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Spatial Analysis of Mycobacterium Ulcerans-Hosting Water Bug Critical Zones in the Amansie West District of Ghana

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Abstract: The World Health Organization (WHO) recognized Buruli ulcer (BU), a skin disease caused by Mycobacterium ulcerans (MU), as the third most prevalent mycobacterial disease in 1998, following tuberculosis and leprosy. In Ghana, there have been over 2000 reported cases in the past decade, with outbreaks in 90 administrative districts, including Amansie West. The mode of transmission remains unclear, but research suggests water bugs may be involved. This study aimed to assess this transmission method by identifying potential water bug habitats using geospatial techniques. Water bugs are found to inhabit freshwater ponds, marshes, slow-moving pools, streams, and mats of vegetation. This study used the Normalized Difference Water Index (NDWI) to locate water bodies and marshy areas, the Atmospherically Resistant Vegetation Index (ARVI) to identify vegetation zones, and Land Surface Temperature (LST) to determine suitable areas for water bugs based on temperature. A spatial multi-criteria evaluation (MCE) pinpointed critical areas for Mycobacterium ulcerans-hosting water bugs, which were mainly located in illegal mining areas due to stagnant wastewater. Notably, 36 communities, including prominent ones like Manso Nkwanta and Pakyi Number 1 and 2, were situated within these critical zones. This study generated a geospatial distribution map highlighting the potential areas for Mycobacterium ulcerans-hosting water bugs in the Amansie West district, crucial for Buruli ulcer transmission. The study recommended improved environmental sanitation in the affected areas to combat this water bug-related health issue.

Keywords: Buruli Ulcer, Environmental Impact, Mycobacterium Ulcerans, Spatial Multi-Criteria Evaluation (MCE), Illegal Mining.

1. INTRODUCTION

Buruli ulcer (BU), a neglected tropical skin disease caused by Mycobacterium ulcerans (MU), has been recognized as the third most prevalent mycobacterial disease globally, trailing only tuberculosis and leprosy (Guarner, 2018). Since its recognition by the World Health Organization (WHO) in 1998, BU has continued to pose a significant public health challenge, particularly in regions with a high incidence of cases (N-Jonaam Mahama et al., 2022). One such region is Ghana, where in the past decade alone, over 2000 BU cases have been reported, and outbreaks have occurred across more than 90 administrative districts, leaving a considerable burden on healthcare systems and local communities (N-Jonaam Mahama et al., 2022).

The epidemiology of BU is characterized by its enigmatic mode of transmission. Despite the profound impact of this disease, there is still no general consensus on how MU is transmitted to humans (Zingue et al., 2018). In this context, a remarkable research endeavour has aimed to shed light on the potential role of water bugs as vectors for MU transmission. Laboratory studies have provided compelling evidence that water bugs possess the capability to transmit MU through their bites, but the translation of this knowledge into real-world implications requires a deeper understanding of the environmental factors that support water bug habitats (Ebong et al., 2012).

In a study by Duker et al. (2004), the spatial relationship between Buruli ulcer (BU) prevalence and arsenic-enriched areas in the Amansie West District of Ghana was examined. It finds higher BU rates in settlements near arsenic-enriched drainages and farmlands. However, the study doesn't establish a direct causal link between arsenic and BU, leaving room for other contributing factors. In a study by Bonyah and Owusu-Sekyere (2012) in the Amansie West District of Ghana, the relationship between Buruli ulcer (BU) and potential risk factors using GIS and geostatistics was explored. It found that BU was more prevalent in the southern part, linked to intense mining and agriculture near rivers. However, the study does not establish a direct causal link between these activities and BU, and additional research is needed to determine the exact mode of transmission. In a study by Bibert et al. (2017), the genetic factors influencing susceptibility to Buruli ulcer (BU) were investigated, found associations with specific single nucleotide polymorphisms (SNPs) in iNOS and IFNG genes, both affecting promoter activity. A previously reported SNP in SLC11A1 also showed a potential link to BU. However, while these findings suggest the importance of IFNG signalling in early defence against M. ulcerans, this study does not address all possible genetic factors contributing to BU susceptibility, and additional research is needed to establish a comprehensive understanding of the genetic basis of BU.

This study, conducted in the Amansie West district of Ghana, sets out to address this critical knowledge gap by employing geospatial techniques to detect potential areas where water

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bugs, suspected vectors of MU, may thrive. These techniques leverage satellite Remote Sensing indices, including the Normalized Difference Water Index (NDWI) for water body identification, the Atmospherically Resistant Vegetation Index (ARVI) for vegetation mapping, and Land Surface Temperature (LST) for assessing suitable temperature ranges for water bug habitats. Furthermore, a spatial multi-criteria evaluation (MCE) approach is employed to identify the Mycobacterium ulcerans-hosting water bug critical areas in the district.

Through this comprehensive analysis, the research endeavours to create a spatial distribution map that delineates potential areas where water bugs may reside and consequently transmit MU. The findings of this study are expected to significantly contribute to our understanding of BU epidemiology and could potentially lead to more effective strategies for BU control. Moreover, the identification of critical zones, especially in areas associated with illegal mining activities, provides valuable insights into the environmental factors contributing to MU transmission, with implications for public health intervention and environmental management.

2. MATERIALS AND METHODS

Study Area

Amansie West District as shown in Fig. 1 is one of forty-three districts in the Ashanti Region of Ghana. It was established in 1988 as an ordinary district assembly from the former Amansie District Council. The southern part of the district was split off on March 15, 2018, to form Amansie South District; the remaining portion was preserved as Amansie West District. Manso Nkwanta, the district assembly's main town, is located in the southern section of Ashanti Region. According to the 2021 population and housing census, it has a land area of 1,230 square kilometres and a population of 109,416 people with 56,048 males and 53,368 females. Aside from its capital, the district's main settlements include Mpatuam, Pakyi No. 1, Antoakrom, and Esuowin. The district is divided into four major ethnic groups: the Akans (86.4%), the Northerners (9.7%), the Ewe (3.6%), and the Ga (1.1%). They are also overwhelmingly Christian (79.4%), with a minor percentage of Muslims (8%), and a much smaller proportion subscribing to other sects or indigenous faiths (Ghana Districts, 2023).

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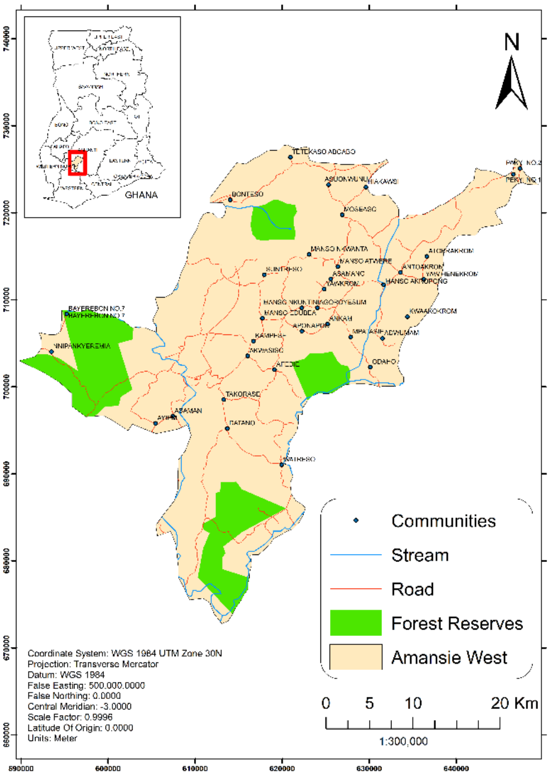

Fig. 1 A Map of Amansie West District in Ghana

Materials Used

The study utilized a range of materials and data sources, including QGIS 3.16 software for geospatial analysis, Google Earth for visualizing spatial information, Landsat Images from the USGS Earth Explorer for remote sensing data, and MS Excel 2019 for data organization and analysis. These tools and resources were crucial in conducting comprehensive geographic research, enabling the examination of spatial relationships, risk factors, and other elements pertinent to the study's focus on topics like Buruli ulcer and genetic associations. Together, they facilitated the exploration and understanding of complex geographic and health-related phenomena.

Table 1: Materials Used with their sources

Material	Source
QGIS 3.16 software	https://www.qgis.org/en/site/forusers/download.html
Google Earth	https://earth.google.com/web/@7.26862982,-2.87470975,263.69494464a,5077.84229066d,35y,0h,0t,0r/data=OgMKATA
Landsat 8 Level 2 Image	https://earthexplorer.usgs.gov/

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AHP calculator (Excel template)	https://bpmsg.com/wordpress/wp-content/uploads/2022/07/AHPcalc-2022-07-08.zip
MS Excel 2019	Microsoft

Methods

Identification of Water Bug Habitats

The study began by identifying potential habitats for water bugs, which are suspected vectors for Mycobacterium ulcerans. These habitats include freshwater ponds, marshes, slow-moving pools, streams, and areas with mats of vegetation.

Freshwater Ponds: Freshwater ponds are standing water bodies typically found in various landscapes, including rural and semi-urban areas. These ponds are often characterized by their relatively calm and non-flowing water, making them potential breeding grounds for water bugs. These insects are known to thrive in stagnant or slow-moving water.

Marshes: Marshes are wetlands dominated by herbaceous vegetation and can be found in both coastal and inland areas. They often have a mix of open water and emergent plants. The presence of water bugs in marshes may be attributed to the accessibility of water sources and abundant vegetation that provides hiding spots and potential prey.

Slow-Moving Pools: Slow-moving pools refer to areas of water with reduced flow or minimal water movement. These could be small pools along streams or riverbanks where water accumulates and becomes stagnant. Such conditions are conducive to water-bug habitats, as they prefer calmer waters for reproduction and feeding.

Streams: Streams are linear bodies of flowing water that can vary in size from small brooks to larger rivers. While water bugs are typically associated with slower waters, certain species can still be found in streams, especially in areas with reduced flow or quiet pools adjacent to the main current.

Mats of Vegetation: Mats of vegetation can be found in aquatic environments, including wetlands, ponds, and slow-moving streams. These mats are often created by the growth of various aquatic plants. Water bugs may inhabit these mats as they offer shelter, breeding sites, and access to potential prey within the vegetation. Identifying these habitats is essential for understanding the ecological context of Mycobacterium ulcerans transmission. Water bugs are suspected to be vectors for the disease, and by pinpointing their potential habitats, researchers can gain insights into the environmental conditions that may contribute to the transmission of the bacterium. Furthermore, this information can help guide preventive measures and public health interventions to reduce the risk of Buruli ulcer in affected regions.

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Remote Sensing and Index Calculation

The use of remote sensing data and specific indices in the study is a powerful and non-invasive way to identify potential water bug habitats and environmental factors conducive to Mycobacterium ulcerans transmission. Here is a more detailed explanation of the Satellite Remote Sensing methods and indices employed:

Normalized Difference Water Index (NDWI): NDWI is a remote sensing index widely used to detect the presence of water bodies and marshy areas. It works by leveraging the differences in how water and other land features reflect and absorb light. Water, being highly reflective in the near-infrared spectrum, appears bright in NDWI images. NDWI values range from -1 to 1, with positive values indicating the presence of water. In the study, NDWI likely helped identify freshwater ponds, marshes, slow-moving pools, and streams, which are key habitats for water bugs.

NDWI = (GREEN – NIR) / (GREEN + NIR) (1)

Where NIR is the near-infrared band from the Landsat 8 Image and GREEN is the green band from the Landsat 8 Image.

Suitable Range for water bug: -0.10 to 0.23

NDWI was used in this study to distinguish water bodies and marshy areas. The index calculated the normalized difference between the green and near-infrared (NIR) spectral bands using Eq. (1). Water typically has high reflectance in the NIR region and low reflectance in the green region, resulting in positive NDWI values. The specified range of -0.10 to 0.23 indicates that areas falling within this range are considered suitable for water-bug habitats. In this case, it likely helped identify freshwater ponds, marshes, slow-moving pools, streams, and other water bodies where water bugs are known to thrive in the study area.

Atmospherically Resistant Vegetation Index (ARVI): ARVI is an index used to detect areas with vegetation. It is designed to minimize the impact of atmospheric conditions on the accuracy of vegetation detection. This index typically uses both the red and near-infrared bands to highlight the presence and health of vegetation. In the context of the study, ARVI was likely employed to identify areas with mats of vegetation in aquatic environments, which can serve as suitable habitats for water bugs.

ARVI = (NIR – (2 * RED) + BLUE) / (NIR + (2 * RED) + BLUE) (2)

Where NIR is the near-infrared band from the Landsat 8 Image and GREEN, RED and BLUE are the green, red and blue bands from the Landsat 8 Image.

Suitable Range for water bug: 0.12 to 0.34

ARVI was used to detect areas with vegetation while minimizing the influence of atmospheric conditions. It calculated the index based on near-infrared (NIR), red, and blue spectral bands using Eq. (2). Healthy vegetation typically has high reflectance in the NIR region and lower reflectance in the red region. The specified range of 0.12 to 0.34 suggests that areas within this range are indicative of the presence of vegetation, which can include mats of aquatic vegetation that serve as hiding spots and breeding grounds for water bugs.

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Land Surface Temperature (LST): LST is a measurement of the temperature of the Earth's surface, acquired through remote sensing. In the study, LST was used to determine suitable areas for water bugs based on temperature preferences. Water bugs are ectothermic organisms, meaning their body temperature is regulated by the environment. By assessing the LST, the study aimed to identify areas with temperatures within the range conducive to water bug activity, typically falling between 25°C to 35°C**.**

$$LST = \frac{Tc}{1+(\lambda\sigma Tc/(hc)In\varepsilon)} \quad (3)$$

where λ is the effective wavelength (11.475 μm for the thermal band), σ is Stefan Boltzmann constant (1.38 x 10^{-23} J/K), h is Plank's constant (6.626 x 10^{-34} Js), c is the velocity of light at a vacuum (2.998 x 10^{-8} m/sc), ε is emissivity.

Suitable Range for Water Bug: 25°C to 35°C

LST representing the temperature of the Earth's surface was computed using Eq. (3). For water bugs, which are ectothermic organisms, environmental temperature is critical. The specified temperature range of 25°C to 35°C indicates that this is the suitable temperature range for water bug activity. Water bugs are more active within this range, and it aligns with their thermoregulatory requirements. the use of these remote sensing indices was advantageous because it allows for a large-scale assessment of the landscape and environmental factors that influence the distribution of potential water bug habitats. By analyzing satellite or aerial imagery, researchers can effectively pinpoint areas with the desired characteristics, reducing the need for labour-intensive, on-the-ground surveys. This approach offers a valuable and efficient means to gather critical spatial information for understanding the epidemiology of Buruli ulcer and the role of water bugs in its transmission**.**

Spatial Multi-Criteria Evaluation (MCE) with the Analytic Hierarchy Process (AHP)

Spatial MCE with the AHP is a method used to combine and weigh multiple criteria or factors to identify critical areas where Mycobacterium ulcerans-hosting water bugs are likely to be found. Here is how it was used in the study:

Criteria Selection: The study selected three (3) key criteria, each associated with an index: NDWI, LST, and ARVI. These criteria are essential for identifying suitable water bug habitats, as explained earlier.

Weighting Criteria: The study assigned weights to these criteria to reflect their relative importance in influencing the presence of Mycobacterium ulcerans-hosting water bugs. The percentages provided indicate the weight assigned to each criterion as shown in Table 2 using the AHP calculator template in Microsoft Excel (Goepel, 2013).

Table 2. Criteria and weight generated from the AHP calculator

Criteria	Weight (%)
NDWI	74.7
LST	11.9
ARVI	13.4

These weights suggest that NDWI is considered the most significant factor, followed by ARVI, and LST is the least influential but still relevant.

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Spatial Analysis: With the criteria and their weights established, the study conducted a spatial analysis. This process involved evaluating each criterion across the study area, taking into account the values derived from the NDWI, LST, and ARVI indices.

Spatial MCE Calculation: The AHP-based MCE method combines these criteria, taking into consideration their respective weights, to generate a composite score for each location in the study area. This composite score reflects the overall suitability of each location for Mycobacterium ulcerans-hosting water bugs.

Critical Areas Identification
The results of the Spatial MCE provide a spatial distribution map highlighting critical areas where Mycobacterium ulcerans-hosting water bugs are most likely to be found. Locations with higher composite scores are considered more suitable for these water bugs, potentially serving as hotspots for Buruli ulcer transmission. By utilizing Spatial MCE with AHP, the study effectively integrated various geospatial factors, giving greater weight to the most influential ones, to pinpoint areas of heightened risk for Buruli ulcer transmission. This method helped guide public health efforts and interventions, focusing resources on areas with the highest probability of hosting Mycobacterium ulcerans via water bugs. The conceptual framework of this study is shown in Fig.2.

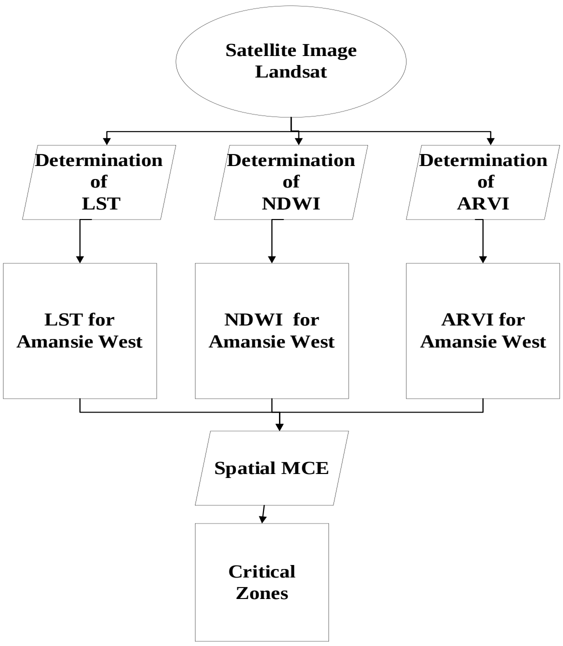

Fig. 2 Conceptual Framework of the study

3. RESULTS

Suitable habitats of Mycobacterium Ulcerans-Hosting Water Bugs in Amansie West
The study successfully identified potential water bug habitats, including freshwater ponds, marshes, slow-moving pools, streams, and areas with mats of vegetation as shown in Fig. 3.

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These habitats are essential for understanding the epidemiology of Buruli ulcers and the role of water bugs in its transmission. Through the MCE process, the study generated a spatial distribution map highlighting critical areas where Mycobacterium ulcerans-hosting water bugs are most likely to be found. Locations with higher composite scores were identified as areas with a higher likelihood of water bug presence as shown in Fig. 4.

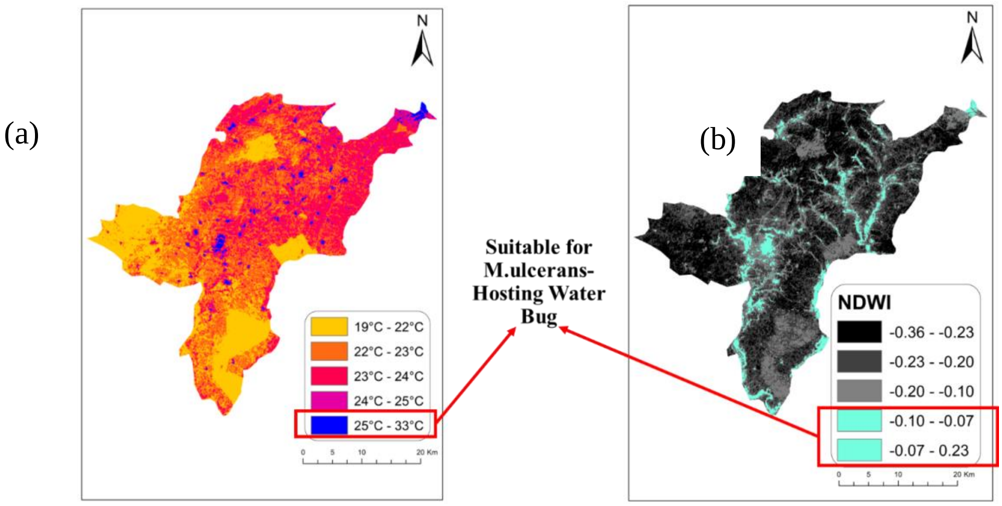

Fig. 3 Suitable habitats of Mycobacterium ulcerans-hosting water bugs in terms of (a) LST and (b) NDWI in the Amansie West district

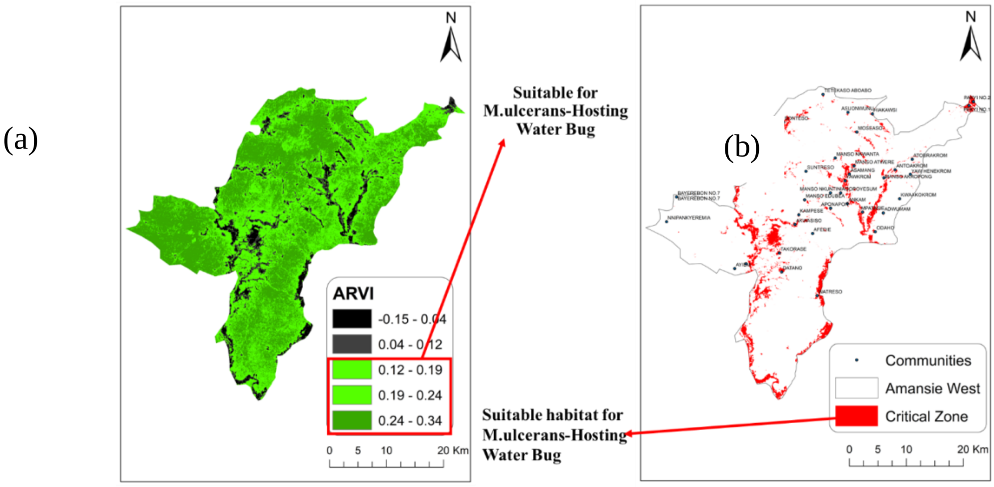

Fig. 4 Suitable habitats of Mycobacterium ulcerans-hosting water bugs in terms of (a) ARVI and (b) the critical zone/ habitats for M.ulcerans-Hosting water bug after Spatial MCE in the Amansie West district of Ghana

4. DISCUSSION

The study addresses the pressing issue of Buruli ulcer (BU) transmission and the potential involvement of water bugs, using geospatial techniques to identify critical areas of concern.

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This discussion encompasses key aspects of the research, its significance, limitations, and implications. The recognition of BU as the third most prevalent mycobacterial disease by the WHO underscores the importance of understanding its transmission. The focus of this study on water bugs as potential vectors is significant for public health in affected regions like the Amansie West district in Ghana. The application of geospatial techniques, including the use of Satellite Remote sensing indices like NDWI, ARVI, and LST, allowed for the identification of water bug habitats. This method provided a non-invasive, large-scale approach to studying the ecological context of BU transmission. The Spatial Multi-Criteria Evaluation (MCE) using AHP, with criteria weighting based on NDWI, ARVI, and LST, pinpointed critical areas. The findings of the study revealed that these areas are concentrated in illegal mining zones with stagnant wastewater. The association between BU prevalence and illegal mining areas is a noteworthy discovery. The stagnant wastewater created by mining activities appears to be a favourable environment for water bugs, potentially contributing to BU transmission. The identification of critical areas for Mycobacterium ulcerans-hosting water bugs in the Amansie West District, particularly within illegal mining zones, is a striking revelation that underscores the profound impact of anthropogenic activities on the local environment. The findings of the study demonstrate a direct correlation between illegal mining and the creation of suitable habitats for water bugs, which have been implicated as potential vectors for Mycobacterium ulcerans. This linkage vividly illustrates the unintended environmental consequences of illegal mining, particularly the formation of stagnant wastewater pools in the mining areas. Moreover, the presence of these stagnant water bodies, where water bugs thrive, elevates the risk of disease transmission, specifically Buruli ulcer. This debilitating skin disease, caused by Mycobacterium ulcerans, poses a considerable health hazard to local communities, with 36 settlements, including well-known ones like Manso Nkwanta and Pakyi Number 1 and 2, located within these critical zones. These communities are at the forefront of potential health risks associated with these water bug habitats. Addressing this issue necessitates immediate action, involving both environmental regulation and conservation efforts. The study serves as a stark reminder of the pressing need to manage and mitigate the environmental impact of illegal mining. This can be achieved through the enforcement of stricter mining regulations and the promotion of responsible mining practices, which limit the creation of stagnant wastewater in mining areas. In tandem, community engagement and education campaigns are essential, empowering local residents to actively contribute to improving environmental sanitation and minimizing the risk of disease transmission. While this research is a significant step towards understanding the dynamics of Buruli ulcer transmission in the region, it should serve as a launching pad for more comprehensive studies that delve deeper into the direct link between water bug habitats and disease transmission. Field studies and genetic analyses are essential to confirm the role of water bugs as vectors. In sum, the study's findings underscore the intricate interplay between human activities and environmental health, demanding a multi-pronged approach to safeguard the well-being of the affected communities in the Amansie West District of Ghana.

5. CONCLUSIONS

In conclusion, this study represents a significant step towards understanding the potential transmission of Buruli ulcer and the involvement of water bugs in this process within the Amansie West District. While the application of geospatial techniques and the utilization of criteria weighting through AHP have yielded valuable insights, certain limitations must be acknowledged. The study does not definitively establish a direct causal link between water bug habitats and BU transmission, emphasizing the need for further comprehensive research, including field studies and genetic analysis, to confirm the role of water bugs as vectors for Mycobacterium ulcerans. This study should serve as a foundational platform for future research endeavours that aim to validate the findings and explore additional factors that may influence BU prevalence. Furthermore, community engagement and participation are essential elements of public health initiatives in the affected areas, as local residents can actively contribute to improving environmental sanitation. The establishment of systematic monitoring and surveillance systems for BU and water bug populations in critical areas is paramount for early detection and timely intervention. Additionally, the implementation of environmental regulatory measures is crucial, particularly in addressing the environmental impact of illegal mining activities, such as the creation of stagnant wastewater, which could have adverse consequences for BU transmission. Lastly, the provision of education and training programs for healthcare workers and communities should remain a priority, focusing on early detection, proper wound care, and effective prevention strategies to mitigate the incidence of Buruli ulcer in the region.

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Declaration of Conflict of Interest
The Authors declare no conflict of interest.

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