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Worldwide Spatial and Temporal Distribution of Tuberculosis (TB)

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Abstract

Background: A detailed analysis of the spatio-temporal correlation of the yearly geo-referenced data indicated that the information obtained through such analysis can contribute to more effective in budget allocation, drug distribution and recruitment of human skilled resources, as well as guiding the design of vaccination programs. Hence, the current literature review was conducted to show the global spatial and temporal distribution of TB and importance of research regarding worldwide spatial and temporal distribution of tuberculosis in TB control programs.

Objective: The purpose of the literature review was to assess the worldwide spatial and temporal distribution of tuberculosis.

Methods: The literature review was done through identification and evaluation of a range of different types of sources including academic and professional journal articles, books, and web-based resources. Search engines were used to search web resources and bibliographic databases following aspects of the process associated with the production of a literature review such as evaluating information sources, searching and locating information resources, developing conceptual framework and mind mapping, and writing the literature review. In addition, references which had themes in common were grouped together. Finally, reflections on the findings of the literature review were made.

Results and Conclusions: There is sufficient evidence about the existence of significant high-rate space and time TB clustering and spatial variability across study regions. Significant clustering of TB was seen in "TB Epidemic" and hyperendemic "hotspots" often characterized by crowding, HIV infection, unemployment, and other social determinants. General development measures which were correlated with TB incidence trends varied geographically. People movement also found to be another risk factor indicating difference in TB occurrence among countries. The information obtained could contribute to more effective budget allocation, drug distribution and recruitment of human skilled resources, as well as guiding the design of vaccination programs.

Keywords: TB; MDR-XDR TB; Spatio-temporal distribution; Clustering; GIS

Abbreviations: CAR: Conditional Auto Regressive; DOTS: Directly Observed Treatment Strategy; Drug: Drug Resistance Tuberculosis; GIS: Geographic Information System; MDGs: Millennium Development Goals; MDR-TB : Multidrug - Resistant Tuberculosis; MTB: Mycobacterium Tuberculosis; OR: Odds Ratio; TB: Tuberculosis; WHA: World Health Assembly; WHO: World Health Organization

Background

Tuberculosis (TB) is an infectious disease caused by the bacillus Mycobacterium tuberculosis [1]. Mycobacterium tuberculosis (MTB) is a pathogenic bacterial species in the genus Mycobacterium and the causative agent of most cases of tuberculosis. Primarily, it is a pathogen of the mammalian respiratory system, MTB infects the lungs and is the causative agent of tuberculosis [2]. It typically affects the lungs (pulmonary TB) but can affect other sites as well (extrapulmonary TB). The duration of tuberculosis from onset to cure or death is approximately 3 years and appears to be similar for smear-positive and smear-negative tuberculosis [3].

Global targets for reducing the burden of disease caused by TB have been set within the context of the Millennium Development Goals (MDGs). One is to halt and reverse the incidence of TB by 2015. The additional targets set by the Stop TB Partnership are to halve TB prevalence and death rates by 2015 [4,5], compared with their levels in 1990, and eliminate TB as public health problem by 2050 [5]. Indicator 23 (prevalence and death rates) and indicator 24 (the proportion of cases detected and cured under a directly observed treatment strategy) (DOTS) are used to measure progress towards this goal [6]. For indicator 24, as part of WHA resolution, in 1991, the World Health Assembly (WHA) highlighted two indicators: 70% global and in-country new smear positive cases detection rates and successful treatment of 85% of such cases by the year 2000 [7-9]. Later on, in 1994, WHO introduced the internationally recommended control strategy, DOTS (Directly Observed Treatment Short-Course) [10] and was implemented in 182 countries [11]. Despite these and availability of highly efficacious treatment for decades, tuberculosis (TB) causes approximately 2 million deaths each year [12], and remains a major and devastating global health problem [1,13,14], and greatest public health challenges of our time [1,13,15]. Of nine million new tuberculosis cases each year [5,12,13], nearly half a million are multidrug-resistant tuberculosis (MDR-TB).

The dynamics of infectious diseases depends on the spatial distribution of pathogens and hosts, and the probability of an encounter between them. The transmission of infectious pathogens from infected to susceptible hosts declines with increasing distance between individuals. TB, like many infectious diseases, is prone to spatial

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aggregation or clustering [16,17]. A cross-sectional study indicated that GIS-based screening can effectively penetrate populations with high disease burden and poor healthcare access. Linkage to care remains challenging and will require creative interventions to impact morbidity [18]. And as TB is known to cluster in hyperendemic "hotspots" often characterized by crowding [16,19], HIV infection [20], and other social determinants [21], new approaches, such as mapping and spatial analysis, may be of value in contributing to basic elements of TB control [22].

The benefits obtained from analyzing the spatial and temporal distribution of tuberculosis in revealing and clarifying processes, structures, etc. and ultimately, its merit of supporting spatial decision-making, and to serve as a tool for assisting with regional planning and the formulation of government policies. Though a few researches were conducted at global level on the spatial and temporal distribution of TB, systematic review of the global spatial and temporal distribution and its importance in planning and implementing TB control programs is not yet done. Hence, the current literature review was intended to show the importance of research regarding the spatial and temporal distribution of tuberculosis at global level.

Methods

The literature review begun by naming and describing tuberculosis and then establishing to show the importance of studying the spatio – temporal distribution of TB to be investigated and perhaps by others. Next, a topic-by-topic description of relevant research related to global spatio – temporal distribution of TB was conducted. Also, references which had something in common were grouped together. The results of the research were included. Finally, conflicts or disagreements in the literature were pointed out.

Identification and location of information sources

The literature review was done through identification and evaluation of a range of different types of sources including academic and professional journal articles, books, and web-based resources. The literature search helped in the identification and location of relevant documents and other sources. Search engines were used to search web resources and bibliographic databases. Hence, the subsequent sections briefly explore the following aspects of the process associated with the production of a literature review: evaluating information sources, searching and locating information resources, developing conceptual framework and mind mapping, and writing the literature review.

Evaluating information resources: The first and main source searched for the purpose of this literature review, was academic and professional literature, articles in scholarly and research journals with firmer theoretical basis, with more critical treatment of concepts and models were considered; those articles which were designed to record and distill systematically researched knowledge in the area, and have typically been peer refereed prior to acceptance for publication. In addition, scholarly and research journals that have reviewed articles and provide a review of all of the recent work in the area of tuberculosis epidemiology with special emphasis on spatio – temporal distribution of tuberculosis. Such reviews included a significant bibliography that had an invaluable source of reference to other work in the area of tuberculosis. Finally, Professional and practitioner journal articles which were useful in identifying recent developments or topical themes in context, policy, legal frameworks, and technological advances were also considered. Another source that, actually not widely searched, was consulted in the literature search was books, standard texts, which include bibliographies or lists of references to other useful sources. Finally, web based resources that were easy to locate through simple searches in standard search engines were searched.

Searching and locating information resources: The following tools were utilized to assist in the identification and location of documents such as library catalogues, search engines and on-line databases.

Developing conceptual frameworks and mind mapping: By constructing computer based concept map, key concepts from the collected documents regarding the spatial and temporal distribution of tuberculosis were identified. Hence, the tool was used to identify additional search terms during the literature search, clarify thinking about the structure of the literature review in preparation for writing the review and understand theory, concepts and the relationships between them. The concept map is a diagram of the issue under study, and represents the concepts in that area and the relationships between them. Concepts are represented by labeled boxes, and relationships are represented by lines. Figure 3 shows concept map for the spatial and temporal distribution of tuberculosis literature review.

Writing the literature review: Five steps in the creation of the literature review were followed: scanning documents, making notes, and structuring the literature review, writing the literature review, and building the bibliography.

Evaluating the sources and documents: The following criteria were considered in evaluating the sources and documents review:

- Relevant to the topic;
- The frequency of update
- The publishing organization
- Links or references to other relevant web, electronic, or print sources
- License or payment necessary for access to the resources
- Up-to-date, as signaled by the publication date;
- Published by a reputable publisher in the discipline;

Results on Literature Review

Globally, many studies have been conducted and documented the spatial and temporal public health importance of tuberculosis. The following summarizes the literature review on the issue.

Spatial and temporal variation

Many studies have dominated the importance studying the geographic variation of TB clustering. For instance, a spatial analysis of tuberculosis in Greater Banjul, Gambia, showed significant high- and low-rate spatial and space–time clusters in two districts [22]. Another spatial epidemiology and spatial ecology study of worldwide drug resistance tuberculosis indicated the presence of marked spatial variability across study regions [23]. In addition, spatio temporal patterns of multidrug-resistant and drug-sensitive tuberculosis in a South American setting indicated spatial aggregation of patients with confirmed MDR in which cases with confirmed MDR disease were found to be more tightly grouped. Subgroup analysis by the study suggested the appearance of resistance that may be driven by increased transmission [24]. Finally, a study concluded the presence of sufficient evidence about the existence of statistically significant tuberculosis clusters in Almora district of Uttaranchal, India, by showing significant high rate spatial and space-time clusters in three areas of the district [25].

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Clustering in endemic and hyperendemic areas

The spatial epidemiology and spatial ecology study of worldwide drug-resistant tuberculosis have also shown the presence of significant clustering of TB in "TB Epidemic" [23]. Similarly, another study in Portugal showed spatiotemporal clustering of tuberculosis incidence hyperendemic "hotspots" often characterized by crowding [16,19], HIV infection [20], and other social determinants [21]. This finding was supported by study in HIV endemic settings which found that populations with clustering of respiratory contacts experience aggregation of TB cases and high numbers of re-infection events [26]. In addition, another study also pointed out high-incidence hotspots could play an important role in propagating TB epidemics [19].

Global burden of tuberculosis

Data in parentheses are 95% uncertainty intervals. Adapted from the 2013 GBD study [27] (Tables 1 and 2).

Table 1 shows a summary at the global and regional level of the ARCs for age-standardised rates of incidence, prevalence, and deaths for tuberculosis in individuals who are HIV-negative.

Figure 1 shows the temporal changes of tuberculosis incident case

	Annualised rate of change (%)		
	2000–2013		
	Incidence	Prevalence	Mortality
Worldwide	−0·60 (−0·73 to −0·50)	−1·31 (−1·41 to −1·20)	−3·72 (−4·42 to −2·99)
High-income Asia Pacific	0·11 (−0·06 to 0·27)	0·13 (−0·18 to 0·40)	−5·03 (−5·85 to −3·99)
Central Asia	−0·76 (−0·92 to −0·58)	−0·68 (−0·85 to −0·50)	−4·97 (−5·83 to −4·07)
East Asia	−2·08 (−2·36 to −1·85)	−3·16 (−3·44 to −2·86)	−7·54 (−8·53 to −6·63)
South Asia	−1·06 (−1·30 to −0·80)	−2·43 (−2·65 to −2·20)	−4·22 (−5·64 to −2·89)
Southeast Asia	−0·54 (−0·68 to −0·42)	0·12 (−0·03 to 0·28)	−3·61 (−4·42 to −2·82)
Australasia	−0·22 (−0·41 to −0·03)	−0·36 (−0·66 to −0·08)	−3·63 (−4·62 to −2·62)
Caribbean	−0·20 (−0·35 to −0·05)	−1·15 (−1·32 to −0·98)	−3·93 (−4·93 to −2·50)
Central Europe	−1·61 (−1·74 to −1·50)	−0·29 (−0·42 to −0·17)	−5·95 (−6·43 to −5·27)
Eastern Europe	−0·58 (−0·80 to −0·39)	−0·75 (−0·97 to −0·53)	−4·80 (−7·62 to −3·91)
Western Europe	−1·18 (−1·28 to −1·08)	−0·64 (−0·78 to −0·52)	−4·88 (−5·53 to −3·78)
Andean Latin America	−0·81 (−1·04 to −0·54)	−0·78 (−1·06 to −0·52)	−4·86 (−5·88 to −3·78)
Central Latin America	−1·69 (−1·83 to −1·55)	−1·51 (−1·67 to −1·35)	−4·21 (−4·74 to −3·03)
Southern Latin America	−2·56 (−2·75 to −2·39)	−1·56 (−1·78 to −1·32)	−3·35 (−4·03 to −2·70)
Tropical Latin America	−1·27 (−1·50 to −1·08)	−0·68 (−1·04 to −0·36)	−4·33 (−5·36 to −3·47)
North Africa and Middle East	−1·10 (−1·18 to −1·03)	−1·26 (−1·35 to −1·16)	−4·58 (−5·34 to −3·89)
High-income North America	−3·32 (−3·55 to −3·10)	−2·28 (−2·57 to −1·97)	−4·14 (−5·14 to −1·90)
Oceania	0·77 (0·60 to 0·98)	0·14 (−0·09 to 0·37)	−2·96 (−4·58 to −0·91)
Central sub-Saharan Africa	0·07 (−0·12 to 0·28)	−0·17 (−0·41 to 0·06)	−3·41 (−4·67 to −1·99)
Eastern sub-Saharan Africa	−0·34 (−0·52 to −0·16)	−0·38 (−0·57 to −0·20)	−3·08 (−4·12 to −2·40)
Southern sub-Saharan Africa	0·14 (−0·26 to 0·54)	−0·09 (−0·41 to 0·28)	−4·12 (−5·91 to −2·91)
Western sub-Saharan Africa	−0·57 (−0·73 to −0·39)	−0·69 (−0·86 to −0·49)	−3·09 (−3·84 to −2·17)

Table 1: Age-standardised tuberculosis without HIV incidence, prevalence, and mortality rates and annualized rates of change for both sexes for 21 Global Burden of Disease regions.

	Annualised rate of change (%)	
	2000–13	
	Incidence	Deaths
Worldwide	−0·60 (−0·73 to −0·50)	−372 (−442 to −2·99)
Developed countries	−1·18 (−1·30 to −1·07)	−4·94 (−6·29 to −4·37)
Developing countries	−0·91 (−1·04 to −0·80)	−4·01 (−470 to −329)
High-income Asia Pacific	0·11 (−0·06 to 0·27)	−5·03 (−5·85 to −399)
Brunei	−1·23 (−1·74 to −0·68)	−365 (−5·51 to −1·69)
Japan	−273 (−3·02 to −243)	−4·61 (−5 98 to −2·71)
Singapore	−1·24 (−1·54 to −0·93)	−5·48 (−6·99 to −382)
South Korea	0·90 (0·68 to 1·10)	−553 (−6·78 to −4·31)
Central Asia	−0·76 (−0·92 to −0·58)	−4·97 (−5·83 to −4·07)
East Asia	−2·08 (−2 36 to −1·85)	−7·54 (−8·53 to −6·63)
China	−2·32 (−2·62 to −2·07)	−7·77 (−8·79 to −6·88)
North Korea	1·74 (1·42 to 2·07)	−3·11 (−5·25 to −0·71)
Taiwan (Province of China)	0·05 (−0·23 to 0·29)	−6·30 (−8·07 to −4·41)

Data in parentheses are 95% uncertainty intervals.

Table 2: Tuberculosis without HIV incidence and deaths for all ages by sex and annualised rates of change for 21 Global Burden of Disease regions and 188 countries. Adapted for the 2013 GBD study [27]

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numbers, the number of prevalent cases, and the number of deaths from 1990 to 2013. Total tuberculosis numbers are shown as well as numbers for tuberculosis in individuals who are HIV-negative.

Figure 2 shows maps of age-standardised incidence rates and death rates for tuberculosis in individuals who are HIV-negative in 2013.

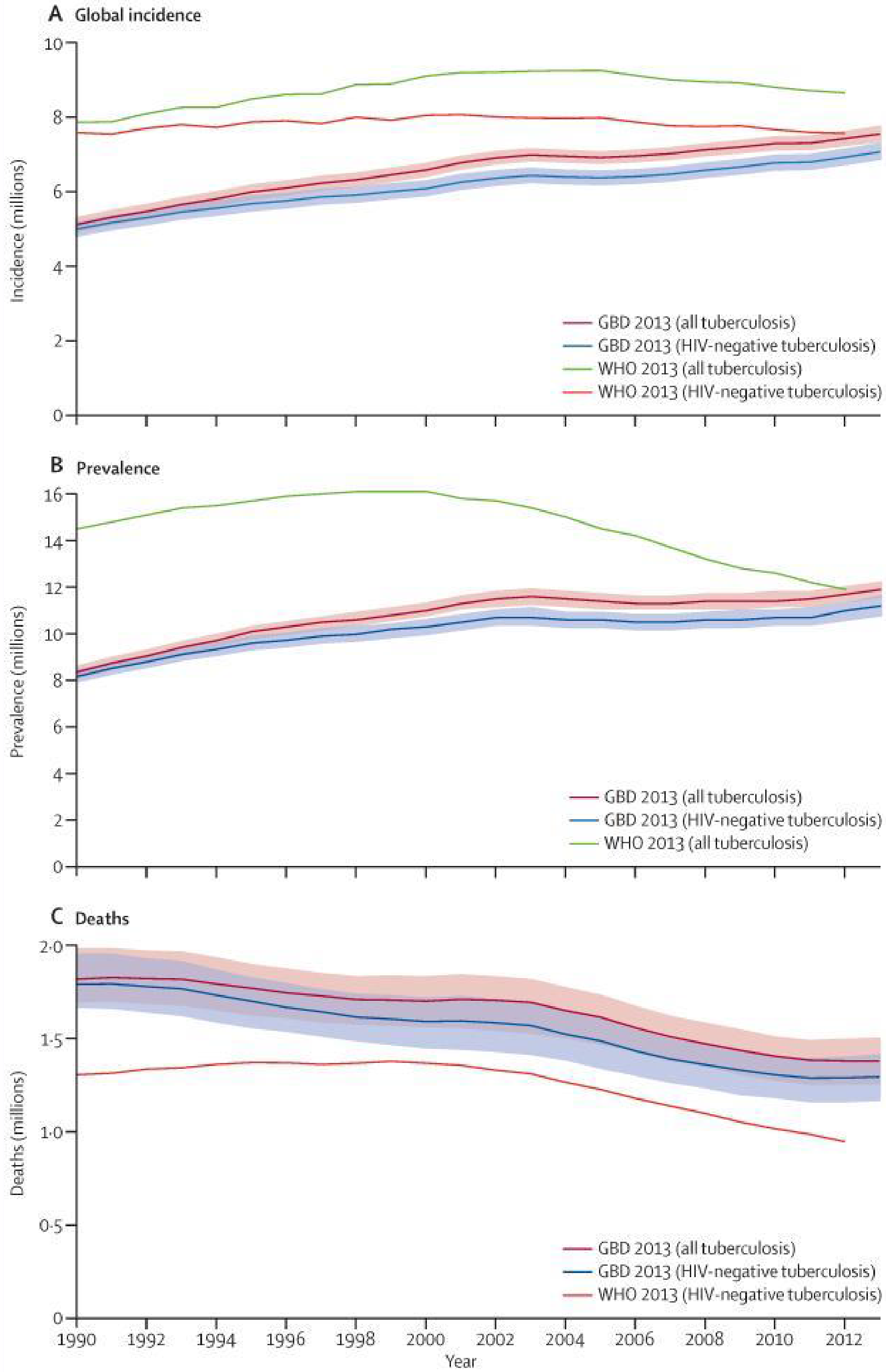

Figure 1: Global tuberculosis incidence (A), prevalence (B), and deaths (C), 1990-2013, for all ages and both sexes combined [27]. Shaded areas show 95% uncertainty intervals. Adapted from the 2013 GBD study.

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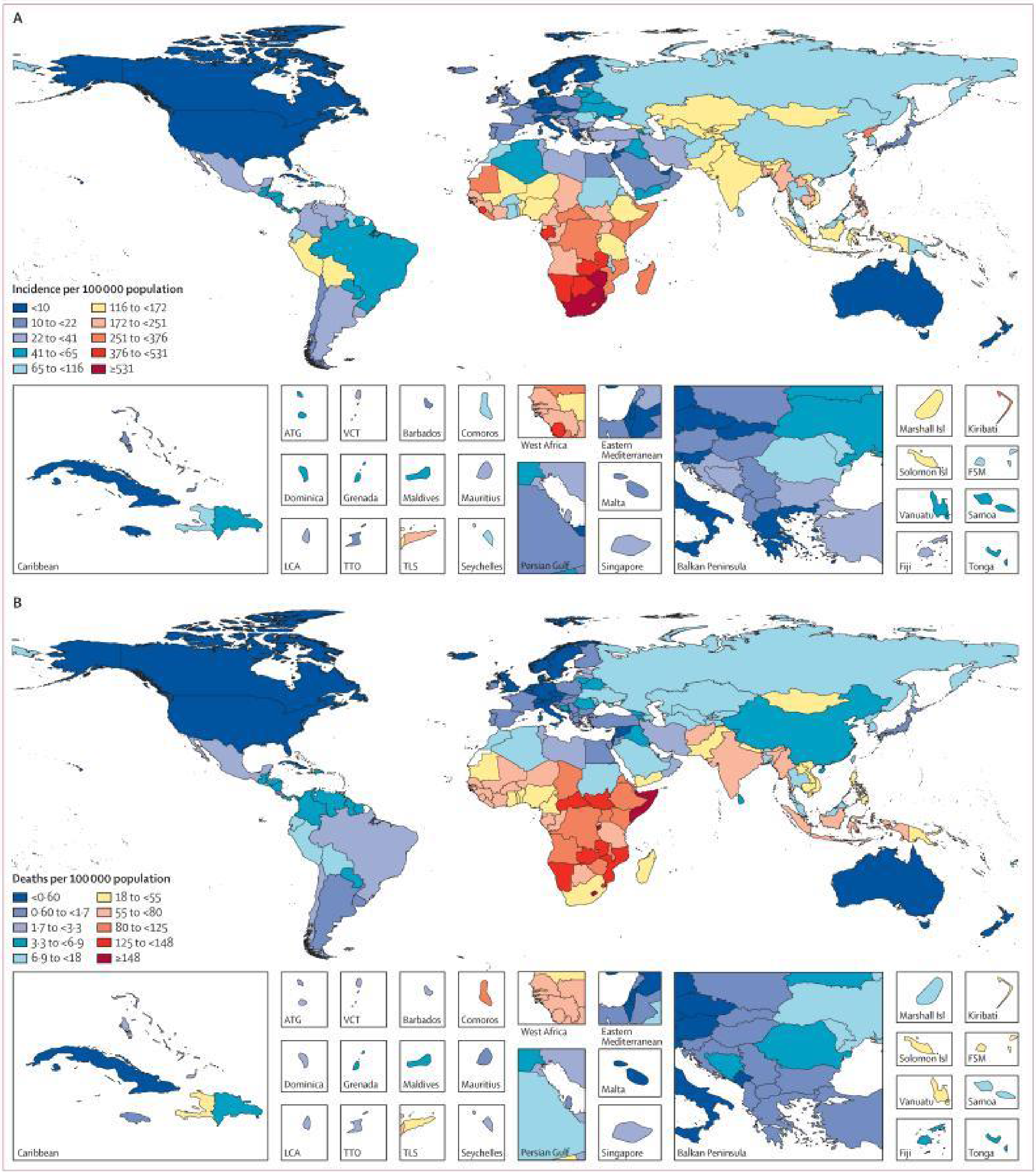

Figure 2: Age-standardised tuberculosis incidence (A) and death rates (B) in HIV-negative individuals in 2013, both sexes [27].

Socio economic determinants

A spatial analysis tuberculosis transmission patterns in a high-incidence area found high tuberculosis notifications with unemployment and its associated poverty having the strongest association with spatial clustering [19]. A study in Antananarivo City indicated that the change in risk of a TB cluster was linked to socio-economic (e.g. household amount of ownership of tap water) and patient care factors (e.g. patients

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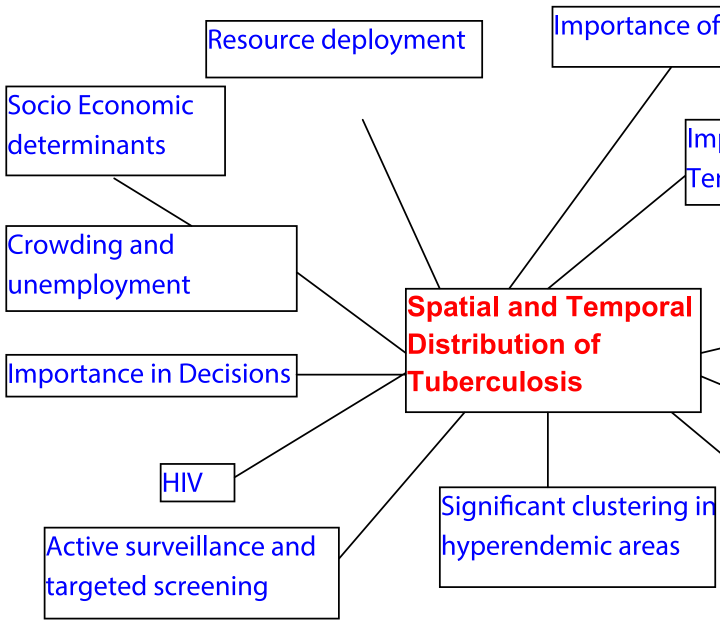

Figure 3: Concept Map relating to Spatial and Temporal Distribution of Tuberculosis.

lost to follow-up) [28]. For instance, Bayesian anlsysi of the patio-temporal patterns of tuberculosis incidence in Ribeireao Preto, Sao Paulo, southeast Brazil, demonstrated that the rate of TB was correlated with the measures of income, education and social vulnerability. The study also observed areas with low vulnerability and high education and income, but with high estimated TB rates [29].

In addition, significant associations of tuberculosis notifications were found with overcrowding [19,30] and the epidemic being most extreme in slum areas [31]. General development measures were also dominant explanatory variables within regions, though correlation with TB incidence trends varied geographically [32]. For instance, mortality due to TB has been declining and incidence was diminishing or stabilizing in all world regions except sub-Saharan Africa and, to some extent, eastern Europe [9].

Population dynamics such as migration as factor

People movement also found to be another risk factor indicating difference in TB occurrence among countries. For instance, travel to the country of origin was a risk factor for TB among Moroccans, but not among Turkish people living in the Netherlands. The difference in travel-associated odds ratio (OR) between these two immigrant groups is probably related to differences in TB incidence in these countries [33]. Another study in Beijing on the impact of new migrant populations on the spatial distribution of tuberculosis found that the increasing migrant population has had a drastic influence on the spatial distribution of TB in Beijing. Spatial analysis could provide additional information in addition to common incidence plots [34]. Generally, a decrease was observed with movement to the South. For example, the study in Antananarivo City showed a decrease in clustering with movement towards the southern neighborhood [28]. Another Bayesian conditional auto regressive model for mapping tuberculosis prevalence in India figured out that northeastern states having higher risk of tuberculosis than other regions [35].

Importance of active surveillance and targeted screening

A study indicated that spatial and temporal information may be useful for targeting testing when access is limited [36] as in a cross sectional geographic information system-based screening for TB, HIV, and Syphilis (GIS-THIS) participants reported high-risk characteristics [18]. And the information that prevalence of infection among household contacts of people with tuberculosis is will guides active case finding [37]. Targeted screening program for discovering persons with TB and LTBI exceeded what would be expected from non targeted screening in a county with a TB incidence of 5.7 per 100,000 population [38]. Systematic characterization of the spatio-temporal distribution of TB cases can widely benefit real time surveillance and guide public health investigations of TB outbreaks as to what level of spatial resolution results in improved detection sensitivity and timeliness [39]. Improved diagnostic and curative efforts need to be combined with additional preventive efforts [30]. Using GIS and spatial scan statistic indicated that spatial scan statistics methodology used to have a potential use in surveillance of tuberculosis for detecting the true clusters of the disease [25].

Importance of resource allocation and deployment

It has been shown that the information obtained could contribute to more effective budget allocation, drug distribution and recruitment of human skilled resources, as well as guiding the design of vaccination programs [40]. For instance, a spatial analysis in Gambia showed that systematic use of cluster detection techniques for regular TB surveillance could aid effective deployment of resources [22].

Importance of spatial and temporal analysis of TB distribution to help national TB control programs

The spatial pattern highlight the importance of the data recorded in the TB registry and the use of spatial approaches for assessing the epidemiological situation for TB [41] and local heterogeneity of effectiveness as a result of the complex patterns of disease transmission within communities should be expected [26]. Dynamic analysis allowed to trace the temporal path of the aetiological agent, locate the sources of infection, and characterize the dynamics of disease spreading thereby pointing out the information obtained could contribute to more effective budget allocation, drug distribution and recruitment of human skilled resources, as well as guiding the design of vaccination programs [40]. Using GIS and spatial scan statistic it was indicated that spatial scan statistics methodology used to have a potential use in surveillance of tuberculosis for detecting the true clusters of the disease [25]. High-incidence hotspots may play an important role in propagating TB epidemics [19]. For example, a study showed that genotyping combined with geographic information systems analysis can potentially be used to define high-risk status and to define areas for location-based TB screenings [38].

Importance of regional DR-TB monitoring planning and prevention and control strategies

Spatial variability in latent synthetic risk factors on drug resistance tuberculosis (DR-TB) indicated the need for formulating regional DR-TB monitoring planning and prevention and control strategies, based on the spatial characteristics of the latent synthetic risk factors and spatial variability of the local relationship between DR-TB and latent synthetic risk factors [23]. For example, the spatial pattern of TB in Antananarivo and the contribution of national control program indicators to this pattern highlight the importance of the data recorded in the TB registry and the use of spatial approaches for assessing the epidemiological situation for TB. These findings may also be useful for guiding decisions related to disease control strategies [41].

In summary, new approaches, such as mapping and spatial analysis, may be of value in contributing to basic elements of TB control [22]. And spatial analysis is proved to be more useful for studying spread of tuberculosis analysis and modeling of disease analysis [31]. It was also indicated that the Bayesian CAR method is proved to be a useful tool for disease modeling of tuberculosis [35].

Conclusions

There is sufficient evidence about the existence of statistically significant high-rate space and time TB clustering in most researched areas. There also was spatial variability across study regions. Significant clustering of TB was seen in "TB Epidemic" and hyperendemic "hotspots" often characterized by crowding, HIV infection, unemployment, and other social determinants. General development measures were also dominant explanatory variables within regions, though correlation with TB incidence trends varied geographically. People movement also found to be another risk factor indicating difference in TB occurrence among countries. Spatial and temporal information may be useful for targeting testing when access is limited.

The information obtained could contribute to more effective budget allocation, drug distribution and recruitment of human skilled resources, as well as guiding the design of vaccination programs. Spatial variability in risk factors on DR-TB indicated the need for formulating and planning regional DR-TB control strategies.

New approaches, such as mapping and spatial analysis, may be of value in contributing to basic elements of TB control. And spatial analysis is proved to be more useful for studying spread of tuberculosis analysis and modeling of disease analysis. Scan statistics methodology used to have a potential use in surveillance of tuberculosis for detecting the true clusters of the disease.

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