Correspondence

Bayesian model, ecological factors & transmission of leprosy in an endemic area of south India

Sir,

The goal of elimination of leprosy as a public health problem as defined by the World Health Assembly *i.e.* attaining a level of prevalence of less than one case per 10,000 population, was reached at the global level in 2000[1]. Although India officially declared elimination of leprosy as a public health problem in 2005, 1.27 lakh new leprosy cases were reported in India during 2013-2014[2]. Interactions between *Mycobacterium leprae,* and the human host and dynamics of its transmission are still not clear. Evidence suggests that the degree of vulnerability of the individual, the extent of exposure and associated environmental factors could potentially influence the transmission. Complete understanding of ecological and environmental components may unfold the gaps in knowledge regarding the mode of transmission of leprosy.

A leprosy vaccine trial from south India[3] provided an opportunity for such an ecological exploration. The entire population [covering 148 *Panchayats* (Rural Administrative Units) comprising 264 contiguous villages from Chingleput district, Tamil Nadu, south India] was screened for leprosy before vaccination. After screening the population, a proportion (5%) was randomly allotted to "blinded" senior officers for quality control. Skin smear examination for detecting acid fast bacilli was done for all suspects and definite cases. A team of independent clinicians visited the field at frequent intervals to monitor the procedures for diagnosis of leprosy. The data collected were validated in many ways with the earlier surveys[4]. Hence, the quality of data collected was remarkable and comparable to world standard as certified by the independent assessment committee consisting of national and international experts[3]. The definitions used are explained in detail elsewhere[5]. Also in the study area, leprosy cases were observed to be geographically clustered. We investigated environmental correlates of leprosy taking into account the spatial dependency using Bayesian model.

Chingleput district in Tamil Nadu State in south India covers an area of 1277 sq km with the minimum and maximum temperatures ranging from 14 to 21°C and 28 to 45°C, respectively. It has an average rainfall of 1200 mm/year and the Normalized Difference Vegetation Index (NDVI) ranging from -0.28 to +0.25[6]. Data from 264 contiguous villages (population size: 300,000) from two *taluks* (sub-district level administrative unit) in leprosy endemic Chingleput district, were used in the Bayesian model. Total 2098 new leprosy cases (1269 males and 829 females) identified in this population in 2001 have been considered.

We employed a Bayesian model with and without spatial random effect using openBUGS[7] software and included demographic data (gender, age, economically higher/poorer strata, and household contacts) as well as environmental and ecological data [rainfall data from Famine Early Warning System (FEWS)[8] of South East Asia; Average Day Land Surface Temperature (DLST) and the mean NDVI from Moderate Resolution Imaging Spectroradiometer (MODIS)][9].

For NDVI, rainfall and DLST monthly data for 2001, with a spatial window extent area (12°N - 14°N and 79°E - 81°E) at a resolution of 250 meters that includes the two *taluks* of south India, were extracted. Annual average for each of the covariate was calculated for each of the data location.

We have assumed that the leprosy status of a respondent at a specified location takes a value of 1 if positive and 0 otherwise, and follows a Bernoulli

distribution. Spatial and non-spatial models were compared using the Deviance Information Criterion (DIC)[10], being a generalization of the Akaike's Information Criterion in the Bayesian framework, *i.e.* lower the DIC values better the model. The spatial model with DIC=52,230 outperformed.

It was observed (Table I) that male gender (relative risk, RR=1.08; 95% credible interval, CI=1.04-6.36), household contacts (RR= 1.26; 95% CI=1.24-1.30) and higher NDVI (denser vegetation) (RR=1.07; 95% CI=1.02-7.98) were significantly related to the risk of leprosy. Age, economic status, DLST and rainfall were not related with the risk of leprosy.

The spatial variation being more compared to non-spatial variation and the range of influence parameter was 250 meters (Table II). The range parameter $3/\xi$ had a posterior median of 0.25; 95% CI 0.02-0.29. This corresponds to a minimum distance of 250 metres for which the spatial correlation becomes

negligible. This indicates a strong spatial correlation in the dataset.

Gender and household contacts have been associated with leprosy. Observations made in earlier studies support soil, humidity, vegetation, water, arthropods and armadillos as possible environmental sources/reservoirs of leprosy[11,12]. Results of an Ethiopian study[13] suggest that vertical transmission is not the only mean of acquiring leprosy and viability of *M. leprae* outside the human body, and the thermal-hydrologic environment also contributes.

Though our study was based on leprosy patients in 2001, they were newly identified and diagnosed patients and not old and prevalent cases. We used corresponding geo-spatial and environmental data of 2001. The significant association observed between NDVI and leprosy cases in Chingelpet district of Tamil Nadu in south India provides additional evidence supporting the role of environmental factors in leprosy

Table I. Median relative risk of leprosy with the factors for two *taluks* in south India, 2001

Covariate	Non-spatial model	Spatial model
	RR (95% CI)	RR (95% CI)
Age	0.99 (0.98-1.00)	0.99 (0.97 - 1.00)
Male gender	1.18 (1.14-1.22)	1.08 (1.04 - 6.36)
Economic status	0.95 (0.91-0.98)	14.61 (0.92 - 20.84)
Household contacts	5.84 (5.44- 10.01)	1.26 (1.24 - 1.30)
Day land surface temperature (°C)	0.25 (0.18-1.32)	0.18 (0.14 -1.62)
Rainfall (in mm)	6.11 (0.49-18.98)	3.11 (0.78-28.98)
NDVI	2.50 (0.80-25.62)	1.07 (1.02-7.98)
DIC	105,600	52,230

RR, relative risk of leprosy with the corresponding factors; CI, credible interval; NDVI, normalized difference vegetation index; DIC, deviance information criterion.
NDVI is defined as the difference in radiation reflected by any surface in two bands of the energy spectrum - the infrared and the red band. The index ranges from -1 to 1. For green vegetation, the reflectance in the red band is low because of chlorophyll absorption, and the reflectance in the near infra-red band is high because of the spongy mesophyll structure of the leaves. The mean vegetation index over a region reflects the degree of urbanization or lack of vegetation. The values greater than 0.2, quantify vegetation greenness and the denser the vegetation the higher are the NDVI values

Table II. Posterior estimates of spatial parameters

Posterior parameter	Spatial model	Non-spatial model
Spatial variation	9.71 (2.13,17.24)	
Non-spatial variation	4.18 (0.89, 11.23)	6.24 (0.96, 17.89)
Range of influence [3/ξ (km)]	0.25 (0.02-0.29)	

transmission. Such factors need to be taken into consideration when planning a control programme. Future field studies may focus more on the risk factors associated with the environmental risk of leprosy.

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