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ORIGINAL ARTICLE

GEOSPATIAL ANALYSIS TO IDENTIFY TUBERCULOSIS HOTSPOTS IN BANYUMAS REGENCY (2023) THROUGH SPATIAL AUTOCORRELATION

Analisis Geospasial untuk Mengidentifikasi Titik Rawan Tuberkulosis di Kabupaten Banyumas (2023) Melalui Autokorelasi Spasial

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ABSTRACT

Background: Banyumas Regency had the second-highest number of TBC cases in Central Java Province in 2023, totaling 7,060 cases. The incidence of TBC increased by approximately 27.27% from 2022 to 2023. Despite various TB control efforts, conventional epidemiological methods often fail to capture the spatial patterns of disease transmission, making it challenging to identify localized hotspots and effectively allocate resources. **Purpose:** This study aimed to analyze the spatial relationship between HIV prevalence, population density, healthy living behaviors, and housing conditions in relation to TBC incidence. Additionally, it sought to identify tuberculosis hotspots in Banyumas Regency. **Methods:** The data were obtained from the Banyumas Tuberculosis System Information in August 2024. Total of 4,853 registered patients who sought treatment and resided in Banyumas Regency in 2023 was assessed. TBC distribution patterns were analyzed using the spatial autocorrelation method through the Moran Index and Local Indicators of Spatial Associations (LISA). **Results:** The analysis revealed significant clustering of TBC incidence with HIV prevalence, clean and healthy living behavior, and population density. The significant dispersion was noted with healthy houses. Notably, six 27 subdistricts—Kembaran, North Purwokerto, South Purwokerto, East Purwokerto,

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Sokaraja, and Sumbang—demonstrated significant local spatial autocorrelation. **Conclusion:** The study found TBC incidence was clustered in areas with high HIV prevalence, poor living conditions, and high population density, while healthy houses showed a dispersed pattern, highlighting the importance of prioritizing interventions, policy changes, and resource allocation.

ABSTRAK

Latar belakang: *Kabupaten Banyumas memiliki jumlah kasus TBC tertinggi kedua di Provinsi Jawa Tengah, pada tahun 2023, dengan total 7.060 kasus. Angka kejadian TBC meningkat sekitar 27,27% dari tahun 2022 ke tahun 2023. Meskipun berbagai upaya pengendalian TBC telah dilakukan, metode epidemiologi konvensional sering kali gagal menangkap pola spasial penularan penyakit, sehingga sulit mengidentifikasi hotspot lokal dan mengalokasikan sumber daya secara efektif.* ***Tujuan:*** *Penelitian ini bertujuan untuk menganalisis hubungan spasial antara prevalensi HIV, kepadatan penduduk, perilaku hidup sehat, dan kondisi perumahan dalam kaitannya dengan kejadian TB. Selain itu, penelitian ini juga bertujuan untuk mengidentifikasi titik-titik rawan tuberkulosis di Kabupaten Banyumas.* ***Metode:*** *Data tersebut diperoleh dari Sistem Informasi Tuberkulosis Kabupaten Banyumas pada bulan Agustus 2024. Jumlah pasien yang terdaftar yang berobat dan berdomisili di Kabupaten Banyumas pada tahun 2023 sebanyak 4.853 orang. Pola persebaran TBC dianalisis dengan menggunakan metode autokorelasi spasial melalui Indeks Moran dan Local Indicators of Spatial Associations (LISA).* ***Hasil:*** *Analisis menunjukkan adanya pengelompokan yang signifikan antara kejadian TBC dengan prevalensi HIV, perilaku hidup bersih dan sehat, dan kepadatan penduduk. Penyebaran yang signifikan terlihat pada rumah sehat. Khususnya, enam dari 27 kecamatan - Kembaran, Purwokerto Utara, Purwokerto Selatan, Purwokerto Timur, Sokaraja, dan Sumbang - menunjukkan adanya autokorelasi spasial lokal yang signifikan.* ***Kesimpulan:*** *Studi ini menemukan bahwa kejadian TBC mengelompok di daerah dengan prevalensi HIV yang tinggi, kondisi tempat tinggal yang buruk, dan kepadatan penduduk yang tinggi, sementara Rumah Sehat menunjukkan pola yang tersebar, menyoroti pentingnya memprioritaskan intervensi, perubahan kebijakan, dan alokasi sumber daya.*

INTRODUCTION

Tuberculosis (TB) is a chronic infectious disease and one of the leading causes of death (1). TBC is caused by the rod-shaped germ, *Mycobacterium tuberculosis* (MTB). The transmission medium for TBC disease is MTB carried in airborne particles, called droplet nuclei. Infectious droplet nuclei are produced when a person with pulmonary or laryngeal TBC coughs, sneezes, shouts, or sings (2). Through close contact, individuals with active tuberculosis can infect roughly 10 to 15 others annually (3).

According to the WHO Global Tuberculosis Report 2023, 7.5 million new tuberculosis cases were reported worldwide in 2022, the highest since WHO began monitoring in 1995. This increase is likely a result of diagnostic delays caused by the COVID-19 pandemic (4). In 2023, tuberculosis-related deaths decreased globally, continuing the downward trend seen in 2022. This decline followed two years of rising fatalities during the peak of the COVID-19 pandemic in 2020 and 2021. Despite this progress, tuberculosis has likely regained its status as the leading cause of death worldwide from a single infectious agent, surpassing COVID-19 (5).

Indonesia was one of the five countries with the highest tuberculosis burden, contributing 10% of the global cases in 2023. The majority of TB cases

worldwide occurred in 30 high-burden countries, which collectively accounted for 87% of all reported infections. Alongside India, China, the Philippines, and Pakistan, Indonesia played a significant role in shaping the global TB landscape (5). The number of tuberculosis cases in Indonesia surged to 821,200 in 2023, marking a significant rise from 677,464 cases recorded the previous year. The highest number of cases was reported from provinces with large populations, namely West Java, East Java, and Central Java (6). In 2023, the tuberculosis coverage rate in Central Java surpassed the national target, reaching 118% compared to the goal of 90% (87,074 TB cases found from the target of 73,856 TB cases) (7).

According to Banyumas Regency's TBC Information System (SITB), The number of TBC cases continue to increase each year, exceeding the estimated target cases set by the Indonesian Ministry of Health. The highest gap was found in 2023, where the target case finding set by the Indonesian Ministry of Health was 3,256 cases. However, the cases found exceeded the Indonesian Ministry of Health target by more than double the target, namely 7,139 cases (219.26%). This number includes patients from outside the district who seek treatment here (8).

The dynamics of TBC transmission have been influenced by the increase in population mobility resulting from socio-economic development and urbanization, as well as the continued presence of risk factors such as HIV infection, diabetes, smoking, and malnutrition (9). Among these, HIV coinfection is one of the most significant risk factors for developing active TB in high-burden settings (10). This can raise the risk of TBC reactivation for individuals with latent TBC and increased vulnerability to primary infection or reinfection (11).

A study conducted by Emilia et al. (12) revealed that significant clustering of TBC incidence was associated with population density (p-value= 0.001) and the practice of personal hygiene and sanitation or clean and healthy living behavior (p-value=0.047). These finding highlights the role of crowded living conditions in facilitating the transmission of TBC bacteria and underscores the importance of personal and environmental hygiene in preventing TBC transmission.

Despite ongoing TB control efforts, the incidence of the disease continues to rise, particularly in areas with high cases of HIV, high population density, poor, unclean, and unhealthy living behavior, and inadequate housing conditions. To better understand the spatial distribution of TB and associated risk factors, spatial analysis is applied to identify disease hotspots, detect geographic clusters, and assess environmental influences such as population density and housing quality. This study evaluates the geographical autocorrelation between HIV prevalence, population density, clean and healthy living behavior, and healthy houses with the incidence cases of spreading TBC and identify TBC hotspots in Banyumas Regency. By pinpointing high-risk areas, this research provides actionable insights for stakeholders to prioritize interventions and allocate resources more effectively, ultimately reducing the TBC burden in Banyumas Regency.

METHODS

Design Study and Ethics

This research is an analytic observational research with an ecological study design that utilizes aggregate data analysis across 27 subdistricts in Banyumas Regency to examine the spatial patterns of tuberculosis (TB) cases recorded in 2023. It has been approved by the Ethics Committee of the Faculty of Medicine, Universitas Negeri Semarang, under exemption number 379/KEPK/FK/KLE/2024.

Population and Sample

The study population includes all registered TB cases in Banyumas Regency in 2023, totaling 4,853 patients. Data were collected from 27 subdistricts within the region.

Data Collection

Data related to health conditions, such as TBC cases, HIV cases, healthy houses, and clean and healthy living behavior, were obtained from the Banyumas District Health Office. Meanwhile, population density data were obtained from the Banyumas Central Agency of Statistics Office.

Variables

The dependent variable in this study is TB case data, with independent variables including HIV cases, the number of healthy houses, clean and healthy living behavior, and population density.

Statistical Analysis

Spatial autocorrelation analysis was performed using GeoDa Software, while map generation was conducted using QGIS version 1.22.0.6. Global Moran's Index and Local Indicators of Spatial Association (LISA) were used with queen contiguity weighting to evaluate spatial distribution

patterns. The Moran's Index values indicate whether spatial autocorrelation is positive ($0 < I \leq 1$), negative ($-1 \leq I \leq 0$), or nonexistent ($I = 0$). Spatial relationships are categorized into four quadrants, which are Quadrant I or HH (High-High), Quadrant II or LH (Low-High), Quadrant III or LL (Low-Low), and Quadrant IV or HL (High-Low). The analysis included the Bivariate Moran's Index and the BiLISA Cluster Map to identify disease clusters and distribution patterns. A pseudo p-value of ≤ 0.05, based on 999 permutations, was used as a significance threshold in spatial autocorrelation analysis.

RESULTS

There are 3 of 4 variables that have significant positive spatial autocorrelation (positive z score and pseudo p-value < 0.05) between subdistricts in Banyumas Regency with a clustered pattern (I>E[I]) on TBC cases: HIV prevalence, clean and healthy living behavior practices, and population density. These variables are interconnected in neighboring subdistricts, while the the healthy houses variable has a dispersed pattern since it shows negative autocorrelation.

Table 1
Global Moran's Index Analysis Results

Variables	I	E[I]	Pseudo p-value	Mean	SD	Z-value	Pattern
HIV Prevalence	0.29	-0.04	0.009	-0.03	0.11	2.93	Clustered
Clean and Healthy Living Behavior Practices	0.32	-0.04	0.001	-0.01	0.09	3.64	Clustered
Healthy Houses	-0.17	-0.04	0.025	0.01	0.09	-2.04	Dispersed
Population Density	0.52	-0.04	0.001	-0.02	0.98	5.53	Clustered

Fig.1(a) shows that twelve subdistricts have spatial interactions between HIV and TBC cases. Subdistricts in High-High quadrant are Kembaran, South Purwokerto, East Purwokerto, Sokaraja, and Sumbang. These five regions have high rates of TBC cases and are encircled by high rates of TBC cases which is associated to HIV cases. North Purwokerto, on the other hand, is in the Low-High quadrant. This indicates North Purwokerto has fewer TBC cases than the neighboring subdistricts, where this condition is linked to HIV cases. In addition, Wangon is in the High-Low quadrant. Wangon's high TBC case rate means that nearby subdistricts need to be careful. Banyumas, Kemranjen, Somagede, Sumpiuh, and Tambak subdistricts are in the Low-Low quadrant. All five regions have low TBC cases and surrounded by areas with low TBC cases associated with HIV cases.

Fig.1(b) shows twelve subdistricts with spatial interactions between population density and TBC cases. Subdistricts in the High-High quadrant are Kembaran, South Purwokerto, East Purwokerto, Sokaraja, and North Purwokerto. These five regions are areas with high TBC cases and surrounded by high TBC cases, where this condition is related to population density. Meanwhile Sumbang is in the Low-High quadrant. This indicates Sumbang has fewer TBC cases than the neighboring subdistricts, where this condition is related to Population Density. In the Low-Low quadrant, there are Wangon, Banyumas, Kemranjen, Somagede, Sumpiuh, and Tambak subdistricts. All these six regions have low TBC cases and surrounded by areas with low TBC cases related to population density.

Fig.1(c) shows that twelve subdistricts have spatial interactions between clean and healthy living behavior and TBC cases. Subdistricts in the High-High quadrant are Kembaran, South Purwokerto, Sokaraja, North Purwokerto, and Sumbang. These five regions have high rates of TBC cases and are encircled by high TBC cases, which are associated with clean and healthy living behavior. Meanwhile, East Purwokerto is in the Low-High quadrant. This indicates that East Purwokerto has fewer TBC cases than the neighboring subdistricts, where this condition is related to clean and healthy living behavior.

Furthermore, Wangon and Tambak are in the High-Low quadrant. Wangon and Tambak have high TBC cases, so neighboring subdistricts must be careful. In the the Low-Low quadrant,, there are Banyumas, Kemranjen, Somagede, and Sumpiuh subdistricts. All these four regions have low TBC cases and are surrounded by areas with low TBC

cases associated with clean and healthy living behavior.

Fig.1(d) shows that twelve subdistricts have spatial interactions between healthy houses and TBC cases. Subdistricts in High-High quadrant are North Purwokerto, East Purwokerto, and Sumbang. These three regions are areas with high TBC cases and surrounded by high TBC cases where this condition is related to healthy houses. Meanwhile, Kembaran, Sokaraja, and South Purwokerto are in the Low-High quadrant. This indicates those subdistricts have fewer TBC cases than the neighboring subdistricts, where this condition is related to number of Healthy houses.

Furthermore, Wangon, Tambak, Banyumas, and Somagede are in the High-Low quadrant. These subdistricts have high TBC cases, so neighboring subdistricts must be careful. In the the Low-Low quadrant, there are Kemranjen and Sumpiuh subdistricts. These two regions have low TBC cases and are surrounded by areas with low TBC cases related to the number of healthy houses.

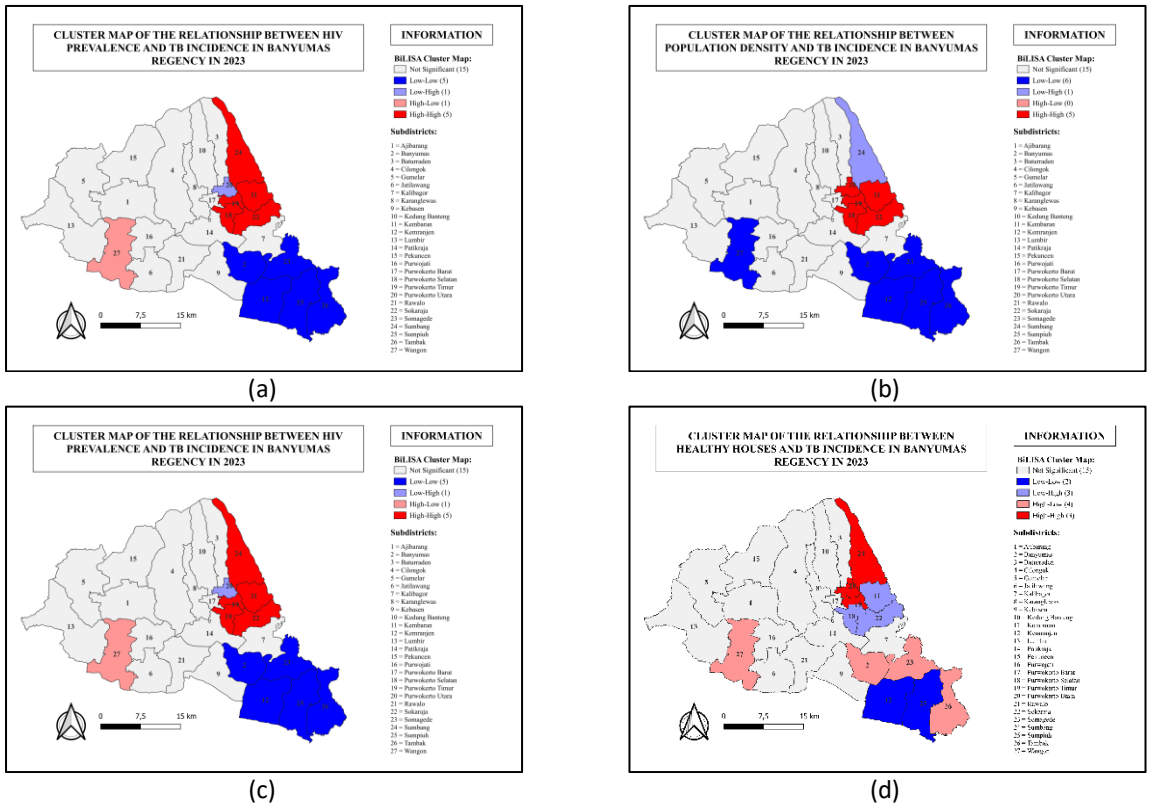

Figure 1. (a) Cluster map of the relationship between HIV prevalence and TBC incidence; (b) Cluster map of the relationship between Population Density and TBC incidence; (c) Cluster map of the relationship between Clean and Healthy Living Behavior with TBC incidence; (d) Cluster map of the relationship between Number of Healthy Houses and TBC incidence in Banyumas Regency 2023

DISCUSSION

The research indicates that there is a correlation between HIV, clean and healthy living behavior, healthy houses, and population density, and the spread of TBC cases in Banyumas Regency in 2023. However, healthy houses have negative Moran's Index, which means that the lower the number of healthy houses in a region, the higher the rate of TBC cases. Local autocorrelation is used to determine which locations have similar risk values and to support modeling in estimating relative risk (13).

The Relationship between HIV Prevalence with TB Incidence

Research done by Lilian et al. (14) showed that People Living with HIV (PLHIV) have a higher prevalence of TBC infection, even with near-universal access to antiretroviral therapy (ART) and TBC preventive therapy (TPT). PLHIV are 20 times more likely to develop active TBC than those without HIV. (15) There was a study done by Nadia

et al (16) in Banyumas Regency that showed a relationship between the number of HIV/AIDS cases and the number of BTA+ pulmonary TBC cases, with a positive correlation coefficient value of 0,38 in 2021. This means that the more the number of HIV/AIDS cases in an area, the more the number of BTA+ pulmonary TBC cases will increase. HIV significantly impacts TBC incidence due to the weakened immune systems of HIV-positive individuals. Research done by Maulana et al. (17) also showed HIV had spatial correlation with TB. Geospatial analysis can identify areas with high HIV prevalence, which often correlate with higher TBC cases. By mapping these areas, public health officials can prioritize interventions such as facilitating access to TBC preventive treatment for TBC control, community-based awareness programs, contact tracing, and equitable access to treatment for vulnerable populations to reduce the dual burden of HIV and TBC (18,19).

The Relationship between Clean and Healthy Living Behavior with TB Incidence

Clean and healthy living behavior practices variable is also shows correlation with the spread of TBC cases in Banyumas Regency in 2023. Poor, clean, and healthy living behavior of the host can increase the risk of pulmonary tuberculosis (20). Research done by Emilia et al. (12) showed that Clean and Healthy Living Behavior has a significant relationship with rates of TBC cases in West Java Province. Another research conducted by Noerhalimah (21) showed that there is a relationship between households with good hygiene practices and the incidence of BTA+ pulmonary TBC in districts/cities in West Java. Good hygiene practices can reduce the transmission of TBC bacteria. For instance, covering the mouth when coughing and regular handwashing can prevent the spread of TB. Awareness and practice of personal hygiene can lead to early detection and treatment of TB, reducing its spread. Areas with poor clean and healthy living behavior practices are more susceptible to TBC transmission (22). Geospatial tools can highlight regions with low clean and healthy living behavior adherence, enabling targeted educational campaigns and interventions to improve hygiene practices and reduce TBC spread.

The Relationship between the Number of Healthy Houses and TB Incidence

Healthy houses and the spread of TBC cases indicates correlation between them in 2023. Affordability and quality aspects of inadequate housing were associated with TBC exposure (TB bacilli inhalation), incidence, and treatment adherence (23). Healthy houses with proper ventilation and sanitation reduce the risk of TBC transmission. Good air circulation helps disperse TBC bacteria, lowering the chance of infection. Adequate housing conditions, including sufficient space and cleanliness, also contribute to lower TBC incidence. Inadequate housing, characterized by overcrowding, poor ventilation, and lack of sanitation, creates an environment conducive to TBC transmission. Poor housing is often associated with low socio-economic status, which can limit access to healthcare and increase vulnerability to TBC (24). A study reported that healthy houses were related to the incidence of TBC in Campurdarat Subdistrict (25).

The Relationship between Population Density and TB Incidence

Population density also correlates with the spread of TBC cases in Banyumas Regency in 2023. TBC incidence was positively associated with higher population density. In densely populated areas, the proximity of individuals facilitates the transmission of TB. This is particularly true in urban settings where people live and work in close quarters. Population density is a well-known risk factor for TBC transmission due to the increased likelihood of close contact and overcrowded living conditions. Geospatial analysis can identify densely populated areas where TBC transmission is more likely. These insights allow for targeted screening and treatment programs, reducing the overall TBC burden in these high-risk areas (18,26). In 2019, the urbanization rate in Banyumas Regency reached 51.34%, the proportion of the urban population reached 39.18%, and the identification of 144 urban villages that formed 26 urban agglomerations (27). This result aligns with studies from Zimbabwe, where TBC hotspots and clusters can be found in urban areas with large populations (28,29). Another study in West Java revealed a positive autocorrelation in TBC cases with population density, which showed a clustered pattern (30).

The application of georeferencing techniques offers a summary of the areas that need attention and should be given priority in the fight against tuberculosis. To develop and implement policies, strategic measures to stop the disease's spread, and identification of areas deemed at risk or with a higher concentration of TBC cases are crucial. Therefore, when it is identified that certain areas where the risk of TBC transmission is higher, top priority should be given to investigating and monitoring risk factors for transmission in these

areas, to prevent the spread of TB, geographical data could be leveraged to implement targeted and practical solutions at the district level such as pinpointing areas with higher transmission rate, mapping socio-economic factors to understand the underlying causes of TBC spread, and allocate resources to high-risk areas.

Therefore, stakeholders at all administrative levels need to concentrate on several key aspects to address and mitigate the spread of TB effectively. Some examples of programs or policies that can be carried out based on autocorrelation results are ensuring that high-risk areas have adequate healthcare facilities equipped to diagnose and treat TB, providing sufficient supplies of TBC medications and diagnostic tools to these areas, implementing regular TBC screening programs to detect cases early especially in high-risk or densely populations, getting used to use geospatial tools to continuously identify and monitor TBC hotspots, collaborating with local government and health authorities to implement TBC control measures, providing socio-economic support to TBC patients such as nutritional assistance and financial aid to improve treatment adherence, addressing houses conditions that contribute to TBC transmission such as overcrowding and poor ventilation, developing and implementing policies that specifically address the needs of high-risk areas, and organizing empowerment in the community. By focusing on these aspects, stakeholders can create a comprehensive and effective strategy to reduce TBC incidence in high-risk areas. Consequently, this study suggests better ways to implement TBC control policies in vulnerable populations, which adds to knowledge.

Research Limitations

This study has several limitations that should be acknowledged. The data used are incomplete, and some TBC risk factors were not analyzed, such as socio-economic status, environmental factors that may influence TB transmission, and migration patterns. Additionally, some of the data had many missing values, which could bias the results. Although the official sources used reflect the real situation, there may still be errors that could affect the findings. It is also important to recognize that TBC is influenced by various interacting risk factors, which can lead to complexities and inaccuracies. Future studies should use more comprehensive data sets.

CONCLUSION

This study found geographical autocorrelation between HIV prevalence, clean and healthy living behavior practices, population density, and healthy houses with the spread of TB cases. The spread of TB cases follows a clustered pattern based on HIV prevalence, population density, and clean and healthy living behavior. In contrast, a dispersed pattern is observed in relation to healthy houses. The findings illustrate the distribution of TB cases across subdistricts in Banyumas Regency, enabling appropriate treatment allocation for each area.

To prevent TBC cases from spreading to areas with low observation values and reduce the number of TBC cases, priority must be given to areas with high observation values, such as Kembaran, North Purwokerto, South Purwokerto, East Purwokerto, Sokaraja, and Sumbang. To identify patterns in fluctuations in TBC cases, both district and subdistrict levels can regularly examine the geographical data. This geographical data can be used to implement targeted and practical solutions at the district level.

CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

AUTHOR CONTRIBUTIONS

SD: Conceptualization, Methodology, Data Curation, Software, Formal Analysis, Visualization, Writing-Original draft; MF: Supervision, Writing- Reviewing and Editing; MSA: Writing- Reviewing and Editing; MM: Writing- Reviewing and Editing; DS: Writing-Reviewing and Editing; MR: Resources, Project administration

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