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Review Article

Does Land-Use Associate with *Escherichia coli* Pollution in Karst Springs? A Review of the Literature

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ABSTRACT

Objective: The presence of *Escherichia coli* bacteria in karst springs, influenced by land cover conditions and land use activities in rainwater catchment areas, indicates a decrease in water quality. The study aimed to describe the effect of land use on *Escherichia coli* contamination in karst springs. **Methods:** This was a narrative review retrieving studies from Scopus and PubMed databases. The keywords used are pollution, Escherichia coli, land use, and karst springs. Of the 52 studies identified in the search phase, ten studies were eligible for inclusion in this review. **Results:** The concentration of *Escherichia coli* increases with increasing rainfall in all types of land use, such as forested land, mixed garden land, residential land, and grazing or livestock land. Factors that cause concentration *Escherichia coli* does not meet water quality standards due to feces from wild animals, feces-contaminated fertilization, construction of non-water impermeable septic tanks, and feces from livestock grazing. **Conclusions:** Repairing septic tanks and sewage in areas with high population density may reduce *Escherichia coli* contamination. Further research is needed to formulate strategies and policies for managing springs in the karst areas.

Key words: Pollution, *Escherichia coli*, Karst Springs, Land-Use.

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INTRODUCTION

The Sustainable Development Goals (SDGs) are a global development agreement aiming to end poverty, reduce inequality and protect the environment.[1] The goal of SDG 7 is to ensure the availability and sustainable management of clean water and sanitation for all.[2] Target by 2030 is to improve water quality by reducing pollution, eliminating waste disposal and minimizing the disposal of hazardous chemicals and materials, halving untreated wastewater proportion, and substantially increasing recycling and safe reuse globally.[2]

The utilization of karst springs for many human needs is continuously increasing every year, in line with the increase of population.[3] The ever-increasing demand for water is not supported with the carrying capacity of the environment that has limits, not only family needs but also for industry and agriculture needs.[4]

Studies show that many factors can affect the quantity and quality of karst springs in the rainwater catchment area, including land cover condition,[5] land-use activities,[6] geomorphological and geological conditions,[7] and personal use of the springs by people. All of these factors are highly dependent on regional development and population growth.[8]

Utilization of karst springs for people's clean water needs is probably not based on the understanding of the characteristics of the springs,[9] formation process,[10] and hydrological dynamics that will occur,[11] leading to a water quality degradation of karst.[12]

A quality reduction of karst springs is mainly affected by the level of population density.[13] The more the population, the greater the amount of waste will be discharged into the environment. [14] The decline in the quality of springs can also be caused by poor sanitation such as seepage of wastewater from households,[15] including seepage from septic tanks.[16] The pollution can be identified by the presence of *Escherichia coli* in karst springs.[17]

Lack of understanding of *Escherichia coli* can lead to a lack of awareness and willingness to take precautions against bacterial contamination.[18] The decline in the quality of karst springs due to E. coli can negatively affect human health, such as diarrhea, urinary tract infections, respiratory diseases, pneumonia, and other diseases.[19] Using the presence of *Escherichia coli* in the water is an important indicator of contamination of the karst springs, Thus, studies in this field are essential.[20] This article will review the current knowledge in the literature about the association of land-use activities and *Escherichia coli* pollution in karst springs.

MATERIALS AND METHOD

Information Sources

We searched for studies through two electronic databases (Scopus and PubMed). In the database search stage, 52 studies were identified. The criteria for including research in this review were a study of land-use models in karst springs and published from 2015 to the present. A review article, unpublished work, and study protocol were not eligible for inclusion. In the final stage, ten studies were included (Figure 1).

Search Terms

The keywords used for the search stage were "land use" ((land use wooded OR use mixed garden land OR use residential land OR use grazing land) AND

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Table 1. Evidence supporting land-use activities and Escherichia coli contamination in karst springs.

Author	Parameter	Results
Buckerfield SJ et al. (2020)[21]	Land use	*E. coli* concentrations increased with increasing rainfall in various land use types and karst hydrological system compartments.
Hugo Henrique Cardoso de Salis et al. (2019)[22]	Land use	The application of correct fertilization, management, and irrigation practices is considered important to reduce the potential for groundwater contamination.
Kai Song et al. (2020)[23]	Land use	Determination of the risk zone for groundwater sources in the karst area, identification of the karst water system, and decision making for the protection of drinking water sources in the karst area.
Liying Liu (2021)[12]	Karst water source protection	The main factors limiting the protection of water resources in karst areas are water pollution caused by agricultural cultivation methods, methods and efficiency of surface water development and utilization, and water storage capacity.
Buckerfield SJ et al. (2019)[5]	*E. coli*	The maximum concentration and the rate of *E. coli* are influenced by rainfall (amount, intensity), the timing of agricultural activities, and position in the hydrological system.
Domenico Savio et al. (2018)[24]	*E. coli*	When water discharge is high, soil surface microbes and nutrients such as soil microorganisms or human settlements can contain faecal-related pathogens that are harmful to water quality and can quickly flow into karst aquifers.
Shoshanit Ohad et al. (2015)[25]	*E. coli*	Contamination of human faeces during the dry season was not associated with contamination during rains, indicating direct and continuous exposure to the karst hydrological system.
Koosha Kalhor et al. (2019)[26]	*E. coli*	Faecal coliform, faecal streptococci, and often specialise *Escherichia coli* in karst aquifers. These organisms often exhibit contamination caused by sewage or animal waste.
Julian Xanke et al. (2017)[15]	*E. coli*	Applying the proposed protection zones for wells and reservoirs is highly recommended, as the results demonstrate the extreme risk of contamination due to livestock, fertile agriculture, and human activities.
Anna Ender et al. (2018)[27]	*E. coli*	Springs from the Bac Son formation displayed the highest microbial contamination. In contrast, polje springs with connections to sinking streams were more contaminated than springs with catchments characterized by more diffuse infiltration. Fecal indicator bacteria (FIB) concentrations depend on the season, with higher values in rainy season conditions. The type of spring catch also affects water quality.

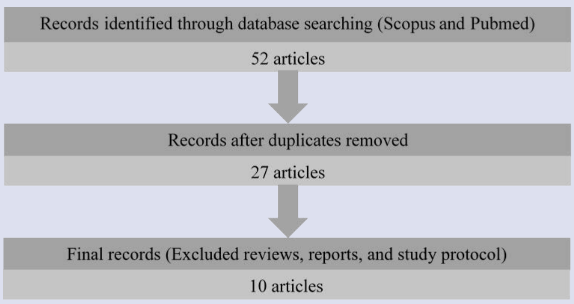

Figure 1. Flow diagram of study selection.

"pollution" (pollution OR *Escherichia coli* OR karst springs)). This literature review did not limit the type or design of the study.

RESULTS

Table 1 shows the relevant studies of land-use activities and *Escherichia coli* contamination in karst springs. Three studies show the effect of land use on karst springs.[21-23] Six studies show *Escherichia coli* contamination in karst springs,[5,15,24-27] while 1 study is related to the protection of karst water sources.[12]

DISCUSSION

Findings of this literature review reveal that land use may be associated with the increase of *Escherichia coli* concentrations affected by rainfall in all types of land use, such as forested land, mixed garden land, residential land, and grazing land or livestock.

Escherichia coli concentration and land use

Karst aquifers have distinctive hydrology and supply 25% of the world's population with drinking water,[20] making it a critical geological setting for understanding and managing microbial contamination in drinking water.[1] Precipitation causes increased concentrations and loading of faecal microorganisms, for example, in rainwater catchments and groundwater systems, increasing the risk of human exposure to faeces-contaminated water.[21] The concentration of *Escherichia coli* increased 1-3 times after the main event.[5] The maximum of *Escherichia coli*'s concentration and the rate of recession are influenced by rainfall (amount and intensity), the timing of agricultural activities, and position in the hydrological system.[22] Based on the results, this study provides new insights into how rainfall characteristics combined with land use and rainwater catchment hydrology can control *Escherichia coli*.[21]

Variations in *Escherichia coli* concentration based on the location and extent of rainwater catchment areas in karst springs indicate higher concentrations in agricultural land or mixed gardens. The samples in forested land are also much lower than in mixed garden lands.[21] Several water quality parameters show grouping determined by the categorical classification of locations according to land-use activities in rainwater catchment areas within the karst.[22] A study shows that the concentration of *Escherichia coli* was determined based on the location, of which less was found in forested land followed by mixed garden land and then urban land.[5] Other environmental parameters such as Temperature and Turbidity show the same pattern, which is lower in forested locations than in agricultural or urban locations.[27]

Land-use regulation of *Escherichia coli* concentration shows the most relevant control in the management of karst springs.[25] The land use modelling method of rainwater catchment areas is the most significant in controlling the concentration of *Escherichia coli*.[21] High concentrations of *Escherichia coli* in rainwater catchment areas might be affected by rainfall and agricultural, livestock, and residential activities. Thus, temporal control, including during the rainy season, agricultural, livestock and residential activities can be more beneficial than control in karst springs.[23] Faecal contamination of karst springs are common worldwide. The concentrations of *Escherichia coli* observed in this study are comparable to concentrations observed in karst areas of the world with human or livestock inputs.[15]

Factors Causing the Increase of *Escherichia coli* Concentration in Karst Springs

Studies reported that wild animal dung, faecal-contaminated fertilization, non-standardized construction of septic tanks, grazing livestock manure could cause the high concentration of *Escherichia coli*.[26] The abundant use of fertilizers in rainwater catchment areas in the karst areas is likely to have a high potential for groundwater contamination unless good management practices are implemented and monitored.[24] Sprinkler irrigation is recommended because it can reduce the migration of nutrients from soil to groundwater and prevent the occurrence of shallow sinkholes in karst areas. This environmental impact is often associated with water concentrated in the soil and can disrupt the soil with negative consequences for economic activities, namely agriculture.[5]

Surface runoff in urban areas is five times higher than other land occupations.[23] The use of a rainwater system to artificially infiltrate excess water is not recommended as it will have negative consequences on the environment, such as a high risk of groundwater contamination with metals, hydrocarbons, and microbiology. Therefore, it is suggested to store quality surface water in forest areas by using a small dam.[21] This surface water can be diverted and used in urban areas complement groundwater supplies in the context of sustainable management of water resources.[12]

Factors that affect the resilience of water resources to the feasibility level of drinking water based on *Escherichia coli* concentrations are the use of fertilizer per unit in cultivated land, irrigation of agricultural land, the rate of urbanization for water resource vulnerability subsystems, the level of development and utilization of groundwater, the level of development and utilization surface water.[21]

CONCLUSION

Land use and hydrology factors in karst springs are in line with the concentration of *Escherichia coli*. The concentration of *Escherichia coli* in forested land is lower than other land uses. A low population and livestock density in the area and the scarcity of wildlife more prevalent in the area could lower risk of *Escherichia coli* contamination. However, due to a limited number of karst springs in forested lands, it is difficult to protect spring karst from human activities such as agriculture, animal husbandry, and settlement.

Advice to maintain karst springs in order to reduce the concentration of *Escherichia coli* could be done by repair septic tanks, managing waste treatment in areas with high population density, regulating grazing or livestock areas. Further research is needed to formulate strategies and policies for managing springs in the karst areas.[12]

What is known about the subject?
Decreased water quality in karst springs is affected by land cover conditions and land use activities in rainwater catchment areas.

What does the study performed add to the literature?
The results of this review literature produce information that can be used as a reference to readers and authors.

What are the implications of the results obtained?
Escherichia concentrations increase with increasing rainfall in all types of land use, repairing septic tanks, formulating spring management strategies in karst areas.

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CONFLICTS OF INTEREST

The authors declare that they have no conflict of interest.

AUTHOR CONTRIBUTION

All authors contributed to this article, and FS carried out this research. Furthermore, AD makes a significant contribution to the implementation of research starting from the initial planning of research and various scientific considerations in conducting research, article review and provided various suggestions for improvement during the preparation of the article. All of the authors listed above contributed to preparing, drafting, and revising the manuscript, giving final approval of the published version, and agreeing to be responsible for all aspects of the work.

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