Spatio-temporal patterns of under-five mortality in Matlab HDSS in rural Bangladesh

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Background: Knowledge of spatial and temporal distributions of mortality and morbidity is important to prioritise areas for adjusting the public health system where people need services most. A Health and Demographic Surveillance System (HDSS) plays an important role where accurate national vital events are not available in identifying areas and periods with excess mortality risks.

Methods: The HDSS in Matlab, a rural area of Bangladesh, provided data on yearly number of deaths and children aged below 5 years for each of 90 villages during 1998-2007, along with village location points, longitudes and latitudes. Kulldorff’s space-time scan statistic was used to identify villages and periods that experienced high mortality risks in the HDSS area with a statistical significance of \( p < 0.001 \). Logistic regression was conducted to examine if village-level education and economic status explained village-level mortality risks.

Results: There were 3,434 deaths among children aged below 5 years in the HDSS area during 1998-2007 with an average yearly rate of 13 deaths per 1,000 under-five child-years. The mortality rate showed a declining trend with high concentration in 1998-2002, but not in 2003-2007. Two clusters of villages had significantly higher mortality risks in 1998-2002, but not later, and the mortality risks in the high-risk clusters reduced little, but remained significant after controlling for adult education and economic status at village level.

Conclusions: Spatial clustering of childhood mortality observed during 1998-2002 had disappeared in subsequent years with a decline in mortality rates. Space-time scanning helps identify high-risk areas and periods to enhance public health actions.

Keywords: clustering; children; mortality; Matlab; Bangladesh

Accepted: 29 June 2010; Published: 30 August 2010

Received: 27 April 2010; Revised: 17 June 2010; Accepted: 29 June 2010; Published: 30 August 2010

A country’s health policy aims to provide health services to all who need them and achieve spatial parity in coverage. Despite the aim of spatial parity, the recent 2009 Multiple Indicator Cluster Survey of the Bangladesh Bureau of Statistics, the national statistical organisation of the government, shows large disparities between districts in education, child health, maternal health, access to safe drinking water and improved sanitation (1). The findings reveal that spatial and environmental factors affect health and social development. The most deprived spatial units (districts) need special interventions and budget allocations in order to catch up with the rest of the country and achieve spatial parity. Spatial disparities may also exist within districts and sub-districts between lower administrative units such as unions or villages.

Identifying spatial disparity requires population-based, up-to-date and reliable statistics on health indicators and appropriate analytical tools. Such statistics, to our knowledge, are lacking in Bangladesh. Until now, routine registration of births and deaths is incomplete or non-functioning. Basic demographic measures often come from a Health and Demographic Surveillance System (HDSS) operating in a well-defined population of small size. The size of the population under the HDSS in Matlab – a rural area of Bangladesh – is 224,039, covering 142 villages (2). Villages may not be very cohesive communities, but there are shared experiences among villagers because of their geographic closeness and exposure to the same common social networks (3). People of the same village go to the same market and to the same mosque or temple for prayer, irrespective of their wealth and education. Village-level institutions: schools, mosques, temples, clubs, etc., are influential forums for dissemination of ideas and homogenisation of knowledge and values. The overall village-level economic, social,
environmental and spatial factors shape behaviour affecting health (4).

The method of identifying spatial disparity is spatial mapping of health events, such as mortality, morbidity and access to health services. Statistical methodology to identify spatial disparity is under ongoing development. With technological advancement, more analytical tools have become available, and the Geographic Information System (GIS) has been developed in recent decades as a powerful and rapid tool to investigate spatial patterns in disease incidence or health services. One such tool is Kulldorff’s (5) spatial scan statistic, which takes into consideration spatial distribution of the population to identify areas with high disease incidence or use of health services. This helps prioritising areas for analysis of cause and planning remedial actions. Kulldorff et al. (6) have extended the spatial scan statistic into a space–time scan statistic to identify disparities in terms of space and time.

In countries with incomplete registration of vital events, survey and surveillance data are used to show spatial disparity. Data from the demographic surveillance research project in Nouna, Burkina Faso, showed non-random distribution of childhood mortality (7). A recent study using geographic data from 10 Demographic and Health Surveys from West Africa shows that child mortality rates were higher in extremely dense (more than 1,000 persons per square kilometre) and extremely dispersed (fewer than 25 person per square kilometre) populations (8). Mortality rates are also higher in land-locked areas. The study of spatio-temporal patterns of malaria in Chiang Mai, Thailand, in 2001–2006 showed clustering of villages with elevated proportions of malaria cases (9). Multilevel analysis showed significant spatial variations between villages in seeking treatment for sick children in Matlab, Bangladesh (10). These findings help planners identify high-risk areas and thus pinpoint interventions more effectively.

The objective of this study is to identify villages and periods of high under-five mortality in Matlab, Bangladesh, using HDSS data in 1998–2007. Estimating mortality risks in high-risk villages, adjusting for village-level education and economic status is another objective of the study.

**Study population and methods**

Data for this study came from Matlab, where the International Centre for Diarrhoeal Disease Research, Bangladesh (ICDDR, B) maintains the HDSS since 1966. Matlab is 55 km south-west of Dhaka – the capital city of Bangladesh. The population under surveillance is 224,039. The majority are Muslims (88%) and the rest are Hindus (12%). The main occupations of men are agriculture, fishery and livestock, and trade. Women usually do household chores. Despite the low level of economic development, fertility and mortality transitions have been progressing slowly for the last four decades (2).

The HDSS area consists of 142 villages of varying population size; ranging from 117 to 9,466 (9). The average population of a village is 1,578. Community female interviewers visited every household monthly up to 2006 and bi-monthly from 2007 to record vital events (births, deaths, migration, marriages and marital disruptions) that happened since their last visit. Since 1986, each death is subject to verbal autopsy for assessment of possible cause of death. Two tiers of supervision and an independent quality control team ensure that registration of vital events is complete and the date of the event is precise. Data on the number of deaths and children aged below 5 years in the HDSS area in 1998–2007 were obtained from the HDSS longitudinal database and disaggregated by village and year.

The 1996 socioeconomic census recorded individual’s education, occupation and household durables: bed stand, chair-table, cupboard, radio, television, bike (including motorbike), land owned, materials of wall, roof and floor of the main dwelling unit and type of toilet used. These durables were used to classify households into quintiles (11). A principal components analysis of household durables retained one factor and assigned a factor score to each household. The higher the score, the higher the number of household assets, indicating better long-term economic status of the household. The factor score was used to divide the households into quintiles – from the lowest 20% to the highest 20%. A higher household assets quintile reflects the higher economic status of the household. Adult (aged 15 years or older) education (measured by persons having education class 5 or higher) and household-level assets quintiles were aggregated across all households in the village to compute the village-level adult education rate (in percent) and economic status (percentage of households in top two asset quintiles). Villages are not homogeneous in education and economic status. Village-level adult education varied from 34 to 83% and economic status from 19 to 57%. Clustering in mortality at the village-level may be an effect of clustering of the risk factors; education and poverty at village-level.

Small villages (having less than 1,000 inhabitants) are merged with adjacent villages that are more similar in terms of adult education and economic status. After merging the small villages, we are left with 90 villages (or clusters) for analysis. GIS of the HDSS generates spatial data: geo-coordinates of each bari (group of households that share a common yard and whose heads are usually related by blood) and land marks (tube-wells, health facilities, schools, markets, mosques and temples) in degree decimal format. ArcGIS software is used to create a polygon of each village and to pick the centroid (defined by the centre of gravity). In case of centroids
lying outside polygons of irregular and complex shapes, the option ‘INSIDE’ in ArcGIS guaranteed the polygon centres lie inside the polygon.

**Data analysis**

Overall childhood mortality rates per 1,000 under-five children and 95% confidence intervals assuming a Poisson distribution of deaths were calculated for each year of 1998–2007. Yearly number of deaths and children aged below 5 years were disaggregated by village. Childhood death rates by village \( i \), \( i = 1, \ldots, 90 \) for years \( j \), \( j = 1998, \ldots, 2007 \) using \( \text{DR}_{ij} = d_{ij}/n_{ij} \), where \( n_{ij} \) denotes the midyear population children aged 0–4 years in village \( i \) and year \( j \), and \( d_{ij} \) is the corresponding observed number of deaths.

Kulldorff et al. (5, 6) have extended the spatial scan statistic into a space-time scan statistic to identify spatial and temporal units with high mortality risks. In this study, we used Kulldorff’s space-time scan statistic, which takes into consideration spatial and temporal distributions of the population as follows. The window imposed on the HDSS area is cylindrical with a circular geographic base and with height corresponding to time. The centre of the base is one of several possible centroids located throughout the HDSS area and the height reflects any possible time interval. The cylindrical window is then moved in space and time and it allows the centre of the circular geographic base to move across the HDSS villages. For any given position of the centre, the radius of the circular base changes continuously so that it can take any value between zero and an upper limit of 50% of the total population. A village is captured if it lies in the circular base. Therefore, the circular base is able to include a different set of neighbouring villages. This scanning was applied to HDSS data for the time window 1998–2007 to scan for space and time with high mortality rates.

**Table 1.** Under-five mortality in the HDSS area for 1998–2007 using purely temporal analysis scanning for high rates

| Type            | Period   | Cases | Expected | Relative risk | \( p \)-Value |
|-----------------|----------|-------|----------|--------------|--------------|
| Most likely     | 1998-2002| 2,047 | 1,824.3  | 1.31         | \( p <0.001 \) |

**Results**

A total of 3,434 under-five deaths were reported in the Matlab HDSS area for 1998–2007 with an average yearly rate of 13.0 deaths per 1,000 under-five child-years (Fig. 1). The corresponding cumulative rate up to age 5 years is calculated as \( (1 - \exp(-5 \times 0.013)) = 0.063 \) (or 63 per 1,000 live births). In the study period, there was a clear gradual decline in mortality; the rate fell from 18.0 in 1998 to 9.2 in 2007; a 49% reduction in a 10-year period. Disaggregation of yearly mortality rates by village shows high fluctuation in rates within and between villages and years for small numbers. Some small villages did not have any deaths in some years and some had more than expected by chance. In 1998, mortality rates in the villages ranged from 0.0 to 37.8, and in 2007, mortality rates in the villages ranged from 0.0 to 27.9.

The SaTScan™ option ‘purely temporal analysis’ showed a significantly higher mortality in 1998–2002 compared to 2003–2007 (Table 1). An alternative analysis using Poisson regression showed a highly significant \( (p < 0.001) \) linear mortality decline over the full period 1998–2007.

The space–time analysis using the discrete Poisson model reveals spatial disparities in under-five mortality in 1998–2002, but not in 2003–2007 (Table 2). Analysis identified three statistically significant sets of villages with high childhood mortality (Fig. 2). Each cluster consists of a set of villages adjacent to each other.

Despite the homogeneity in many other aspects, villages are heterogeneous in education and economic status. One may hypothesise that spatial disparity in mortality is due to spatial disparities in the distribution of the risk factors. To examine the hypothesis, logistic regression analysis is undertaken for high-risk clusters identified by the space–time analysis. The dependent variable was death of the child before the fifth birthday (coded ‘1’ if died, ‘0’ if survived). The independent variables were the risk order of the clusters of villages and adult education and economic status at village level. The most likely cluster of villages was coded ‘1’, the secondary cluster 1 of villages coded ‘2’, the secondary cluster 2 of villages coded ‘3’ and the rest of the villages were coded ‘0’ (or reference category). Model I contained the risk factor, ‘risk order of the cluster’ only and Model II contained the risk factors, ‘risk order of the cluster’ plus village-level education and economic status. These two models show the changes in odds ratio and log likelihood statistics for adjusting for education and economic status at village level.
Logistic regression Model I shows that two of the three sets of villages identified as high risk by Kulldorff’s space–time analysis remained as high risks (Table 3). The secondary cluster 2 with marginally high risks turned out to be non-significant. The factor ‘village-level economic status’, but not ‘adult education’ was negatively associated with the high mortality risk. The odds ratios reduced, but remained significant after controlling for the village-level economic status. The reduction is also indicated by the deviance between the two log likelihoods, which is distributed as Chi-square and is found significant.

**Discussion**

The gradual decline in under-five mortality in the HDSS area is consistent with the results of the nationally representative sample survey, the five Bangladesh Demographic and Health Surveys conducted between 1993 and 2007, and the National Sample Vital Registration System (12, 13). Concentration of deaths was observed in 1998–2002, but not in 2003–2007. The lack of concentration in 2003–2007 was not due to systematic error in the reporting of births and deaths across villages over the years. Monthly (and bi-monthly from 2007) household visits to register vital events and pregnancy, two tiers of supervision and checking by an independent quality control team ruled out the possibilities of under- or over-reporting. Each death in an HDSS area is subject to verbal autopsy for assigning possible cause of death, which minimises the chances of missing neonatal deaths and misclassification between stillbirths and early neonatal deaths.

Identifying clusters with high mortality risks is a first step in prioritising areas for analysis of cause and planning of remedial actions. Space–time analysis using Kulldorff’s method (6) identified two clusters of villages with high mortality risks in 1998–2002. This reveals that mortality

Table 2. Under-five mortality in the HDSS area for 1998–2007 using spatial–temporal analysis scanning for high rates

| Period    | Type       | Location    | Cases | Expected | Relative risk | p-Value |
|-----------|------------|-------------|-------|----------|---------------|---------|
| 1998–2002 | Most likely| 22 villages | 677   | 509.8    | 1.41          | p < 0.001 |
|           | Secondary  | 18 villages | 393   | 288.6    | 1.41          | p < 0.001 |
| 1998      | Secondary  | 9 villages  | 59    | 31.3     | 1.90          | p = 0.068 |

Fig. 2. Map showing sets of villages with high under-five mortality rates in the HDSS area for 1998–2002.
Table 3. Odds ratios (and 95% CI) of under-five deaths for the risk factors

| Risk factors | Model I         | Model II        |
|--------------|-----------------|-----------------|
| Risk order of the cluster: |                  |                 |
| Average likely cluster (reference) | 1               | 1               |
| Most likely cluster | 1.24* (1.15–1.35) | 1.17* (1.08–1.27) |
| Secondary cluster 1 | 1.31* (1.19–1.44) | 1.21* (1.09–1.33) |
| Secondary cluster 2 | 1.08 (0.95–1.23)  | 1.03 (0.90–1.16)  |
| Village-level factors: |                  |                 |
| Adults with education class 5+ (%) | 0.998 (0.994–1.003) |                 |
| Households in top two quintiles (%) | 0.985* (0.980–0.991) |                 |
| Log likelihood (df) | −18878.9 (3), p < 0.001 | −18857.1 (5), p < 0.001 |

*p < 0.01.
Note: The dependent variable was coded ‘1’ if the child had died, otherwise coded ‘0’.

decline was faster in the high-risk clusters than in the average-risk cluster and achieved equity. A common drawback of Kulldorff’s method is that clusters are defined as circles or cylindrical windows with circular base (5, 6). Actual clusters (or villages) are irregular in shape. This feature has some implications for the interpretation of the results. If a village with low mortality is surrounded by villages with high mortality, it is included in the cluster although some characteristics of the village are different from other villages. If clustering of mortality is, say, along the river, then a circular shape is not appropriate to detect it. The first limitation is similar to that of the control trial cohort, and the overall effect on the result would be small. The second limitation can be minimised by viewing an ArcGIS map.

Each high-risk cluster comprises a set of adjacent villages. The most likely mortality cluster consists of 22 villages adjacent to each other. They are in close proximity of the big river, the ‘Meghna’, and are exposed to more natural disasters such as river erosion and monsoon flooding. The secondary cluster consists of 18 villages on the banks of the rivers Gumti and Dhonogoha and in adjacent low-lying areas. These villages are remote – far away from the sub-district town and health facility. What causes difference in mortality between clusters demands in-depth study.

People in high-risk clusters may be of lower education and economic status compared to their peers in average-risk clusters in addition to the natural disasters and geo-access to health services. Control for the village-level adult education and household economic status reduced the odds ratios of dying in the high-risk clusters a little, but remained significant. This suggests that spatial and some environmental factors in addition to education and economic factors affect health. Causal factors may be at the demand side (hygiene and health care seeking) and supply side (availability and accessibility). Non-random distribution of local formal or informal health facilities and access to them may be causing the inter-cluster differences in under-five mortality. The overall cluster-level variance for childhood mortality is quite small, but significant. This is expected because the clusters are adjacent to each other. The populations across clusters can be somewhat homogeneous in terms of health belief and practice and environmental factors.

That education at the village level was not associated with mortality risks is a surprise and needs investigation in the future. Perhaps education benefits one’s family members, not others in the community. Another possibility is error (over or under) in self-reported education, which is likely to be random and underestimate the mortality effect. Socioeconomic status of households was determined in 1996 – 2 years before the study period, and must have changed over the years. Such change across villages can be uniform or non-uniform, but there is no data to determine what it was. Non-uniform change, if any, may have disproportionately affected the result. Error in measurement of economic status also underestimates the strength of the association. In conclusion, the findings indicate that spatial disparity observed in childhood mortality in the HDSS area in 1998–2002 has disappeared in recent years in which there have been lower mortality rates.

Acknowledgements

This research activity was funded by ICDDR, B and its donors, which provide unrestricted support to the Centre for its operations and research. Current donors providing unrestricted support include: Australian Agency for International Development (AusAID), Government of the People’s Republic of Bangladesh, Canadian International Development Agency (CIDA), Embassy of...
the Kingdom of the Netherlands (EKN), Swedish International Development Cooperation Agency (Sida), Swiss Agency for Development and Cooperation (SDC), and Department for International Development, UK (DFID). We gratefully acknowledge these donors for their support and commitment to the Centre’s research efforts. SaTScan™ is a trademark of Martin Kulldorff. The SaTScan™ software was developed under the joint auspices of (a) Martin Kulldorff, (b) the National Cancer Institute and (c) Farzad Mostashari of the New York City Department of Health and Mental Hygiene.

Conflict of interest and funding
The authors have not received any funding or benefits from industry to conduct this study.

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