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MORALITY BEFORE KNOWLEDGE

Safe Breath: A concept for air quality monitoring app using internet of things and early detection to support Tuberculosis elimination by 2030

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ABSTRACT
Background: Tuberculosis (TB) remains a significant global health challenge, particularly in countries with poor air quality and high population density. Delayed diagnosis and environmental factors, such as air pollution, contribute to the high prevalence and mortality rates associated with this disease despite advancements in treatment and prevention. A review of the literature highlights a significant association between long-term exposure to air pollutants, such as delicate particulate matter ($PM_{2.5}$) and an increased risk of TB. Internet of Things (IoT) technology, which integrates real-time environmental sensors with analytical algorithms, offers the potential to support TB prevention through data-driven and modern technological approaches. This study aims to design a conceptual framework based on IoT technology to enhance early TB detection through air quality monitoring. **Methods**: A literature review was conducted from 2020 to 2025, focusing on designing the Safe Breath conceptual framework. Relevant articles were retrieved from databases including PubMed, ScienceDirect, and Google Scholar, filtered by inclusion criteria and full-text availability. Data were synthesized to explore the relationship between air quality and TB incidence. **Findings** Poor air quality is closely linked to TB risk, making environmental monitoring essential in disease control. IoT technology can collect real-time data through air quality sensors, monitoring environmental risk factors continuously. The Safe Breath application concept integrates air sensors with early detection features to improve TB screening accuracy while encouraging community participation in disease prevention efforts. **Conclusion**: The proposed Safe Breath application combines IoT technology with air quality monitoring and early detection systems, improving screening accuracy and proactive TB control through a community-based approach. **Novelty/Originality of this article:** This study presents a novel approach by integrating IoT technology and environmental monitoring for TB control. The combined use of air sensors and early detection tools offers a scalable, data-driven solution for global TB prevention.

KEYWORDS: air quality; early detection; internet of things; tuberculosis.

1. Introduction

Over the past century, Tuberculosis (TB) has been one of the most significant infectious diseases globally (Akbar et al., 2021). According to the World Health Organization (WHO) (2022), TB remains one of the leading causes of death worldwide from infectious diseases, second only to COVID-19. The WHO report (2024) highlights that this disease disproportionately affects populations in countries with a high TB burden. The report notes that in 2023, a total of 8.2 million people were diagnosed with TB, marking the highest

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global monitoring record since 1995. Some of the countries with the highest burden include India (26%), Indonesia (10%), China (6.8%), the Philippines (6.8%), and Pakistan (6.3%). Collectively, these five countries accounted for 56% of the total global TB burden. Furthermore, these countries also rank among the top nations with severe air pollution, such as India and Pakistan, which are in the top three, followed by Indonesia and China, which rank in the top twenty.

TB is an infectious disease caused by the bacterium *Mycobacterium tuberculosis* (Orgeur et al., 2024). TB infection generally spreads through air contaminated by the bacteria when an infected person coughs, talks, or sings (Syadzali, 2024). The bacteria can survive in the air for several hours depending on environmental conditions and are more likely to spread in crowded places with poor air circulation. Research has shown that long-term exposure to air pollution can weaken the immune system, making individuals more susceptible to TB infection (Findi & Juan, 2020). This phenomenon indicates that air pollution plays a significant role in exacerbating the spread of this disease. High levels of air pollution worsen respiratory conditions and increase vulnerability to TB transmission. Studies in several countries also support the claim that air pollution can heighten the risk of TB transmission. For example, research in China conducted by Li et al. (2024) found that long-term exposure to air pollutants significantly increases the risk of TB transmission. Similarly, research by Suyetno et al. (2023) concluded that there is a strong correlation between air pollution exposure and TB cases in Indonesia.

According to the report of WHO (2023a), Indonesia recorded 1,060,000 cases of TB, placing the country as the second-highest globally in terms of TB burden after India. The annual death toll of 134,000 due to TB underscores the severe threat posed by this disease (Rahma et al., 2024). This alarming situation has driven global efforts, spearheaded by WHO and various nations, including Indonesia, to commit to eliminating TB by 2030 as part of the Sustainable Development Goals (SDGs), particularly Goal 3, which focuses on good health and well-being (TB Indonesia, 2023).

Authorities and organizations actively implement various strategies and initiatives, including enhancing healthcare facilities, expanding screening programs, and advancing vaccine development. Despite ongoing prevention and control measures, delayed TB detection remains a significant challenge in combating this disease (Yayan et al., 2024). For example, delayed early detection is a major contributor to TB transmission in Pakistan (Khan et al., 2022). Delays in case detection often result in wider bacterial spread and increased mortality rates. Furthermore, the shortage of healthcare professionals and a lack of public awareness about the symptoms and transmission of TB also contribute to the rise in cases. Many patients fail to recognize that they have TB, as its symptoms often resemble those of other illnesses, such as a common cough or upper respiratory tract infections (Stop TB Partnership ID, 2023). Additionally, some patients delay seeking treatment due to a lack of knowledge about the disease. Therefore, early detection is crucial to reducing mortality rates, accelerating treatment, and preventing further transmission.

Early detection is one of the strategies that can aid in controlling TB (Pramono et al., 2023). Through early detection, treatment can begin earlier, improving treatment outcomes and reducing the risk of transmission to others. Early detection also facilitates the diagnosis of TB symptoms that resemble those of other diseases. However, the effectiveness of early detection is often hindered by limitations in existing healthcare systems and technologies. This underscores the need for developing and integrating new technologies to enhance the effectiveness and efficiency of early TB detection (Martiningrum et al., 2024). One promising technology for improving the efficiency of early TB detection is the Internet of Things (IoT) (Sari, 2024). IoT has transformed many aspects of daily life, and the healthcare sector has greatly benefited from its advancements. IoT refers to a network of physical devices connected to the internet that can collect and share data in real-time (Sawitri, 2023). In this context, IoT can be utilized to integrate air quality sensors in specific areas (Kirana, 2024). These sensors can continuously monitor parameters such as fine particulate matter concentrations ($PM_{2.5}$and PM_{10}), carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3), and humidity. The data collected by these sensors is transmitted via internet-connected networks to a centralized platform for analysis (Erwin et al., 2023). Additionally, this data can be combined with TB diagnosis data to identify correlations between air pollution exposure and medical conditions. This approach offers a more holistic understanding of the dynamics of TB transmission.

This technology enables more accurate and faster data collection, which can assist healthcare professionals in making better-informed decisions. Its advantages demonstrate that the implementation of IoT sensors in air quality management can have a significant impact on efforts to eliminate TB, particularly in developing countries like Indonesia, which face challenges of air pollution and high TB case rates. This technology not only helps detect environmental factors influencing TB transmission but also serves as a vital tool for preventing further spread by providing actionable air quality data. Such efforts align with the goal of eliminating TB by 2030. With proper integration, IoT holds the potential for sustainable infectious disease control while simultaneously improving the overall quality of life for communities.

2. Methods

This study uses a literature review method to formulate the conceptual framework for developing the Safe Breath application to support the early detection and elimination of tuberculosis (TB) using IoT. The literature was obtained from scientific databases such as PubMed, ScienceDirect, Google Scholar, and ProQuest using keywords like "air quality and TB correlation," "early detection of TB," and "role of IoT in healthcare." From the initial search, 30 articles per keyword were screened based on abstracts to assess relevance, resulting in 4 articles per keyword, which were then analyzed further.

The inclusion criteria include articles available in full-text format, with accessible abstracts, published on Open Journal Sources platforms, and published within the last five years (2020–2025). Preference was given to peer-reviewed articles to ensure the credibility of the findings. The analysis is conducted in three stages: (1) identifying relevant articles based on keywords and abstracts, (2) full reading to gather data on the correlation between air quality and TB, early detection of tuberculosis, and the role of IoT in healthcare, and (3) synthesizing the findings into thematic categories, focusing on the correlation between air quality and TB, the early detection of TB, and the role of IoT in healthcare.

This synthesis provided the foundation for designing the conceptual framework of the Safe Breath application, which integrates IoT technology, air quality monitoring, and machine learning algorithms for early detection of TB. To ensure the reliability of the conceptual framework, findings from the selected literature were cross-validated with similar studies. Potential biases in the literature were acknowledged during the synthesis process to improve the robustness of the framework. The outcome of this study provides a structured foundation for applying IoT technology in a health application that is data-driven and scalable to address TB prevention and elimination effectively

3. Results and Discussion

3.1 Literature findings synthesis

The search for articles in scientific databases relevant to the theme of the correlation between Air Quality and TB, the Role of IoT in Health, and Early Detection of TB resulted in 12 research samples meeting the inclusion criteria. These articles include studies from various countries, namely China, the United Kingdom, Peru, Iraq, Indonesia, Bangladesh, Switzerland, Pakistan, and Colombia. The diversity of research locations reflects the global attention toward TB as a significant health concern.

The research designs of the 12 samples used varied greatly, including General Additive Model, Systematic Review, Meta-Analysis, Spatial Analysis, Regression Statistics, Experimental, System Design and Development, Research Review, Comprehensive Review, Systematic Literature Review, Machine Learning-Based Experimental, Retrospective Using Machine Learning, and Expert System-Based Experimental. This variation demonstrates that the correlation between air quality and TB, the role of IoT in health, and early detection of TB are studied from diverse perspectives, both theoretical and practical.

These studies highlight the importance of a multidisciplinary approach in understanding the relationship between the three aspects under discussion, considering that TB is an infectious disease influenced by various factors, including the environment. The diverse research designs not only provide in-depth insights into epidemiological and ecological aspects but also serve as a foundation for developing more effective and measurable interventions to prevent and manage TB.

The results of the article search discussing the relationship between air quality and the risk of tuberculosis are presented in Table 1. These articles highlight air pollutants such as $PM_{2.5}$, PM_{10}, and carbon monoxide as environmental factors contributing to the increased prevalence of TB.

Table 1. Articles on the correlation between air quality and TB

No.	Author(s), Year	Country	Research Design	Research Focus
1.	Yang, et al., 2020	China	General Additive Model (GAM)	Exploring the relationship between air pollution ($PM_{2.5}$, PM_{10}, SO_2, NO_2, CO, and O_3) and the incidence of TB.
2.	Dimala & Kadia, 2022	United Kingdom	Systematic Review and Meta-Analysis	Determining the relationship between ambient air pollution ($PM_{2.5}$, PM_{10}, SO_2, NO_2, CO, and O_3) and the incidence, hospitalization, and mortality due to Pulmonary Tuberculosis (PTB).
3.	Carrasco-Escobar et al., 2020	Peru	Spatial Analysis and Regression Statistics	Studying the spatial relationship between TB incidence, poverty, and air pollution ($PM_{2.5}$) in Lima, Peru, and determining high- and low-risk zones.
4.	Khambali et al., 2024	Indonesia	Experimental	Analyzing the effectiveness of Cyclone Ventilator Modification (CVM) in improving indoor air quality, specifically in the homes of TB patients and those with Acute Respiratory Infections (ARI), to reduce transmission risks and improve environmental conditions.

Various studies have revealed a correlation between air quality and TB cases, with exposure to $PM_{2.5}$, PM_{10}, and SO_2 significantly increasing the risk of TB incidence by 12%, 6%, and 8%, respectively (Dimala &Kadia, 2022). A study conducted by Yang et al. (2020) in China, using a General Additive Model, found that exposure to air pollutants such as $PM_{2.5}$, PM_{10}, SO_2, NO_2, and can increase the risk of developing TB. The study revealed that a 10 $\mu g/m^3$ increase in $PM_{2.5}$ levels is associated with a 1,12 times higher risk of TB incidence (95% CI: 1.06–1.19). The effect of this exposure also exhibits a delayed response (lag effect), where the impact on new TB cases may appear several months after the initial exposure.

This relationship is not only observed in overall air quality but also within social and spatial contexts (Carrasco-Escobar et al., 2020). The study by Carrasco-Escobar et al. showed that areas with high poverty levels tend to have a higher number of TB cases, worsened by high $PM_{2.5}$ exposure. Additionally, indoor air quality also plays a significant role in the risk of TB transmission (Khambali et al., 2024). The study by Khambali et al. evaluated the effectiveness of the CVM technology to improve indoor air quality in the homes of TB patients and those with ARI. The research found that CVM was able to reduce $PM_{2.5}$ concentrations by 24.28%, while also lowering room temperature and humidity. This improvement in air quality creates an environment less conducive to the survival of TB bacteria, thus potentially reducing transmission risks.

On the other hand, the use of sensors connected to the internet network, through IoT technology, enables real-time air quality data collection, including detecting concentrations of pollutants such as $PM_{2.5}$, PM_{10}, SO_2, NO_2, CO, and O_3 (Buelvas et al., 2023). The development of IoT-based technology makes it easier to monitor air quality and offers an effective solution to prevent the increased risk of TB transmission. For example, a study by Narayana et al. (2022) demonstrated that IoT-based air quality monitoring systems, as prototypes for air quality surveillance, can integrate hardware and software to produce calibrated data. These systems are capable of providing up-to-date information about air quality, enabling communities to enhance awareness and take preventive actions.

Table 2 includes articles discussing the role of IoT technology in supporting healthcare systems. These articles highlight how IoT is used to monitor health risk factors through real-time data. This information supports faster, data-driven decision-making in public healthcare services.

Table 2. Articles on the role of IoT in healthcare

No.	Author(s), Year	Country	Research Design	Research Focus
1.	Mohammed & Hasan, 2023	Iraq	System Design and Development	Developing an application to monitor health conditions with the role of IoT.
2.	Rahman et al., 2022	Bangladesh	Research Review	A comprehensive analysis of the existing literature on the use of AI and IoT in the monitoring, detection, and control of infectious diseases such as COVID-19 and dengue in Bangladesh.
3.	Ajagbe, 2024	Switzerland	Comprehensive Review	A comprehensive literature review on the application of IoT technology and deep learning techniques in pandemic detection.
4.	Bolhasani et al., 2021	Swiss	Systematic Literature Review	Reviewing the implementation of deep learning in IoT for healthcare services, including disease prediction, diagnosis, treatment, and health informatics. Additionally, this study examines the challenges, opportunities, and practical applications of this technology in the medical field.

A study by Mohammed & Hasan (2023) explains that IoT is a manifestation of the rapid development of internet technology, which has seen significant growth in the field of Information Technology (IT) and plays a crucial role in healthcare. IoT is described as the ability of an object to transmit or send data through a network without the use of computers or human intervention. IoT has the capability to monitor health parameters, providing valuable information that serves as a foundation for effective decision-making by doctors.

The discussion on the role of IoT in healthcare was also conducted by Rahman et al. (2022) in Bangladesh. According to them, Bangladesh, being a country with a large population and low income, faces significant challenges in public health, facilitating the spread of diseases, particularly in controlling infectious diseases like COVID-19 and dengue. With the advancement of technology, Rahman et al.'s study proposed or suggested an IoT and Artificial Intelligence (AI)-based digital healthcare and surveillance system for deadly diseases like COVID-19 and dengue. The role of IoT is crucial in gathering necessary data and predicting future situations, thereby assisting the Ministry of Health in making effective decisions to control the situation.

Another study also highlights the crucial role of IoT in disease detection (Ajagbe et al., 2024). The study conducted by Ajagbe et al. in Switzerland, using a Comprehensive Review method, addresses an issue faced by infectious diseases such as COVID-19. The COVID-19 pandemic demonstrated that early detection and disease control require a fast, accurate, and scalable approach. However, traditional methods, such as manual laboratory tests, are often expensive, slow, and require significant human intervention.

IoT plays a vital role by collecting real-time data from smart devices, such as temperature sensors, oxygen saturation monitors, and heart rate detectors. This data is processed using deep learning, which can analyze patterns and trends in large datasets to detect disease symptoms, identify high-risk patients, and predict disease spread with high accuracy. The combination of IoT and machine learning enables automated systems that not only monitor patients in real-time but also offer accurate predictions based on big data. For example, the use of Long Short-Term Memory (LSTM) models integrated with IoT devices can provide early diagnosis without the need for lengthy manual examinations. This solution enhances the speed of public health response while ensuring timely and cost-effective treatment.

Another study also discusses the role of IoT in healthcare. The study by Bolhasani et al. (2021) states that IoT addresses issues similar to those identified in the study by Ajagbe et al., such as the current healthcare system facing various challenges, including inefficiencies in diagnosis and treatment, high dependence on human medical staff, and limited access to healthcare services, particularly in remote areas. Additionally, the increasing volume of health data requires a more integrated and automated approach to management.

Table 3 includes articles discussing various methods of early detection of tuberculosis. The approaches described include the use of expert systems, machine learning algorithms, and mHealth applications. These articles highlight how technology can improve access, accuracy, and efficiency in the TB screening process at the community level.

Table 3. Articles on early detection of TB

No.	Author(s), Year	Country	Research Design	Research Focus
1.	Karmani, at al., 2024	Pakistan	Experimental	Developing a TB prediction model based on machine learning using early symptoms, signs, and risk factors in patients.
2.	Orjuela-Canon et al., 2022	Kolombia	Machine Learning-Based Experimental Studies	Using machine learning algorithms to support tuberculosis diagnosis in healthcare facilities with limited resources, involving various predictive models to expedite the early detection process.
3.	Chen et al., 2024	China	Retrospective Studies Using Machine Learning	Developing a TB prediction model for patients with HIV using structured electronic health record data and LSTM-based machine learning algorithms for early detection and more precise clinical intervention.
4.	Dewi et al., 2024	Indonesia	Expert System-Based Experimental Studies	Developing an expert system for early detection of TB spread, relying on clinical symptom data input by users to reduce the number of TB cases in the community.

Early detection of tuberculosis is a crucial element in global efforts to control the disease (WHO, 2021). A study by Dewi et al. (2024) in Indonesia developed a rule-based expert system with an IF-THEN logic approach to classify patients as suspected TB or non-suspected TB. The expert system approach has long been used as an early screening method for TB, relying on clinical symptom data input by either patients or healthcare providers.

The variables used include cough for more than two weeks, prolonged fever, and weight loss. This system is designed to support community screening processes with direct assessments of the symptoms reported by patients.

Expert systems support symptom-based screening by providing direct assessments of the symptoms reported by patients. While expert systems are effective for supporting symptom-based screening, this approach has limitations in handling large, complex datasets, necessitating further development. The advancement of technology opens opportunities to integrate expert systems with more sophisticated machine learning algorithms. These technologies enable deep data analysis, including interactions between clinical variables, health history, and other risk factors, leading to more accurate predictions (Adewole et al., 2022). A study by Karmani et al. (2024) in Pakistan, for example, adopted algorithms like Decision Tree and Neural Network to detect potential TB disease spread cases using clinical symptom data such as chronic cough, night sweats, and prolonged fever. The developed AdaBoost model achieved an accuracy of 93.42%. Another study by Orjuela-Canon et al. (2022) in Colombia utilized Random Forest, Logistic Regression, and Multilayer Perceptron (MLP) algorithms to perform TB screening in healthcare facilities with limited resources. Among the various models tested, the MLP algorithm showed the best performance with an AUC value of 0.84.

A study by Chen et al. (2024) in China used the LSTM algorithm to predict the risk of TB spread in patients with HIV, utilizing immunological parameters, laboratory results, and health history analyzed longitudinally. This model achieved an AUC of 0.85, demonstrating the significant potential of integrating longitudinal data in the early detection of tuberculosis.

Future innovations also include the integration of machine learning technology with wearable devices to automatically detect symptoms such as chronic cough or prolonged fever. Additionally, the use of IoT technology to monitor environmental risk factors, such as air quality, can complement the screening process. This combination allows for the development of systems that are not only accurate but also proactive in detecting and preventing the spread of TB. Thus, modern technologies like machine learning and IoT not only enhance the accuracy of screenings but also contribute to achieving the global TB elimination target by 2030.

3.2 Development of a safe breath conceptual framework

The use of mobile health (mHealth) technologies in the early detection of TB disease has become an increasingly adopted approach in the global health system (Htet et al., 2023). Studies have shown that mHealth can improve access to screening for diseases including TB through technology-based methods that are more accessible at the community level (Osei & Mashamba-Thompson, 2021). Research by Rahayu et al. (2022) developed the SIKRIBO application, an mHealth platform designed to assist health cadres in detecting cases of TB disease spread in Semarang, Indonesia. This application utilizes clinical symptom data such as cough, fever, and weight loss as the basis for initial screening which is directly input into the application. This study shows that the use of mHealth technology can expand the coverage of early detection of TB disease with easy access and integrated educational features.

Another study, a systematic study conducted by Mudzengi et al. (2024) assessed the effectiveness of mHealth technologies in infectious disease detection, including TB, in several African countries. The study identified various mobile app, SMS, and Geography Information System (GIS) based approaches applied in contact tracing and case detection. The results showed that the application of mHealth technologies contributed to accelerating the case reporting process, although most of the studies reviewed had not been conducted on a large scale with long-term evaluation methods.

Based on the findings from both studies, the application of mHealth has been shown to have the potential to support the early detection of TB disease. The Safe Breath app was designed by combining mHealth concepts that have been reviewed in previous literature with a more innovative technological approach. Safe Breath extends the concepts introduced by SIKRIBO by combining symptom-based screening features and risk factors with the use of real-time case distribution maps. Furthermore, Safe Breath integrates IoT-based air quality sensors capable of detecting air pollutant levels and uses machine learning algorithms to improve accuracy. The use of machine learning and IoT integration in Safe Breath reflects an effort to overcome the limitations of rule-based expert systems that only rely on static data and are limited to certain symptoms. This approach enables more complex data analysis with higher accuracy, thus supporting more comprehensive early detection of TB disease.

Safe Breath is a mobile-based application designed to increase awareness, monitoring, and prevention of TB disease through the integration of IoT air sensor technology and self-detection features. The app provides up-to-date information on TB disease, early detection of TB disease, and mapping of TB disease distribution. It also provides location-based and air quality notifications to help app users take appropriate and quick preventive steps.

The Safe Breath application is designed with a user-friendly interface accessible to people from diverse backgrounds. The process begins with account registration, where users provide basic information such as their name, age, and location, or connect using their personal email, Microsoft account, or Apple ID. After registration, the application directs users to the homepage, where they can immediately access its four main features: the alert feature, TB screening feature, TB distribution map feature, and education feature, as shown in Fig. 1. Through these features, the Safe Breath application aims to enhance public health monitoring systems, bridge information gaps, and raise awareness about the importance of early TB detection. This initiative contributes to achieving the goal of eliminating TB in Indonesia by 2030 (Farhana et al., 2022).

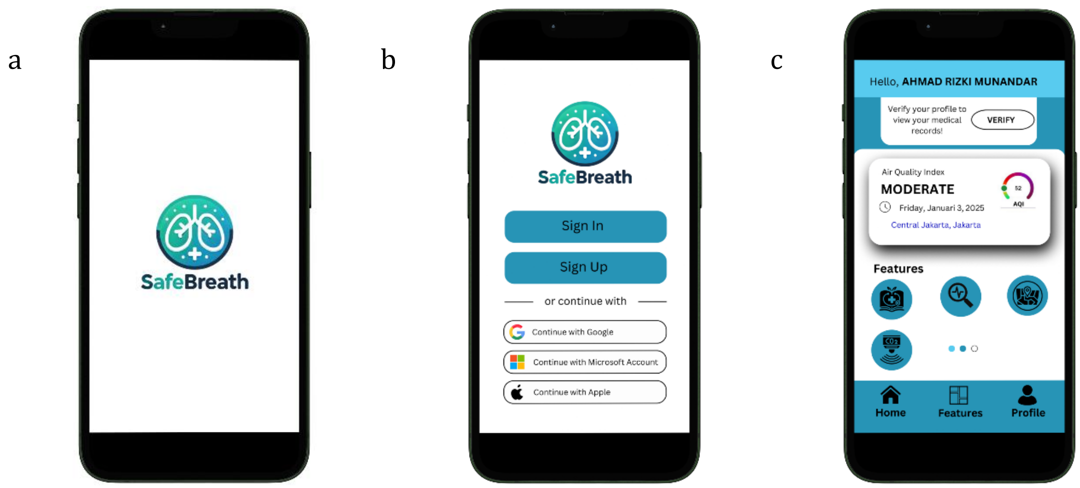

Fig. 1. Safe breath application view; (a) application logo; (b) application list page; (c) home page

The navigation of the Safe Breath application is designed to be intuitive, with a user-friendly interface ensuring that users can quickly locate and utilize the various features available without difficulty. The Safe Breath application is crafted with a user-centric design, making it accessible to individuals from diverse backgrounds, including those who may not be familiar with advanced technology (Floresia, 2023). The features developed in this application include the following.

3.2.1 Alert Feature

This feature is developed by integrating IoT technology into air quality sensors to detect and monitor air quality in real-time. The air quality is measured based on the Air Pollution Index (API). The air quality parameters monitored include pollutants that can increase TB transmission, such as $PM_{2.5}$, PM_{10}, SO_2, NO_2, CO, and O_3 (Wang et al., 2022). IoT sensors collect this data continuously and transmit it to the system, where it is processed using algorithms to assess air quality levels and their potential impact on TB transmission risks.

Studies have shown that air pollution, particularly fine particulate matter ($PM_{2.5}$), can exacerbate respiratory tract infections (WHO, 2023b). This highlights the critical role of real-time air quality monitoring in preventing diseases like TB. When users enter high-risk zones characterized by poor air quality and high TB case rates, the sensors enable the application to send automatic notifications. These alerts are accompanied by actionable recommendations, such as wearing masks, avoiding crowded areas, or relocating to environments with better air quality (Fig. 2).

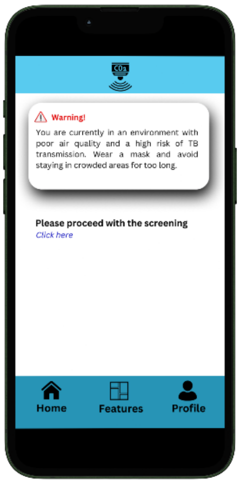

Fig. 2. Alert feature page view

Beyond individual notifications, the data collected by these IoT sensors can serve broader public health goals. For instance, aggregated air quality and TB data can be analyzed to identify high-risk areas and guide policy decisions for resource allocation or environmental interventions. This feature not only empowers individuals to take preventive actions but also supports health authorities in implementing targeted strategies to reduce TB transmission. Additionally, the system's adaptability makes it suitable for deployment in regions with varying TB prevalence and air quality challenges, offering a scalable solution to global TB control efforts.

3.2.2 TB screening features

The TB Screening feature in the Safe Breath application is a self-assessment tool designed to help users evaluate their initial risk of TB infection. This feature integrates various aspects, including user demographic characteristics, specific risk factors, and TB symptoms, which are systematically presented in Table 4. The screening process is user-friendly, with step-by-step guidance to assist users in completing the questionnaire, as illustrated in Fig. 3.

Table 4. TB Risk and symptom screening questionnaire

Category	Variable	Option
Characteristics Demographic	Age	Child (≤ 15 years), Adult (> 15 years)
	Nutritional status	Very thin, Thin, Normal, Overweight, Obese
Risk factors	History of TB contact	Never, Household contact, Close contact
	Ever diagnosed/treated for TB	Yes, no

	Ever treated for TB but not completed	Yes, no
	Malnutrition	Yes, no
	Smoking	Yes, no
	Passive smoker	Yes, no
	History of Diabetes	Yes, no
	People with Human Immunodeficiency Virus (HIV)	Yes, no
	Elderly (> 65 years)	Yes, no
	Pregnant	Yes, no
Symptom	Cough (all forms, regardless of duration)	Yes, no
	Coughing up blood	Yes, no
	Weight loss without a clear cause	Yes, no
	Fever that comes and goes without a clear cause	Yes, no
	Night sweats without activity	Yes, no
	Lethargy or malaise	Yes, no

The process includes several stages: collecting demographic information from users, where basic details such as age, gender, and region of residence are provided, which are essential to determine risk levels based on the prevalence of TB in specific populations; assessing risk factors, by gathering information about known risk factors, such as close contact with TB patients, smoking history, malnutrition, or underlying health conditions like diabetes or HIV; and symptom screening, where users report common TB symptoms, such as prolonged cough, weight loss, fever, and night sweats.

The collected data is then analyzed using ML algorithms trained on large datasets to provide an initial assessment of the likelihood of TB infection (Mishra, 2022) For users identified as high-risk, the application provides access to educational materials about TB prevention and recommends further actions, such as visiting a healthcare facility for additional tests, to help prevent the wider spread of the disease.

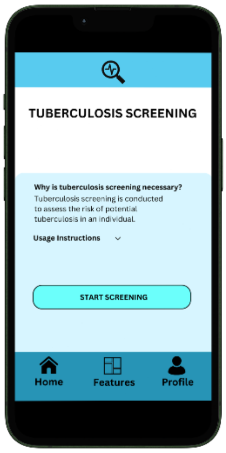

Fig. 3. TB screening feature page view

3.2.3 Interactpuslive TB risk map feature

The Safe Breath application features an interactive map designed to provide real-time visual information about TB risk zones. These zones are categorized into three levels of risk high, moderate, and low based on a combination of TB case density data and air quality parameters. The map is updated periodically to ensure that the information provided remains relevant and up-to-date. Through this feature, users can understand the potential risks in a specific area and take appropriate preventive measures.

The visualization of risk zones, as shown in Fig. 4, helps users gain a clearer understanding of disease transmission patterns. This interactive map serves as a practical guide for reducing the risk of transmission, such as wearing masks, avoiding crowded areas, or seeking locations with better air quality. Additionally, the mapping feature allows users to track their travel history to identify whether they have passed through high-risk zones. This data can be utilized to support more in-depth analyses and assist in planning more targeted interventions.

Fig. 4. Map features page view

3.2.4 Education Feature

The Safe Breath application offers a comprehensive educational feature, providing users with up-to-date information about TB, including definitions, causes, prevention, and treatment options, as illustrated in Fig. 5. This educational content is designed to be accessible to a wide audience by utilizing various formats, such as text for detailed explanations, graphics for visual representation of data and trends, and videos for dynamic and interactive learning. These diverse formats ensure inclusivity, reaching not only literate individuals but also those with limited literacy or those who prefer audio-visual learning methods.

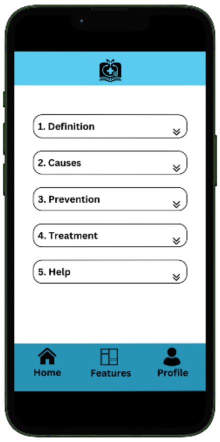

Fig. 5. Educational feature page display

The information provided is curated to raise awareness about TB and encourage proactive preventive actions. For example, users can learn about high-risk behaviors and environmental factors contributing to the spread of TB, as well as simple yet effective prevention measures such as wearing masks, improving ventilation, and seeking early medical treatment (Chakayaa et al., 2021). This feature also includes updates on the latest developments in TB treatment, government health programs, and global campaigns aimed at eliminating TB, ensuring users remain informed about the resources available in their communities.

3.3 Implications and Challenges

The Safe Breath application holds great potential in raising public awareness about TB. By providing detailed information on symptoms, transmission modes, treatment, and prevention in various formats such as text, graphics, and videos, the application is designed to make TB-related issues more accessible to people from diverse backgrounds. Improved knowledge is expected to help users recognize symptoms early, seek appropriate treatment, and prevent disease transmission (Tumuhimbise, 2021). The anticipated positive impact includes a reduction in transmission rates and new TB cases within the community (Marwah et al., 2024).

The application is also expected to significantly contribute to controlling TB transmission, particularly in high-risk areas. With its interactive mapping feature based on real-time data, the application is designed to highlight risk zones by integrating air quality and TB case density data. A study by Wang et al. (2021) demonstrated that real-time interactive mapping effectively helps communities understand environmental risks and take necessary preventive measures. Integration with IoT sensors allows the application to send notifications to users when they enter areas with a high risk of TB transmission. This fast and accurate information aims to encourage users to take preventive actions, such as wearing masks or avoiding crowded areas, thereby reducing the potential for further transmission (Tarmizi, 2024).

The Safe Breath application has the potential to be further developed, providing significant benefits to the healthcare system, particularly in reducing the number of new TB cases. Through its educational features to enhance public awareness and early detection capabilities, it is expected that individuals infected with TB will promptly receive treatment. This not only aims to reduce TB-related mortality but also to alleviate the burden on healthcare facilities. The application is designed to support national strategies in achieving TB elimination by 2030, aligning with global targets for reducing the impact of infectious diseases.

One of the primary strengths of Safe Breath lies in its use of IoT technology for real-time air quality monitoring. The IoT sensors integrated into the application are designed to provide users with immediate information on pollution levels and other environmental parameters influencing TB risk. These real-time notifications are expected to encourage communities to take preventive measures, such as wearing masks or avoiding crowded areas. This technology is proposed to enhance public awareness and responsiveness toward their environmental and health conditions proactively. However, the successful implementation of this application requires strategic analysis, such as a Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis. The innovation's strengths include leveraging IoT technology and efficient early detection to prevent TB transmission. The risk zone information and educational content provided by the application are expected to raise public awareness and vigilance. Weaknesses include the high costs of development, provisioning, and maintenance of infrastructure, as well as the limited technological literacy among certain community groups. Opportunities include integrating the application with national health programs in various countries and securing financial support from international organizations such as the WHO or global health initiatives. However, threats include the digital infrastructure disparities in remote areas and sensor performance disruptions caused by extreme weather conditions that could damage the equipment.

The challenges in implementing this application concept span various aspects, from IoT technology and machine learning to application deployment. At the IoT technology level, the primary challenges include the availability of adequate network infrastructure, particularly in remote areas, and the resilience of sensors to extreme weather, which can affect the accuracy of air quality measurements (Jabbar et al., 2022). Additionally, the application of machine learning faces obstacles such as the availability of high-quality data required to optimally train the model and limited computational resources in areas with low technological infrastructure (Singh et al., 2022). At the application level, challenges include low digital literacy, especially in areas with limited technological access, which can reduce the effectiveness of the application (Hernandez-Ramos et al., 2021). Addressing these challenges requires cross-sector collaboration among governments, academics, and technology providers to ensure that the application can be implemented widely and deliver maximum benefits.

The Safe Breath application offers an innovative solution to enhance awareness, control, and prevention of TB through IoT technology and data-driven approaches. However, as a concept, challenges in implementation, such as infrastructure limitations and technological literacy, must be addressed with well-planned strategies and cross-sectoral support to fully realize the application's potential.

4. Conclusions

The Safe Breath application concept offers an innovative technology-based approach to support global TB control. By integrating IoT technology for air quality monitoring, machine learning-based early detection, and health education, this application is designed to provide an effective and scalable multidisciplinary solution. This data-driven approach not only enhances the accuracy of TB risk identification but also promotes proactive preventive behavior within the community.

The key features of this application include real-time air quality monitoring, mapping of TB risk zones, self-screening for early detection, and educational content accessible to users from diverse backgrounds. The use of IoT sensors enables the collection of air pollution data, such as $PM_{2.5}$, PM_{10}, and SO_2, which is combined with machine learning algorithms to provide risk-based recommendations. This system allows users to take immediate preventive measures to avoid TB transmission. Additionally, the application expands health monitoring coverage through interactive visualization of risk zones, designed based on real-time data on air pollution levels and TB case density. With this information, users can understand disease transmission patterns and choose appropriate actions to reduce the risk of infection. Furthermore, the educational features, available in various formats such as text, graphics, and videos, ensure that the public can easily access relevant information about TB prevention and treatment in a user-friendly manner.

However, the optimal implementation of Safe Breath requires cross-sector support, particularly to address challenges such as limited technological infrastructure, low digital literacy, and reliance on IoT devices that may be affected by environmental factors. This solution also necessitates collaboration with governments, health organizations, and the global community to ensure the availability of adequate resources and funding.

Further research is needed to evaluate the effectiveness of Safe Breath on a larger scale, particularly in regions with a high TB burden. With a holistic approach and strategic support, this application has the potential to become a key tool in achieving the target of TB elimination by 2030, in line with the Sustainable Development Goals (SDGs). Safe Breath not only addresses global health challenges but also establishes a new paradigm in technology-based infectious disease control.

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