The Internet Journal of Epidemiology
Volume 11 Number 2

Population Migration Through Railroads And Spatial Diffusion Of Polio In India: A Cross-Sectional Proximity Analysis Using Geographic Information System

A S Bandyopadhyay, J Blossom, J Wenger, M C Castro

Citation

A S Bandyopadhyay, J Blossom, J Wenger, M C Castro. *Population Migration Through Railroads And Spatial Diffusion Of Polio In India: A Cross-Sectional Proximity Analysis Using Geographic Information System*. The Internet Journal of Epidemiology. 2013 Volume 11 Number 2.

DOI: 10.5580/IJE.1633

Abstract

Background

The recent occurrence of polio outbreaks in countries previously considered polio-free such as Tajikistan, Russia and China, and the economic and public health burden of managing such outbreaks underscored the importance of importation of infectious diseases across geographical regions, transcending political boundaries. It also questioned the appropriateness of classifying geographic regions, countries, states and provinces, as endemic and non-endemic and the implications such classifications had on the quality of surveillance and immunization strategies. Although molecular epidemiology and field-surveys have been useful in demonstrating the possible source of reintroduction of virus transmission in disease-free areas, the mode of importation often remains unexplored. The goal of this study is to explore the role played by popular modes of transport, such as the railways, in the importation of polio transmission from endemic to non-endemic states in India.

Methods

To explore the association between cases in non-endemic states and the geographical distribution of the railroads, we evaluate the spatial pattern of spread of polio from endemic to non-endemic states in India during the last four years (as of April 2013) of virus circulation in the country, 2008 - 2011, in a cross-sectional design. We geo-coded addresses of serotype 1 (P-1) cases followed by mapping and proximity analysis using geo-spatial tools. Fisher's exact 2-tailed test was used to assess the statistical significance of the proximity analysis.

Results

Our analysis established that cases in non-endemic states were more likely (64.7% in non-endemic states compared to 38.9% in endemic states) to be geographically closer to the railroads compared to cases in endemic states. The results were statistically significant (Fisher's exact 2-tailed P: 0.01) and the null hypothesis of no association between location of P-1 cases in non-endemic areas and proximity to the railroads was rejected. All P-1 wild type cases (n = 173) from all states and Union Territories in India were included for the most recent 4-year period, and knowing the predominant sub-clinical nature of polio infection, the results were based on a robust set of data from a large cohort of infected population.

Conclusions

The findings suggest the potential role played by popular modes of migration in the spread of polio. As the global polio eradication initiative prepares for the critically important polio endgame, the purpose of this analysis is to inform policy makers on understanding the dynamics of polio transmission through population movement. Our analysis indicates that railroad travel may be linked to transmission of poliovirus to non-endemic areas, and that prevention programs should be developed to address this potentially important mode of spread. Such program enhancements may include mapping of travel patterns and population migration through trains or other modes of transport, depending on the context of the country or the area.

BACKGROUND

The global eradication of smallpox by 1980 demonstrated that certain infectious diseases could be eradicated.(1) With proven success of industrialized countries in controlling polio by improvement in routine immunization coverage, and the remarkable progress made in Latin America in reducing polio transmission by adopting mass vaccination strategies, the World Health Assembly in 1988 launched the Global Polio Eradication Initiative with a target of eradicating polio globally by the year 2000.(1) Although global interruption of all polio transmission has not been achieved yet, the number of polio endemic countries has fallen from 125 in 1988 to only three, namely, Pakistan, Afghanistan and Nigeria, by early 2013. India, once a major epicenter of polio transmission and the source of many episodes of international spread of the disease, was taken off the list of polio endemic countries after no wild polio virus cases were reported for a period of one year since January 2011.

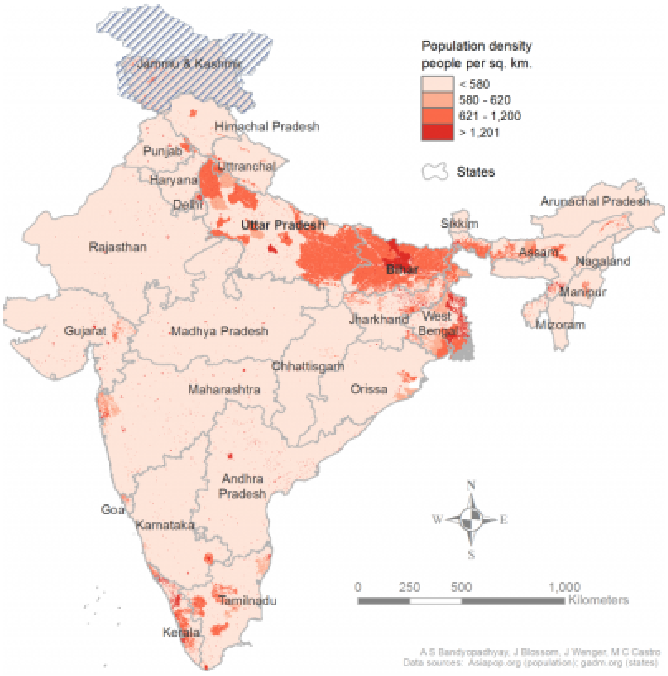
It is important to note that only 1% of polio infected cases are symptomatic, and thus detection of every case of polio indicates continuing circulation with a large cohort of infected population.(2,3) Therefore, identification and confirmation of even one case of polio anywhere in the world is considered to be an outbreak. The International Health Regulations (2005) considers a single case of polio to be a public health emergency of international concern.(2)

Among the three types of wild poliovirus (WPV) identified in the pre-vaccine era, only two serotypes (P-1 and P-3) are still in circulation. P-1 strain is considered to be highly virulent and responsible for most of the global spread of polio.(2) P-1 poliovirus has the propensity to spread rapidly across large geographical areas. Over the last decade, continuing P-1 circulation in the endemic countries led to outbreaks in nearly twenty polio-free countries all over the world. Eradication of P-1, therefore, is considered an urgent priority and targeted mass vaccination campaigns with type-specific oral polio vaccines (OPV) are being conducted in the priority regions, particularly in the three endemic countries, to interrupt wild P-1 circulation.(4)

By 2002, circulation of indigenous WPV in India was successfully interrupted in 26 (out of a total of 28) states and 7 Union Territories, with the help of trivalent Oral Polio Vaccine (tOPV).(1,5) Since then, all WPV cases reported from these areas were importations from either Uttar Pradesh (UP) or Bihar, the two states where circulation of WPV was not interrupted.(5) UP and Bihar are the poorest states of India (based on per capita Gross Domestic Product), with high birth rates, suboptimal routine immunization coverage, and poor sanitation practices. As evident in Figure 1, large areas in these two states are densely populated, and thus the likelihood of maintaining the circulation of an infectious disease such as polio, and its eventual spread to other areas through population movement are expected to be high.

Figure 1

India: States and Union Territories with density of population per sq. km(6,7)



In India, public transportation system is heavily utilized by the population. The railroad network of the country is considered to be the longest (63,000 Kilometers) and the fourth most used transportation system of the world.(8,9) Indian railways transport an estimated 20 million passengers daily across the country, and account for 60% of all passenger traffic in the country.(8,9) "Broad gauge" is the main gauge used by the Indian railways and it covers approximately 87% of the entire track length of all gauges.(8,9)

Inter-state migration is a growing phenomenon in India. The 2001 census categorizes 30% of the Indian population as migrants, and the figure is not inclusive of the temporary migrants who usually follow a seasonal trend of migration based on occupational requirements.(10,11) Poor socio-economic status and limited access to employment opportunities are considered to be the major drivers of migration in states like UP and Bihar. Studies have shown the proportion of migrants in northern Bihar, the erstwhile 'polio epicenter' of India, as 49%.(10) However, data on the modes of internal migration are lacking. Among the few studies done on migration and mobility in India, the one conducted by Dyson et al. showed a significant increase in commuting over the recent years but did not provide specific numbers or further insight into the pattern of commuting.(12,13) Train commuter data available for Mumbai, the industrial capital of India and a common destination for migrants from UP and Bihar, shows that approximately five million people travel in and out of the city on a daily basis.(10,13)

There is a continued trend of employment-driven population migration from UP and Bihar to the other parts of the country. The vast network of Indian railways connecting major cities, towns and rural areas, its affordability, the trend of clustering of nomadic shelters and shanties besides the major railway stations and railroads, and the relative scarcity of other private modes of transport in India lead us to hypothesize that one of the important routes of distant spread of polio could be the railroads. In this paper we test this hypothesis with an objective to better understand the spread of polio in an endemic country setting. Such knowledge of transmission dynamics of polio is critical to ensure policies on outbreak response strategies are in place, so that any reintroduction of virus circulation in polio-free areas can be detected early and controlled efficiently both in the currently endemic countries and also in the polio-free regions of the world. In addition, such analysis and findings should inform proactive strategies to reduce likelihood of disease spread through this mechanism. In the current global context of shrinking endemic regions of polio transmission and increasing risk of importation into non-endemic areas through population movement, the assessment of various aspects of spatial spread of the disease is more relevant than ever.

METHODS

Data

Data on P-1 cases reported from India were obtained from the Ministry of Health & Welfare, Government of India; and from web-portals of the Global Polio Eradication Initiative and the World Health Organization.(4,14) A total of 173 P-1 cases were reported from India from 2008--2011.

Laboratory confirmation as a wild P-1 poliovirus case based on stool analysis and date of onset of paralysis anytime between January 1, 2008 and December 31, 2011 were considered as eligibility criteria for inclusion in the analysis. Railroad locations as published in shapefile format from Collins Maps (http://www.collinsmaps.com/) were used for the analysis. These railroads are classified into: main; main under construction; secondary; and secondary under construction. The "main under construction" and "secondary under construction" were eliminated from the analysis, as travel is not possible on railroads under construction. The "main" and "secondary" railroads were visually inspected against the ESRI Imagery high resolution satellite imagery basemap. In some cases, "main" railroads were 200 kilometers apart, yet were connected by "secondary" railroads. In order to capture all railroads across which long distance population migration takes place, both main and secondary railroads were included in the analysis. Maps with boundaries for districts and sub-districts in India were extracted from the Global Administrative Areas database.(7)

Georeferencing, Mapping and Analysis

All P-1 cases were geocoded to the geographic center of the smallest available administrative unit using ArcGIS 9.3.1 (ESRI, Redlands, CA, USA). This geocoding resulted in matching 91 cases to the sub-district level and 82 cases to the district level. On 12 of the sub-district and 12 of the district cases, Google Maps was used to verify that the geocoded locations were correct. This process was performed by entering the "sub-district, district" name into the Google Maps search engine, and comparing the resulting latitude/longitude values to those generated by ArcGIS. The resulting locations were projected into the Universal Trans-Mercator Kalianpur 1975 Zone 47N coordinate system that has a linear unit of meters.

The Euclidean distance between each P-1 case and the nearest railroad was calculated with the ArcGIS "Near" function. The distances calculated were categorized as within 5 Kilometers (km) and beyond 5 km from a railroad. The 5 km cut-off was chosen based on two criteria. First, 5 km is considered as the feasible distance of local/on-foot travel for people residing in a settlement in India. Second, outbreak response immunization (ORI) for polio following an outbreak in non-endemic area is conducted for a cohort of at least 500 children or within 5 km in the neighborhood of the index case.(15) Potential differences in distances observed in endemic and non-endemic areas were evaluated with the Fisher's Exact Test (two-tailed). All calculations were done in Epi InfoTM version 7.0.

RESULTS

The use of Geographic Information Systems (GIS) and spatial analysis in public health has been growing substantially, with important contributions in the monitoring and mapping of disease outbreaks, planning emergency preparedness, modeling infectious disease transmission, and planning responses to humanitarian disasters.(16,17,18) However, very few spatial applications have been conducted to study the spread of polio, a highly infectious disease notorious for intra- and trans-national spread. Specifically, we are not aware of any attempt to analyze migration patterns of population and geospatial distribution of polio cases in an endemic setting such as India, and the spatial factors associated with its spread in non-endemic areas. This study is thus the first attempt to use GIS methods to explore the association of the spread of polio and the modes of popular transport in a high disease burden setting.

Figure 2

P-1 case locations (2008 – 2011) and distribution of railroads in India(4,14,19)

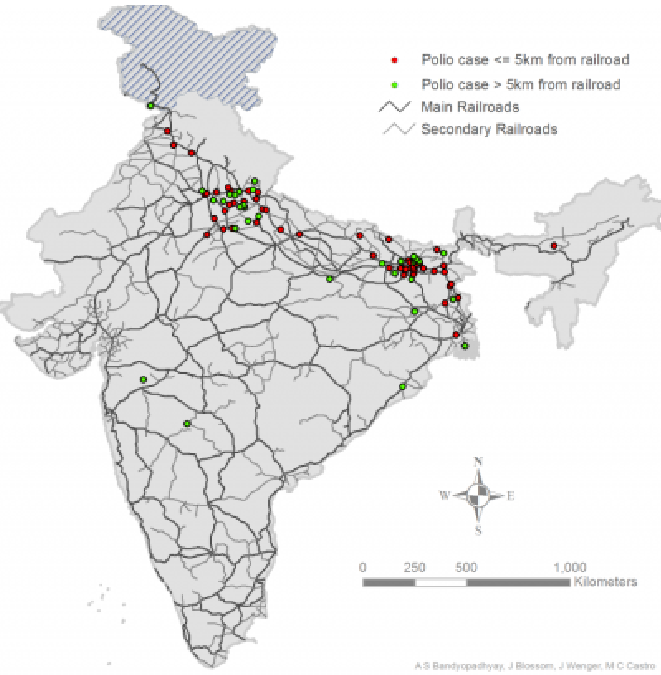


Figure 2 (as seen above) displays the distribution of P-1 cases during 2008 – 2011, as well as the main and secondary railroads. The cases are color-coded based on their distance (in kilometers) from the nearest railroad. Table 1 (as seen below) shows that the majority (64.7 %, Fisher's exact 2-tailed P: 0.01) of the P-1 cases in the non-endemic states of India were more likely to be located in areas that were at 5 km or less from railroads in contrast to the cases in non-endemic states. The results were statistically significant ($p < 0.05$) and the null hypothesis of no association between location of P-1 cases in non-endemic areas and proximity to the railroads was rejected. Since the analysis included all P-1 cases (n = 173) from all states and union territories in India reported during a 4-year period, the findings are robust. Considering the fact that one clinical case of paralytic poliomyelitis represents approximately 100 – 1000 sub-clinical but infected cases around the primary case, a sample size of 173 in this analysis represents a large cohort of infected individuals for the specified time-frame and geographic area.(2,3)

Table 1

P-1 Cases reported in endemic and non-endemic areas by distance (in km) from railroads, India, 2008 – 2011

Zone	Cases by distance from railroads		Total
	≤5 km (%)	>5 km (%)	
Endemic	54 (38.9)	85 (61.1)	139
Non-endemic	22 (64.7)	12 (35.3)	34
Total	76	97	173

This analysis entails some limitations. First, factors such as immunization coverage and surveillance indicators of the states, pattern of migration through other modes of transportation, and status of polio transmission in the neighboring countries could not be explored in details due to unavailability of data. These factors may act as potential sources of confounding. Second, analysis based on the exact locations of the railway stations could have been more relevant in establishing the epidemiological link between imported cases and the mode of migration. But in the absence of such data, the shortest distance between a polio case and the nearest railroad track was considered to be an acceptable proxy.

DISCUSSION

The complex dynamics of poliovirus circulation in India over the years has been an area of interest for many researchers. In January 2009, the Executive Board of the WHO requested a study to address the concerns raised by the global community about the delay in attaining complete interruption of transmission. The study focused on the need to effectively address the issue of population-mobility and poliovirus transmission in India. The report reiterated the importance of identifying the mobile populations and busy transit points such as train stations.(5) There is constant movement of population from Bihar and UP to the more economically developed cities and states such as Mumbai, Delhi, Punjab, Haryana and Gujarat.(5) The report also stressed the critical role of vaccinating the migrant population, mostly poor labor workers, through intensive planning and strategic placement of mobile vaccination camps.(5) Monitoring efforts revealed that migrants working in construction sites and agricultural fields were not being covered adequately and the report called for a targeted approach to effectively reach out to the migrant and nomadic population groups who are always on the move.(5)

It is evident from our analysis of the distribution of polio cases that the imported cases of polio in the non-endemic states are more likely to be geographically closer to the railroads. It has to be understood that in addition to being the largest mode of population transport in India, the physical locations of railways are also linked with the nomadic and shelter-less population. Most of the nomadic population groups dwell in temporary shanties alongside the railroads and major stations. The overall hygienic and sanitation standards are extremely poor in these areas. Also, since these migratory groups have no permanent settlement, they are often missed from the routine and mass vaccination programs. Based on these factors and our findings, we conclude that maintenance of a strong immunization strategy for the migratory population remains critical in ensuring continuation of polio-free status. Such vulnerable areas across the country should be prioritized in the routine and mass immunization programs to ensure any chance-importation of poliovirus from other countries does not establish new circulation. Targeted monitoring with greater focus on the vulnerable areas like transit sites and temporary shelters should be intensified with greater emphasis on finding missed children. The estimated coverage of trivalent OPV in routine immunization campaigns was only 53% in Bihar and 40% in UP in the recent past.(5,20) The routine immunization coverage of the migrating population from these states would naturally be poorer. Specific attention is required to develop mechanisms to cover the migrant population under routine immunization program through strengthening of the out-reach centers and special-area coverage planning. In addition, as India and other countries in the region move closer to the goal of sustained control of polio circulation, strengthening of surveillance will be pivotal to detect any low-level virus transmission. The quality indicators of acute flaccid paralysis (AFP) surveillance are much lower in the non-endemic states compared to the indicators in the endemic states. (19) Increased focus on surveillance, both AFP and environmental surveillance, across the regions, irrespective of previous endemic or non-endemic status, is needed.

CONCLUSIONS

The distribution of imported P-1 cases in the non-endemic states in India show a distinct pattern of association along the railroads. This finding has implications for planning future vaccination campaigns because the analysis establishes that the non-endemic areas that are well-connected through popular modes of transport with the endemic areas are at risk of re-establishment of polio circulation. Therefore, implementation of vaccination campaigns and enhancement of disease surveillance interventions need to be planned in a synchronized manner so that these vulnerable areas are covered adequately along with the known endemic areas. Further research, however, is needed to explore the association between quality of surveillance and the detection of cases in non-endemic areas and to rule out possible confounding in the association of P-1 cases with the railroads. The role of other relevant factors, such as existing immunization status of children in these areas and quality of sanitation and hygiene in the community, should also be taken into consideration while making policy decisions to ensure a comprehensive approach for improving the quality of disease control. Also, the pattern of spread of P-3 type wild poliovirus, which is known to be localized in circulation and that of circulating vaccine derived polioviruses (cVDPV) should be studied to assess the dynamics of transmission within the endemic zones. India has set examples in controlling polio transmission under challenging circumstances. However, the fact that the last P-1 case reported from the country was from a non-endemic state (West Bengal) and was in close proximity to the railroads indicates a continued risk of the virus being carried through the migratory population from the endemic to the non-endemic areas.

Considering the fact that the neighboring polio-endemic country, Pakistan, has railroad connection with India with a train running twice a week between Lahore, in Pakistan and New Delhi, in India, such enhanced focus on all immunologically vulnerable and well-connected geographical areas is all the more important and may require strategic collaboration between the two countries for coordinated vaccination campaigns and improved surveillance activities. In Africa, non-endemic countries such as Chad and the Democratic Republic of Congo reported higher number of cases than the endemic Nigeria in 2010. Several areas of Pakistan, Afghanistan, and neighboring countries such as Tajikistan, Russia and China, reported fresh outbreaks over the last few years which indicate continued risk of both intra-national trans-national importations. Timely public health interventions to prevent virus importations from establishing circulation in the freshly infected areas and future research to explore the patterns and routes of geographic spread of poliovirus can accelerate the achievement of complete global polio eradication.

COMPETING INTERESTS

The author(s) declare that they have no competing interests.

AUTHORS

ASB, Program Officer - Polio Research, at The Bill and Melinda Gates Foundation, made substantial contribution in conceptualizing the study design, methods and analytics. He also did the literature search, and took lead in writing this manuscript. He contributed to data cleaning, data analysis and geocoding of the cases.
JB, Senior GIS Analyst at Harvard University, did the geocoding and geo-processing of case-data, and conducted proximity analysis with ArcGIS, created the maps, and wrote the corresponding methods section of the paper.
MCC, Associate Professor of Demography at Harvard School of Public Health, contributed with the study design, analysis; and writing and editing of the manuscript.
JW, Director, Polio Program, at The Bill and Melinda Gates Foundation, contributed to the writing and editing of the manuscript.
All authors read and approved the final manuscript.

ACKNOWLEDGEMENTS

The authors would like to thank Dr. Pradeep Haldar, Deputy Commissioner (Immunization), Ministry of Health and Family Welfare, Government of India for the permission to access and use the data on polio cases in India. The authors would also like to thank the staff and officials of World Health Organization - National Polio Surveillance Project – India and the countless health workers, volunteers and vaccinators who are key to the collection and maintenance of surveillance and immunization data related to polio. Lastly, the authors would like to thank Iva Li, Consultant, Booz Allen Hamilton, for her help in formatting the manuscript and helping the authors with the finalization of bibliography.

References

1. Heymann DL, Sutter RW, Bruce R Aylward: Polio eradication: interrupting transmission, towards a polio-free world. Future Virology; 2006; 1:181-188.
2. Heymann DL: Poliomyelitis. In Control of Communicable Diseases Manual. 19th edition. Washington DC: American Public Health Association; 2008; 484-491.
3. Park K: Park's Textbook of Preventive and Social Medicine. 21st edition. India: Banarsidas Bhanot Publisher; 2009.
4. Global Polio Eradication Initiative [http://www.polioeradication.org/].
5. World Health Organization: Independent evaluation of major barriers to interrupting poliovirus transmission in India. [http://polioeradication.org/content/general/Polio_Evaluation_Report.asp/].
6. AsiaPop [www.asiapop.org/].
7. Global Administrative Areas [http://www.gadm.org/].
8. Ministry of Railways (Railway Board): Year Book. India; 2007.
9. Acharya RC: Indian railways- where the commuter is the king. Japan Railways and Transport Review; 2000; 25:35-45.
10. Deshingkar P, Kumar S, Chobey HK, Kumar D: The role of migration and remittances in promoting livelihoods in Bihar. London: Overseas Development Institute; 2006.
11. Mukherji S: Low Quality Migration in India: The Phenomena of Distressed Migration and Acute Urban Decay. In 24th IUSSP Conference: August 2001; Salvador.
12. Dyson T, Visaria P: Migration and urbanization: retrospect and prospects. In Twenty-first century India: population, economy, human development, and the environment. Edited by Dyson T, Cassen R, Visaria L. New York: Oxford University Press; 2004; 108-129.
13. Deshingkar P, Grimm S: Voluntary internal migration an update. London: Overseas Development Institute; 2004.
14. World Health Organization: Polio Case Count. [http://apps.who.int/immunization_monitoring/en/diseases/poliomyelitis/case_count.cfm]
15. Mukherji S, Jindal AK, Singh ZB, Bajaj SM: Polio Eradication in India: Myth or Reality. MJAFI; 2005; 61:364-366.
16. Kamadjeu R: Tracking the Polio virus down the Congo River: a case study on the use of Google EarthTM in public health planning and mapping. International Journal of Health Geographics; 2009; 8:4.
17. Bandyopadhyay AS, Bandy U: Emerging Global Epidemiology of Measles and Public Health Response to Confirmed Case in Rhode Island. Rhode Island Medical Journal; 2013; 41-44.
18. Koch T: Knowing its place: mapping as medical investigation. The Lancet; 2012; 379: 887 – 888.
19. The National Polio Surveillance Project – India [http://www.npspindia.org].
20. Mohammed AJ: Independent evaluation of major barriers to interrupting poliovirus transmission- Executive Summary. [http://www.polioeradication.org/content/general/Polio_Evaluation_CON.pdf].

Author Information

Ananda Sankar Bandyopadhyay
The Bill and Melinda Gates Foundation
Seattle, WA, USA
ananda.bandyopadhyay@gatesfoundation.org

Jeff Blossom
Center for Geographic Analysis, Harvard University
Cambridge, MA, USA

Jay Wenger
The Bill and Melinda Gates Foundation
Seattle, WA, USA

Marcia C Castro
Department of Global Health and Population, Harvard School of Public Health
Boston, MA, USA