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Abstract

Background: Due to the several interconnected crises that Lebanon has been facing for the past 4 years, many important social and environmental issues have been overlooked until more "pressing" ones are dealt with. Consequently, water pollution in Lebanon continues to worsen.

Aim: This study aimed to describe the microbiological and chemical properties of the 10 main rivers in Lebanon and to assess their suitability for irrigation, while exploring some of the

solutions to the problem.

Methods: This cross-sectional study evaluated the pollution level of water from 10 rivers in Lebanon in June 2023 and their suitability for irrigation. Samples were collected at 3°C and their quality parameters were measured. Statistical analysis was conducted using R statistical software version 4.0.2.

Results: Compared to the Food and Agriculture Organization (FAO) guidelines for safe irrigation water use, 4 out of the 10 samples had pH levels exceeding the permissible threshold, resulting in severe limitations on their usability. Three rivers had nitrate concentrations that exceeded the approved range, thus constraining their severe usage. Among the rivers, 60% had Escherichia coli levels higher than the permissible spectrum and 40% had faecal coliform counts exceeding FAO's upper limit recommendation. All water sources, however, had total dissolved solid levels that were within the recommended range.

Conclusions: Polluted water can have a negative impact on human, wildlife and ecosystem health. Most of the assessed rivers in our study contained bacterial colonies, above the maximum recommended internationally. There is therefore an urgent need to address pollution issues in Lebanese waters to make them suitable for irrigation and other uses.

Keywords: water pollution, agriculture, environmental health, irrigation, public health, farming, water quality, One Health, FAO, Lebanon

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Background

Over the past century, global health has faced many challenges, including increasing rates of drug-resistant pathogens, environmental pollution, climate change and disease outbreaks (1). However, one of the most underestimated serious public health challenges is water pollution, which involves the introduction of harmful substances or pollutants into water bodies (2,3). Among all water resources, rivers are of particular concern given that their water serves a wide array of domestic, industrial and agricultural purposes (4).

Assuring the quality of river water routinely used for irrigation of crops is crucial as it can be a source of foodborne pathogens (2,5). When polluted water is used for irrigation, fruits and vegetables may absorb contaminants introduced into the soil (5,6). Subsequently, these pollutants are consumed by humans, significantly contributing to the emergence of severe health problems and even fatalities across the food chain (2,5–7). This problem has global implications with far-reaching consequences, especially considering that approximately 62% of the world's irrigated lands depend heavily on surface water for agricultural purposes (2).

Alarmingly, an estimated 10% of this irrigated agricultural land, equivalent to 20 million hectares of cropland, uses wastewater for irrigation (8). This issue affects developed and developing countries alike (7,9,10). Globally, millions of people die from diarrhoeal diseases each year (9). A report from the United States illustrated an association between the use of contaminated irrigation water and several foodborne disease outbreaks involving pathogens like Shigella, norovirus and Escherichia coli (E. coli) (6,10–12). In addition to causing fatalities, water-related diseases hinder individuals from maintaining employment and leading active lives (13).

Lebanon, a developing country known for its diverse hydrological landscape and characterized by a network of 14 large rivers (14), suffers from the same issue. Many of the country's water bodies face significant challenges from water pollution, given the lack of pertinent laws and regulations (2,15). Leading contributors of pollution include solid waste mismanagement and industrial discharges concentrated in heavy metals and toxic substances (2). Agriculture is not only a passive victim of pollution, but also actively propagates it (16,17).

Worldwide, agricultural pollution has surpassed contamination originating from urban settlements and industrial sources (18). Nitrate, originating from chemical and organic fertilizers, is the predominant anthropogenic pollutant in river water (16,18). Insecticides, herbicides and fungicides, when improperly applied or disposed, can introduce carcinogens and other harmful compounds into adjacent water bodies (16–18). For instance, Lebanon's largest river, the Litani,

is contaminated with agricultural fertilizers and pesticides from adjacent power plants and farm lands (15).

Another key contributor to Lebanese river water pollution is the increase in population, particularly with the influx of more than 1.5 million Syrian refugees (19–21). Many refugees reside in camps located near rivers (21) and the lack of wastewater treatment plants and sewage networks has led to the contamination of water bodies with poorly treated sewage rich in nitrogen, phosphorus and pathogens (2,21–23).

It is estimated that more than 90% of collected wastewater is released directly into rivers without treatment (24). This strongly implies that surface water in Lebanon harbours a variety of microbial pathogens, including bacteria, viruses and parasites (2). Subsequently, rivers can act as a conduit for the spread of pathogens to other essential resources, including the food chain (2), especially since farmers depend mainly on this water source for agriculture (2). It is estimated that 45% of the irrigated lands in Lebanon rely on river water as a primary source (3).

Several national projects have been conducted to assess the water quality of Lebanese rivers. One study reviewed the chemical and microbiological characteristics of water in 8 coastal rivers during the dry season (25). An article published in 2018 assessed the chemical properties of 4 major rivers year-round (26). Other publications focused on individual rivers, for example, Massoud et al. wrote about the impact of land-based projects on the Abou Ali River, while Merhabi et al. assessed the effect of contaminants on the Kadisha River (27,28).

Unfortunately, there have been no studies in Lebanon to evaluate the implications of river water pollution for human health, particularly for waterborne diseases. In recent years, growing attention from organizations like WHO has focused mainly on cholera due to outbreaks in the country (29–31), notably in areas neighbouring the rivers (20,30).

Following several interconnected crises that Lebanon has faced in past years (32), studies examining the country's river water pollution have been halted. Consequently, we decided to provide an update, given the need to develop solutions to meet this challenge. Our primary objective was to describe the microbiological and chemical properties of the main rivers of Lebanon and to assess their suitability for irrigation. Our secondary objective was to find associations between different analysed parameters, and to compare them to the available literature while identifying solutions that can be implemented to address river water pollution.

Methodology

Study design and setting

This cross-sectional study evaluated the water pollution levels of rivers in Lebanon. The 14 rivers in Lebanon can be divided into 10 coastal rivers originating from Mount Lebanon and stretching towards the Mediterranean Sea, and 4 central rivers (El Kabir, Litani, Al Assi, Hasbani) characterized by distinctive flow directions and discharge areas (14).

In this study, we assessed the quality of irrigation water sourced from the 10 primary rivers in Lebanon used for agricultural purposes, listed in order from north to south Lebanon: El Kabir, Kadisha, El Jaouz (Kfarhelda), Abraham, Antelias (a branch between El Kalb and Beirut rivers), Damour, El Awali, Litani and 2 of its branches, the Al Ghzayel and Ammiq rivers. The selection of these rivers was guided by their paramount importance in agriculture, their substantial water resources and the potential consequences of pollution on crop development. The need to ensure minimal impact on human health underscored the rationale for this choice.

We chose these 10 rivers because they serve as the primary water sources for Lebanon's irrigation needs, allowing us to offer a comprehensive view of water quality in agriculturally significant regions. We selected rivers from each of Lebanon's 8 provinces to ensure a diverse and representative sample that would capture regional variations influenced by environmental factors and human activities.

The sampling was conducted in June 2023. We chose this month because it marks the onset of Lebanon's summer season. By this time, winter snow would have already melted into the rivers, increasing water flow, and the minimal rainfall in June reduces the risk of rainwater infiltration. This choice provided a stable baseline for assessing water quality when farmers commence river water use for irrigation, given that river water use is highest during early summer.

Sampling strategy

To assess irrigation water quality, samples of river water were collected from the 10 river shores already mentioned. For the sampling procedure, trained team members unsealed sterile cups at one-third under the water surface to prevent environmental contamination. Once collected, samples were stored at 3ºC in a portable refrigerator and transported immediately to a dedicated laboratory, where they were analysed in a blinded manner.

Measurement parameters

For each sample, we measured a comprehensive range of water quality parameters: physical, such as water aspect and pH; chemical, including dissolved oxygen, the percentage of oxygen saturation, and the levels of phosphate, nitrate, sulfate and total dissolved solids (TDS); and microbiological, in which the properties were examined by assessing the presence and quantity of E. coli and faecal coliform bacterial colonies. From this we established the total coliform count.

Data analysis

Continuous variables were presented as mean ± standard deviation, while categorical variables were presented as frequency (percentage). The Spearman correlation test was used to correlate 2 continuous variables. P values lower than 0.05 were considered as a significant association. Analyses were performed using R statistical software, version 4.0.2.

Results

Descriptive results

Table 1 presents the chemical parameters of the 10 investigated rivers. The pH values of our samples ranged between 7.31 and 9.11, with an average of 7.8 ± 0.87. Only El Kabir, Abraham and Ammiq rivers presented a clear water aspect. Six out of 10 rivers presented low dissolved oxygen and oxygen saturation percentages.

Regarding the nutrients, Ammiq River had the highest concentrations of nitrate and phosphate (39.8 mg/L and 2.1 mg/L, respectively) while the Litani River presented the lowest concentrations (0.9 mg/L and 0.03 mg/L, respectively). The lowest concentration of sulfate was in Damour River, while the highest was in El Awali River.

Table 2 shows the microbiological parameters of the rivers. The counts of E. coli, faecal coliform, and total coliforms were variable, displaying wide ranges. Out of the 10 rivers, only Kfarhelda, Abraham, Damour and Ammiq were found to be free from parasitic contamination. The presence of E. coli and faecal coliform was undetectable in Abraham and Ammiq rivers, and slightly detectable in Kfarhelda and Damour rivers.

However, in the remaining rivers we found large quantities of E. coli and parasites. Notably, samples from El Kabir, Kadisha, Antelias and El Awali rivers had exceedingly high levels of E. coli and faecal coliform with low dissolved oxygen and high phosphate and TDS levels (Tables 1 and 2).

Correlation between water quality parameters

Figure 1 shows the correlation between water quality parameters. A strongly positive correlation was found between phosphate and TDS (r=0.96, P

Discussion

Lebanon's agriculture is rich and, for a country that relies on river water for irrigation, securing clean water is essential. Ensuring safe water use can reduce waterborne diseases and, in turn, the overall burden on the healthcare system (33). However, with Lebanon's worsening economic crisis and poor infrastructure, water pollution levels continue to rise drastically with insufficient efforts to curtail it (2). This study aims to raise awareness of the implications for public health and elicit appropriate actions for positive change.

Compared to the Food and Agriculture Organization (FAO) guidelines for safe irrigation water use (pH=6–8.5) (34), 4 rivers, namely, El Kabir, Kadisha, Damour and Litani, had a pH above the acceptable limit, corresponding to severe restriction on use. This finding differs from previous Lebanese studies where pH values of the Litani and Damour rivers were within the normal range (4,35).

Half of the rivers – El Kabir, Kadisha, Kfarhelda, El Awali and Ammiq – exceeded the acceptable limit for nitrate levels. The nitrate concentrations in the latter 3 rivers surpassed 30 mg/L, corresponding to severe restriction on their use, according to FAO guidelines (34). Both pH and nitrates present miscellaneous effects on susceptible crops.

High nitrate levels may cause excessive vegetative growth and retard crop maturity, thus delaying fruit production and maturity (34). This issue may disrupt the overall farming calendar and limit the availability of nutrient-dense foods, leading in the long-term to an increased risk of malnutrition and chronic diseases, especially in certain Lebanese regions known for their agricultural wealth and local products consumption.

In the absence of a wide variety of fresh fruit options, individuals may opt for processed foods that are rich in sugar, salt and saturated fat. These dietary options are linked to an elevated risk of developing chronic conditions, such as cardiovascular diseases, diabetes and obesity.

TDS refers to the amount of organic and inorganic materials found in water, such as salt, minerals or metals. According to FAO guidelines, TDS levels must range between 0 and 2000 mg/L in irrigation water (34). A value above 2000 mg/L could reflect water pollution due to human activities (34). In our study, all water sources had a TDS within the acceptable limit

The presence of E. coli and faecal coliform is an indicator of water pollution and a benchmark for assessing the quality of irrigation water (34). Our study demonstrated a wide range in E. coli and faecal coliform counts, and our analysis revealed a significant positive correlation between these 2 parameters. These results were in line with a Canadian study conducted by Steele et al. (36).

Consequently, either E. coli or faecal coliform could be used to measure faecal contamination. As per FAO recommendations, a maximum of 1000 faecal coliform per 100 ml and 126 E. coli coliform per 100 ml are considered acceptable for irrigation water (34).

In contrast to the Canadian study (36), which found that around 90% of the irrigation water samples had acceptable levels of E. coli, only 40% of the rivers that we evaluated had levels within the acceptable range. Four rivers, namely El Kabir, Kadisha, Antelias and El Awali, exhibited faecal coliform counts surpassing the upper limit recommended by FAO. Elevated levels of these bacteria constitute a major threat to public health as they are associated with severe illness outbreaks (37).

Various microbiological studies have found pathogenic microbes in raw fruits and vegetables (38,39). Raw fruits and vegetables may become contaminated through contact with soil or through irrigation with contaminated water (40). For instance, previous experimental studies have shown that irrigation water can transmit E. coli to lettuce plants (41,42). The risk of disease transmission increases when fruits and vegetables are eaten raw, leading to outbreaks of foodborne infectious intestinal disease, which can cause symptoms such as stomach discomfort, vomiting, diarrhoea and fever (38).

We observed a significant inverse relationship between dissolved oxygen and both E.coli and faecal coliform levels. Certain rivers exhibited diminished dissolved oxygen concentrations alongside elevated coliform levels. This can be explained by the fact that

E. coli and faecal coliform – originating mainly from the dumping of waste into water bodies – are facultative anaerobes that deprive the environment of dissolved oxygen as the waste decomposes. Subsequently, depleted dissolved oxygen levels interfere with the life cycle of aquatic organisms, negatively affecting the overall environment (43).

Potential solutions

Citizens' lives depend on public health authorities addressing river water pollution in Lebanon. This requires an urgent multifaceted approach, including:

Sewage treatment

One of the sources of river water pollution in Lebanon is untreated or poorly treated sewage. Improving sewage treatment plants and enforcing regulations to ensure that they are properly maintained and operated can reduce the amount of wastewater that is released into rivers. This can be achieved by investing in new technologies, such as advanced wastewater treatment systems, and by training operators to use these systems effectively.

Improving the overall infrastructure for sewage collection and treatment can reduce the risk of sewage overflow, which can contaminate rivers during heavy rainfall. It is also vital to follow WHO guidelines for the safe use of wastewater, excreta and greywater (44). These guidelines emphasize risk assessment, management and communication to ensure the safe use of wastewater and related materials in agriculture, aquaculture and other activities (44).

Regulation of industrial discharge

Another significant contributor to river water pollution is industrial discharge, especially in the Beqaa Region. Regulating industrial discharge and implementing best practices for waste management can prevent chemicals and toxic substances from contaminating rivers. This can include regulations to ensure that industrial facilities properly treat and dispose of waste, and regulations that limit the amount of pollutants that can be released into waterways.

Encouraging industries to adopt more sustainable practices, such as reducing their use of hazardous chemicals and implementing recycling programmes, can also mitigate the impact of industrial activities on rivers.

Regulation of agricultural practices

Agriculture is another source of water pollution, due to fertilizer and pesticide runoff into rivers. Implementing best practices for agricultural waste management, such as using cover crops and crop rotation, can reduce the amount of fertilizer and pesticide runoff into rivers.

Encouraging farmers to adopt more sustainable practices, such as using low-toxicity pesticides and reducing the use of fertilizer, can also reduce the impact of agricultural activities on rivers.

Education and awareness

Raising public awareness about the dangers of water pollution and the importance of proper waste disposal can encourage individuals to take action to protect rivers. This can include campaigns to educate the public about the importance of not littering, as well as programmes to educate communities about the dangers of polluting rivers and the benefits of protecting them.

Collaborating with schools and universities to incorporate environmental education into the curriculum can instil a sense of environmental responsibility in the next generation.

Monitoring and enforcement

Regular monitoring and enforcement of water quality standards can ensure that polluters are held accountable and rivers are protected. This can include regular water quality testing and monitoring of discharge levels, as well as enforcement of regulations that limit the amount of pollutants that can be released into waterways.

Holding companies and individuals accountable for the impact of their activities on rivers can motivate them to adopt more sustainable practices.

Restoration and protection of riverine ecosystems

Restoring damaged ecosystems and protecting natural areas along rivers can improve water quality and reduce the impact of pollution. This can include planting trees and other vegetation along riverbanks to reduce erosion and improve water quality, as well as restoring damaged wetlands that serve as important habitats for wildlife and filter pollutants from water.

Protecting areas of high conservation value, such as wildlife sanctuaries and national parks, can

ensure that these important ecosystems are preserved for future generations.

Implementing international conventions

Lebanon is a signatory to several international conventions related to water pollution, such as the United Nations Framework Convention on Climate Change and the Convention on Biological Diversity. These conventions provide a framework for addressing water pollution at the national level, and implementing them can ensure that Lebanon is taking appropriate measures to protect its rivers. By implementing these conventions, Lebanon can demonstrate its commitment to reducing water pollution and preserving the health of its rivers.

By implementing these steps, we can ensure that future generations have access to clean and safe water.

Study strengths and limitations

This study is one of the few that address the environmental impact of the economic crisis on water quality in Lebanon’s main rivers. It was intended to shed light on the importance of maintaining the sustainability of these resources and to emphasize the need to invest time and money into developing solutions to meet this national challenge.

Water samples were collected only once from each river for biochemical and microbiological assessment. Several readings would have offered more accurate and certain results. Sampling from different sites of the rivers could have enriched our results.

Samples taken during other seasons could have made comparison possible, widening the assessment to cover seasonal impacts on river pollution. Our study’s data were collected at the beginning of the summer; thus, our results are skewed towards one extreme, failing to assess year-round values. Moreover, conclusions on the safety of irrigation water cannot be drawn based only on laboratory results; they must be tested and confirmed through field trials.

Future studies are needed to accurately assess the level of water pollution in Lebanese rivers across the seasons while using sequential and temporal readings.

Conclusion

Polluted water in Lebanon can have a negative impact on the health of humans and wildlife, as well as the wider ecosystem, making it an urgent issue that must be addressed. Most of the assessed rivers in our study contained bacterial colonies, which contravenes FAO guidelines. By taking action to address this pollution, Lebanon can help protect the health of its citizens and the environment, and ensure that its rivers remain a source of pride for generations to come.

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Pollution des cours d'eau au Liban : le problème de santé publique le plus msous-estimé du pays

Résumé

Contexte : En raison des nombreuses crises interdépendantes auxquelles le Liban a dû faire face au cours des quatre dernières années, certaines problématiques sociales et environnementales ont été négligées au profit d'autres jugées plus « importantes ». En conséquence, la pollution de l'eau au Liban continue de s'intensifier.

Objectif : La présente étude visait à décrire les propriétés microbiologiques et chimiques des 10 principaux cours d'eau du Liban et à évaluer si elles sont adaptées à l'irrigation, tout en examinant certaines solutions au problème.

Méthodes : La présente étude transversale a évalué le niveau de pollution de 10 cours d'eau au Liban en juin 2023 et a déterminé s'ils sont adaptés à l'irrigation. Les échantillons ont été prélevés à une température de 3 °C et leurs paramètres de qualité ont été mesurés. Une analyse statistique a été réalisée à l'aide du logiciel de statistiques R version 4.0.2.

Résultats : Par rapport aux lignes directrices de l'Organisation des Nations Unies pour l'alimentation et l'agriculture (FAO) concernant l'utilisation sûre de l'eau d'irrigation, quatre des 10 échantillons présentaient des taux de pH supérieurs au seuil autorisé, entraînant de sévères limitations quant à l'utilisabilité de ces eaux. Trois cours d'eau présentaient des concentrations de nitrate supérieures à la fourchette autorisée, ce qui limitait leur utilisation intensive. Soixante pour cent des cours d'eau affichaient des niveaux d'Escherichia coli supérieurs à la fourchette

autorisée et 40 % enregistraient un nombre de coliformes fécaux excédant la limite maximale recommandée par la FAO. Cependant, tous les cours d'eau présentaient des niveaux totaux de solides dissous compris dans la fourchette recommandée.

Conclusion : L'eau polluée peut avoir un impact négatif sur la santé des humains, des espèces sauvages et des écosystèmes. La plupart des cours d'eau évalués dans notre étude contenaient un nombre de colonies bactériennes supérieur au seuil maximal recommandé à l'échelle internationale. Il est donc urgent de remédier aux problèmes de pollution des eaux au Liban afin de les rendre aptes à l'irrigation et à d'autres usages.

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