) in Serbia [75], which found high cancer and non-cancer risks associated with heavy metal contamination in groundwater, primarily due to smelting and mining activities. Additionally, the review highlights the impact of nitrate and fluoride contamination on public health, with studies such as those by Wang et al. (2024) in China [37] and Bisht et al. (2023) in India [55] showing significant health risks from these contaminants in groundwater. These studies emphasize the urgent need for remedial actions to reduce exposure to chemical contaminants and protect public health, particularly in regions where drinking water sources are heavily affected by industrial and agricultural activities. This finding is consistent with the work of Prüss-Ustün et al. (2019) [10], who reported that improving water quality through effective management could significantly reduce the global burden of disease from inadequate water, sanitation, and hygiene (WASH) practices.

In Kano, Nigeria, for example, elevated levels of heavy metals such as lead and cadmium in water, which stem from insufficient pollution control and inadequate NRM practices, have been associated with gastrointestinal illnesses and chronic kidney disease [82]. Similarly, in Banjar District, Indonesia, high concentrations of dissolved organic components in water, related to poor watershed management and lack of proper treatment systems, have been correlated with respiratory and digestive disorders, emphasizing the critical role of effective water quality management [83]. Vulnerable populations are particularly at risk from poor water quality linked to suboptimal NRM practices. Older adults, for instance, may experience worsened age-related health issues, including cognitive decline and cardiovascular diseases, as a result of ongoing pollution [84]. Additionally, children in areas with poor NRM practices face a higher incidence of waterborne diseases such as cholera and typhus, which are prevalent in communities with compromised water quality [85]. Compared to other studies, this review provides a comprehensive and integrated analysis of the inter-relationships between NRM practices, water quality, and public health outcomes. While other studies have often focused on single aspects of NRM or specific health outcomes, this review highlights the need for a holistic approach that considers the interconnectedness of environmental management practices and their broader implications. For example, Mohan et al. (2022) [23] concentrated specifically on riparian ecosystem restoration and its impact on local water quality, demonstrating significant reductions in pollutants due to targeted efforts. This study complements the findings of our review by providing a more detailed examination of specific NRM practices and their direct impacts on water quality. Additionally, the review's findings align with the conclusions of Prüss-Ustün et al. (2019) [10], who highlighted the global burden of disease attributable to inadequate water management practices, stressing that effective water quality management can significantly mitigate health risks. While Prüss-Ustün et al. provided a broader, global perspective on WASH-related health outcomes, our review offers a more targeted analysis of specific NRM strategies and their effects on water quality and health outcomes in various geographical and socio-economic contexts. Socio-economic factors also intersect with water quality and health. In Lagos, Nigeria, inadequate NRM practices exacerbated by industrial pollution have led to significant health challenges, illustrating the disparity in water quality management between the Global South and North [86].

The effectiveness of NRM practices varies significantly depending on local environmental, socio-economic, and cultural contexts, highlighting the need for tailored strategies. The review indicates that one-size-fits-all approaches may not be effective across diverse geographical regions. For example, Ren et al. (2023) in China [40] demonstrated that tailored interventions in a sub-watershed of the upper Yangtze River, which included both agricultural and industrial pollution control measures, significantly improved water quality during both warm and cold seasons. This approach led to a notable decrease in health risks related to waterborne pathogens and chemical pollutants, emphasizing the necessity of context-specific NRM practices.

Similarly, Opiyo et al. (2022) in Kenya [70] found that community-led water quality monitoring and pollution control measures in the Migori River significantly reduced microbial contamination, thereby improving overall public health outcomes. These findings support the conclusions of studies like that by Freeman et al. (2005) [24], who advocate for context-specific NRM strategies that align with local needs and resources, emphasizing the need for flexibility and adaptability in water management practices. However, studies such as that by Syafri et al. (2020) in Indonesia [19] suggest that broader, well-resourced policies can still achieve significant benefits when implemented with strong regulatory frameworks and sufficient financial support, indicating that the effectiveness of NRM strategies is highly context-dependent.

Tailored natural resource management (NRM) strategies are crucial for effectively addressing local contexts by leveraging regional knowledge and adapting to specific socio-economic conditions. Such strategies enhance sustainability and foster community engagement. Recent research underscores several key aspects of tailored NRM approaches. Digital health communication exemplifies how tailored strategies can improve accessibility and personalization. Algorithms can match individual assessments with relevant information, a concept that can be adapted to NRM by providing localized guidance and resources to communities [87]. This ensures that information is pertinent and actionable for local needs. Place-based development is another critical component. Empowering subnational governments to design contextually tailored economic development strategies allows for a reflection of local characteristics and needs [88]. Successful NRM often involves coordinated governance approaches that maximize synergies among various government tiers, crucial for effective management and implementation.

Insights from local implementation highlight the importance of understanding local realities. The Greenfield approach, illustrated by the Mahatma Gandhi National Rural Employment Guarantee Scheme, emphasizes that tailoring policies to local socio-economic and political contexts can significantly enhance their effectiveness [89]. Similarly, district-level approaches, such as empowering local health teams to tailor malaria control strategies, demonstrate how allowing local authorities to adapt interventions to specific environmental challenges can improve outcomes [90].

Community empowerment through adaptive co-management is also vital. By promoting local governance, this approach enhances socio-economic standards and raises awareness about resource management [91]. Engaging local communities in decision-making processes ensures that NRM strategies are not only relevant but also effectively address local issues. Successful community engagement in natural resources management is often underpinned by robust partnerships, strong social capital, and effective institutional frameworks. In Western Michigan, for example, collaboration between scientists, local decision-makers, and stakeholders has been crucial in addressing environmental policy issues and protecting valuable natural assets threatened by fragmentation and development [92]. Similarly, in the Lake Eyre Basin, formal institutional arrangements have created an enabling environment for community involvement, which is essential for the management of natural resources in remote areas [93]. Research indicates that community-based natural resources management (CBNRM) can significantly advance conservation efforts, yet its effectiveness often hinges on a robust regulatory framework and adequate institutional support [94]. The "3 I's" model, Information dissemination, Inclusion, and Identification, proposed by Sharma, emphasizes the need for strategic planning that aligns with community needs, thereby enhancing engagement and sustainability outcomes [95]. Furthermore, the Community Voice Method (CVM) demonstrates how situating public participation within the community context can build trust and ensure diverse voices are heard, leading to more effective natural resources management (NRM) [96]. The role of social capital is also evident in highly organized groups, where community-based programs expedite progress toward environmental sustainability. This was highlighted in a study where factors like social cohesiveness and normative beliefs significantly influenced farmers' collective action in natural resource management in Nagaland, India [97]. In another instance, participatory science in Madidi National Park, Bolivia, demonstrated how collaborative methods could bridge the research–implementation gap and empower local communities [98]. Moreover, the integration of indigenous technical knowledge with modern tools, such as Geographic Information Systems (GISs), has proven successful in managing natural resources sustainably. This approach was effectively implemented by the Teso Community in Kenya, where indigenous knowledge and GISs were combined to enhance resource management [99]. In contrast, a one-size-fits-all approach to NRM often fails to address the unique challenges faced by different communities, leading to ineffective interventions. Tailoring strategies to local contexts is not merely beneficial but essential for achieving sustainable resource management and improving community resilience.

4.1. Limitations

While this systematic review provides valuable insights into the impact of NRM on water quality and public health, several limitations must be acknowledged. The inclusion of only studies published in English introduces a language bias, potentially excluding relevant research in other languages. Additionally, reliance on published studies may lead to publication bias, as studies with positive findings are more likely to be published than those with negative results. The included studies varied widely in their design, methodologies, and quality, creating heterogeneity that complicates the synthesis of findings. The review focused on studies from 2014 to 2024, which may have excluded older studies that could provide additional context. The availability and quality of reported data also varied, affecting the accuracy and reliability of the findings. Most of the studies were from developing countries, limiting the generalizability of the findings to high-income countries with different contexts. The effectiveness of NRM practices can be highly context-specific, influenced by local environmental, socio-economic, and cultural factors, making the findings less universally applicable. The review primarily focused on direct health outcomes related to water quality, potentially overlooking indirect health impacts such as psychosocial effects or economic burdens. Due to the heterogeneity of the studies, a quantitative meta-analysis was not feasible, limiting the ability to statistically aggregate the findings. These limitations highlight the need for cautious interpretation and ongoing research to address these gaps and improve the evidence base for effective NRM.

4.2. Recommendations for Future Research and Policy

To enhance future research and policy, several recommendations should be considered. Firstly, longitudinal studies are essential for understanding the sustained impacts of natural resource management (NRM) practices on water quality and public health over time. Additionally, the adoption of standardized assessment tools for evaluating water quality and health outcomes is crucial, as these tools can facilitate more robust comparisons across different studies and regions. Addressing water quality and public health issues also requires interdisciplinary approaches that integrate environmental science, public health, policy, and community engagement. Furthermore, greater emphasis on community involvement in NRM practices can enhance the effectiveness and sustainability of interventions, and policy-makers should prioritize the integration of public health perspectives into NRM policies, ensuring these policies are adaptable to local contexts. Given the exacerbating effects of climate change on water resources, *NRM strategies should* include climate adaptation measures to ensure resilience and sustainability.

Implementing integrated water resource management (IWRM) approaches is vital, focusing on comprehensive watershed management and pollution control measures that address both point and non-point sources of water pollution. Alongside these, targeted pollution control strategies should be developed and enforced to limit industrial discharge and agricultural runoff, coupled with investments in modern wastewater treatment technologies to reduce microbial and chemical contamination. To further improve water quality, promoting sustainable agricultural practices that minimize the use of harmful pesticides and fertilizers is recommended, along with supporting initiatives for organic farming and integrated pest management (IPM). Establishing robust monitoring systems to continuously assess water quality indicators and utilizing advanced technologies such as Geographic Information Systems (GISs) and remote sensing for spatial analysis can enhance the monitoring of water quality and associated health risks.

Developing tailored NRM strategies for different geographical contexts is also important, as this customization allows for interventions that consider specific regional challenges, such as heavy metal contamination in industrial areas or nitrate pollution in agricultural zones. Addressing the barriers to effective water management, such as limited financial resources and technical expertise, is crucial for supporting the implementation of effective NRM practices, and fostering collaboration among different sectors can help overcome these barriers. Emphasizing climate adaptation measures within NRM policies is also necessary to tackle the increasing challenges posed by climate variability and change and enhance resilience through measures like drought-resistant water supply systems and sustainable groundwater management.

Focusing on vulnerable populations, such as children and infants who are more susceptible to health risks from contaminated water, is another critical recommendation. Developing targeted public health interventions to ensure access to safe water for these high-risk groups is essential. Moreover, promoting interdisciplinary research and collaboration that integrates environmental science, public health, policy, and community engagement can facilitate the development of holistic NRM solutions. Regular review and adaptation of NRM strategies are vital to respond to new challenges and opportunities and to ensure strategies remain effective and context-appropriate in the face of changing environmental conditions.

4.3. Conclusions

Overall, this review substantiates the direct correlation between NRM practices, water quality, and public health outcomes. Effective water management practices that encompass comprehensive watershed management, pollution control, sustainable agriculture, and community engagement are shown to improve water quality and reduce public health risks. The diversity of geographic contexts and socio-economic settings examined in the studies highlights the necessity for tailored approaches to NRM that consider local conditions and community dynamics. Future research should continue exploring these interconnections to develop more adaptable and context-specific NRM strategies, particularly considering the growing challenges posed by climate change and increasing human activities. By doing so, it will be possible to better protect public health and ensure the sustainability of water resources globally.

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Appendix A

Table A1. Detailed characteristics of included studies and extracted data on water quality and public health outcomes (n = 42).

Study/Year	Country	Objective	Type of Water Source	Key Findings	Conclusion/Implications
[34] 2020	China	Assess water quality status of primary tributaries in the middle and lower reaches of the Yellow River Basin.	Surface water	Poorest water quality in lower river reaches; TP, TN, BOD5, COD, TOC, and coliform bacteria exceed standards.	Critical need for customized policies to address varied pollution sources in different tributaries, with a focus on the Jindi and Dawen Rivers.
[35] 2017	China	Assess human health risk of heavy metals in marine reserve waters of Tianjin, identifying connections between metal pollution and health risks.	Surface water	Heavy metal pollution detected; health risks identified from high As and Pb concentrations.	Methods effectively assessed heavy metal pollution and health risks, aiding in prioritizing pollutants for control measures.
[63] 2022	Ghana	Evaluate non-carcinogenic and carcinogenic risks of heavy metals in groundwater for adults and children.	Groundwater	Pb and Cr exceed WHO limits in 40% and 56% of samples; HI suggests non-carcinogenic effects in 61.04% of adults and 62.34% of children; CR total indicates carcinogenic effects in 64.94% of samples.	Significant presence of Pb and Cr in groundwater in Kassena Nankana area, posing health risks, especially to children; calls for ongoing monitoring and effective management.
[36] 2020	China	Investigate contents and seasonal–spatial variations of DTEs and evaluate water quality and health risks using WQI and HQ/HI.	Surface water	Minimal heavy metal pollution in river; DTECs below hazard levels, indicating good water quality.	Carbonate and urban land significantly influence DTE concentrations in the Chishui River; further research needed on natural processes, lithology, hydrology, and urban development impacts.
[37] 2024	China	Evaluate groundwater quality and potential human health risks of fluoride (Fa) and arsenic (As) for different age groups.	Groundwater	85.7% of shallow groundwater samples exceed fluoride standards; 21.4% exceed arsenic standards.	Significant health risks from fluoride and arsenic contamination in shallow groundwater necessitate urgent remedial actions.
[38] 2024	China	Assess groundwater suitability for drinking, identifying distribution, sources, and health risks of nitrate (NO_3).	Surface and groundwater	NO_3- levels in 67.2% of samples exceed WHO criteria; non-carcinogenic health risk in over 91.38% of samples for infants.	Younger populations, especially infants and children, face higher health risks from nitrate exposure.
[75] 2024	Serbia	Allocate health hazards from groundwater PTEs to pollution sources, accurately assessing health risks with Monte Carlo simulation (MCS).	Groundwater	Arsenic, Cd, Cr, and Pb are primary risk factors; HI and ILCR exceed limits, indicating high cancer and non-cancer risks.	Anthropogenic activities, particularly from smelting and mining, significantly influence health risks; targeted pollution mitigation measures needed.
[73] 2023	USA	Apply microbial source tracking (MST) to monitor fecal pollution in a mixed land use watershed, addressing prevalence of fecal pollution from multiple sources.	Surface water	Land use practices crucial in fecal contamination levels; physiochemical water quality impacts fecal contamination.	Combining MST markers with traditional FIB effectively identified fecal contamination sources; further research needed on specific fecal pathogens and antibiotic-resistant bacteria.
[72] 2021	Romania	Investigate impact of various factors on groundwater quality and assess associated health risks.	Groundwater	Wastewater, industrial, and agricultural activities alter groundwater quality; heavy metals pose health risks.	Health risk index exceeded for lead, zinc, and nickel in Palazu Mare, Lumina, and Casimcea; emphasizes need for enhanced pollution prevention and remediation.
[47] 2019	India	Evaluate heavy metal and metalloid pollution, assess human health hazards using various indices for two age groups, and evaluate incremental lifetime cancer risk.	Surface water	HPI and HEI indicate water generally suitable, but Pn shows some stations as polluted; HI analysis shows non-carcinogenic health risks.	Ongoing monitoring and sustainable management practices needed to address potential health risks from heavy metals and metalloids in river water.

Table A1. *Cont.*

Study/Year	Country	Objective	Type of Water Source	Key Findings	Conclusion/Implications
[39] 2024	China	Determine effects of pollutants on human health by conducting a health risk assessment using trapezoidal fuzzy number-Monte Carlo stochastic simulation model.	Groundwater	Exceedances of Fe and Cu from natural and anthropogenic sources; children face higher risks than adults.	Health risks from nitrogen, metal ions (Cu, Mn), and fluoride impacting both children and adults.
[48] 2023	India	Compute health risk assessments for infants, children, and adults exposed to toxic heavy elements in groundwater.	Groundwater	Children at greater carcinogenic and non-carcinogenic risk due to unsafe Fe and As levels in groundwater.	Children face higher carcinogenic and non-carcinogenic risks from unsafe Fe and As levels, highlighting need for mitigation strategies.
[40] 2023	China	Assess water quality and apportion pollution sources in a sub-watershed of the upper Yangtze River.	Surface water	Poorer water quality in Laixi River tributaries during cold seasons; industrial and agricultural discharges highlight health risks.	Agricultural activities primary pollution source in cold seasons; domestic sewage dominates warm seasons; industrial wastewater and meteorological effects significant; integrated approaches needed.
[71] 2023	Pakistan	Assess water quality, hydro-geochemistry, spatial distribution, geochemical speciation, and human health impacts related to heavy metal contamination in groundwater.	Groundwater	Higher heavy metal contamination in mining areas; children and females more vulnerable to toxicity.	Higher health risks from heavy metal toxicity for children and females; elevated lifetime cancer risks (LCRs) for Cr and Ni in chromite mining areas; effective management practices needed.
[62] 2021	Saudi Arabia	Assess groundwater quality and associated health risks.	Groundwater	Predominantly alkaline groundwater, with significant non-carcinogenic health risks for adults, children, and infants.	Substantial non-carcinogenic health risks from groundwater consumption; comprehensive management strategies needed to protect public health and sustain agriculture.
[70] 2022	Kenya	Examine water quality status of the Migori River, determining spatio-seasonal variations, influencing factors, and potential health risks.	Surface water	CCME-WQI ranks Migori River water as 'poor' to 'marginal'; better quality observed upstream.	Migori River pollution poses health hazards; urgent pollution control measures recommended.
[49] 2023	India	Conduct water quality assessment for drinking purposes using WQI model and evaluate health risks.	Groundwater	90% of groundwater samples within good to excellent category; high fluoride and nitrate pose health risks.	Elevated non-carcinogenic risks from nitrate and fluoride in adults; urbanization and anthropogenic activities significantly impact groundwater quality; wastewater treatment and waste management needed.
[50] 2022	India	Assess human health risks associated with heavy metals in ground and surface water.	Surface and groundwater	HQ values show non-carcinogenic risks for Zn and Ni; high ELCR levels for As, indicating significant carcinogenic risk.	Gastrointestinal issues linked to different drinking water sources; mercury levels in urine exceed NHANES study levels.
[60] 2020	Iran	Study physicochemical parameters in drinking water resources and assess associated health risks.	Surface water	High nitrate levels in groundwater pose severe health risks, especially for infants.	Significant contamination of cadmium, arsenic, and lead in Lake Urmia groundwater; Arsenic poses unacceptable carcinogenic risk; immediate remedial actions needed.
[41] 2021	China	Analyze spatiotemporal evolution characteristics of groundwater nitrate and assess associated health risks.	Groundwater	Heavy metal pollution in landfill leachate highlights potential toxicity hazards.	Health risks vary by demographic group, with infants facing highest risks; mitigation strategies needed to protect vulnerable populations.
[66] 2024	Vietnam	Evaluate pollution levels and health risks of heavy metals and quantify pollution sources in various surface waters.	Surface water	Intensive groundwater exploitation exacerbates nitrate contamination; higher risks in urbanized areas.	Need for targeted interventions to reduce heavy metal pollution in surface water bodies, especially in areas frequented by children.

Table A1. *Cont.*

Study/Year	Country	Objective	Type of Water Source	Key Findings	Conclusion/Implications
[51] 2023	India	Characterize hydrochemistry, identify source factors, and assess health risks associated with sulfate (SO_4) and nitrate (NO3) in groundwater.	Groundwater	Nitrate concentrations exceed national standards; control measures needed for safer water consumption.	Addressing groundwater quality issues in Bemetara district requires concerted efforts in monitoring, regulation, and management.
[74] 2024	West Africa	Assess potential health risk from trace metals in estuarine water by analyzing concentrations of copper (Cu), chromium (Cr), and zinc (Zn).	Surface water	Heavy metal exposure in wells poses health risks; high cancer risks from Pb and Ni.	Complex dynamics of water quality in the Gulf Guinea coastline necessitate continued research and proactive management strategies.
[67] 2023	Bangladesh	Determine human health risk of toxic elements in river water by assessing non-carcinogenic and carcinogenic risks for adults and children.	Surface and groundwater	Trace metals and pesticides in water and sediment pose potential human carcinogenic risks.	Critical need for effective environmental management strategies to mitigate contamination of surface and deep waters by toxic elements.
[68] 2023	South Korea	Evaluate seasonal effects on hydrochemistry and microbial diversity in radon-contaminated groundwater, and consequent health risks.	Groundwater	Health risks from heavy metals acceptable, but highest for children; pollution control measures effective.	Groundwater Quality Index indicates overall good water quality, but concerns with radon contamination and seasonal microbiological pollution.
[52] 2021	India	Examine human health risks associated with nitrate contamination in groundwater.	Groundwater	Lake of Birds shows poor water quality with high eutrophic substances and fecal contamination.	Nitrate contamination in Texvally requires regulatory actions, sustainable agricultural practices, and community engagement.
[53] 2020	India	Identify source, occurrence, controlling factors, and exposure risk of fluoride (F) and boron (B) contaminations in groundwater.	Groundwater	56% of groundwater sources unsuitable for consumption pre-monsoon, reducing post-monsoon; higher risks for children.	Children face higher non-carcinogenic risk than adults and infants, emphasizing importance of precautionary measures.
[42] 2019	China	Assess surface water quality and potential health risks.	Surface water	90% of groundwater samples show seawater intrusion; Cr and As display high carcinogenic risks.	Proactive management strategies essential to ensure sustainable water quality and protect human health.
[69] 2023	Afghanistan	Assess suitability of shallow groundwater for drinking using WQI and GIS, explore trends in bacteriological contamination and associated health risks.	Groundwater	High nitrate concentrations in groundwater pose health risks; nitrate from waste identified as primary risk.	Health Risk Assessment indicates substantial health risks from consuming untreated groundwater.
[54] 2024	India	Analyze heavy metal contamination in groundwater.	Groundwater	Metal Index and HPI indicate significant contamination; RQ values suggest escalated non-carcinogenic risks.	Findings expected to influence urban planning and policy decisions in Mumbai, emphasizing sustainable waste management techniques.
[43] 2022	China	Conduct health-risk assessment of groundwater nitrate using USEPA-recommended models.	Groundwater	Only 14.4% of water supply schemes had a water safety plan; 20.7% practiced safety measures.	Urgent need for comprehensive measures to address nitrate pollution to safeguard public health and promote sustainable groundwater management practices.
[44] 2020	China	Evaluate quality of groundwater in coal mining areas.	Groundwater	HQ values exceed unity for nitrate and chromium; higher doses of E. coli observed during rainy season.	Human activities significantly impact groundwater quality in the Selian mining area; immediate pollution control measures and alternative water sources needed.
[59] 2017	Iran	Investigate concentrations of heavy metals in 39 water supply wells and 5 water reservoirs.	Groundwater	Higher non-carcinogenic risk in areas with elevated nitrate and fluoride levels, especially for children.	Non-carcinogenic risks acceptable for all metals in wells, but elevated carcinogenic risks for lead and nickel; sensitivity analysis highlights heavy metal concentration and body weight as key factors.

Table A1. *Cont.*

Study/Year	Country	Objective	Type of Water Source	Key Findings	Conclusion/Implications
[45] 2020	China	Clarify current contamination status in surface water and sediment of the reservoir, followed by a human health risk assessment.	Surface water	High concentrations of manganese, iron, and arsenic in some groundwater sources; increased health risks.	Carcinogenic risks from hexachlorobenzene and arsenic in sediment and soil; mercury poses relatively low health risk despite exceeding domestic standards in some water samples.
[46] 2017	China	Investigate magnitude of heavy metal contamination and health risks to local population via ingestion and dermal contact with water.	Surface water	Elevated nitrate levels from agricultural runoff causing significant health concerns.	Despite generally acceptable health risks, children aged 0–5 years face highest risks.
[65] 2024	Algeria	Assess physicochemical and microbiological properties of Lake of Birds in northeastern Algeria.	Surface water	Fluoride contamination in groundwater beyond safe limits, leading to health issues.	Contamination poses health risks to nearby populations; lake still used for domestic purposes, irrigation, and cattle.
[55] 2023	India	Assess groundwater chemistry and potential human health risks of nitrate (NO3) and fluoride (F) via ingestion for adults and children, using USEPA methodology.	Groundwater	Increased arsenic levels in groundwater affecting human health adversely.	High non-carcinogenic risks from NO3- and F- exposure, particularly affecting children; Total Hazard Index indicates health risks from multiple contaminants.
[61] 2024	Saudi Arabia	Delineate extent of seawater intrusion, evaluate nitrate and heavy metal pollution in groundwater, and assess potential health and ecological risks of heavy metals and toxic elements.	Groundwater	Groundwater in industrial areas shows higher heavy metal contamination, posing health risks.	High carcinogenic risks from chromium and arsenic; nitrate levels above permissible limits pose health risks, particularly to vulnerable populations.
[64] 2017	Ghana	Assess status and spatial distribution of nitrate contamination and ascertain potential human health risks from exposure to nitrate contamination.	Surface and groundwater	Urban areas show higher levels of fecal contamination in water sources.	Significant non-carcinogenic risks from nitrate contamination highlighted.
[56] 2021	India	Assess groundwater quality regarding arsenic and heavy metal contamination in three industrial areas.	Groundwater	Significant seasonal variation in water quality; worse during monsoon season.	Groundwater unfits for consumption without treatment, posing high non-carcinogenic and carcinogenic health risks.
[57] 2024	Ethiopia	Assess vulnerability of water supply systems in Upper Awash River subbasin using DRASTIC model and National WASH Inventory-2 (NWI-2).	Surface water	Remediation measures are needed to reduce contamination and health risks.	Robust protection measures, enhanced institutional capacity, and supportive legal frameworks needed for sustainable water supply systems and public health protection.
[58] 2024	Ethiopia	Investigate public health risks associated with water consumption from drinking water sources in Upper Awash sub-basin.	Surface and groundwater	Sustainable management practices are crucial for maintaining water quality and protecting public health.	Need to evaluate water quality due to significant impact on public health; several concerning chemical parameters and microbial indicators present in drinking water sources.

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