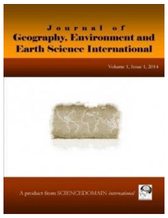

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Assessing and Monitoring Malaria Epidemiology using Remote Sensing and GIS in Murshidabad District, West Bengal (India)

Poly Patra[1], Anukul Ch. Mandal[1], Raja Majumder[1], Debashish Ghosh[1] and Gouri Sankar Bhunia[1*]

[1]*Department of Geography, Seacom Skills University, Kendradangal, Santiniketan, Birbhum - 731236, West Bengal, India.*

Authors' contributions

This work was carried out in collaboration between all authors. Author PP collected the data, managed the literature searches and wrote the first draft of the manuscript. Author ACM wrote the protocol and helped to write the first draft of the manuscript. Authors DG and RM managed the analyses of the study. Author GSB designed the study, performed the statistical analysis and finalized the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

A retrospective analysis of malaria cases was investigated at the block level in Murshidabad district between 2009 and 2016 to apprehend the trend and dynamics of transmission. A personal geodatabase was prepared in ArcGIS environment. The local spatial auto-correlation was investigated using Local Moran's *I* statistics. The local Getis-Ord G statistics was used to estimate spatial clustering pattern of malaria. The maximum annual malaria incidence rate was recorded as 6.05/ 10,000 individuals in 2009 whereas, the low incidence rate was recorded in 2016. The occurrences of *Plasmodium falciparum* (*P. falciparum*) malaria were typically 3 ~ 5 times lower than those of *P. vivax* malaria incidence. The results also illustrated that the central part of the district was highly affected by the disease. The Moran's *I* values for *P. falciparum* malaria were remarkably fluctuant and generally higher than those *P. vivax* malaria. The statistically significant high-low

**Corresponding author: E-mail: rsgis_gouri@rediff.com, rsgis_gouri@rediffmail.com;*

clustering pattern were observed for both the malaria cases in 2012 and 2013. Spatial cluster of *P. vivax* and *P. falciparum* malaria rehabilitated with time. However, this study suggests that appropriate countermeasures should target high threat areas accordingly and the undelaying sources of increased risk in the recognized areas.

Keywords: Malaria incidence; Moran's I; Getis-Ord G statistics; malaria control.

1. INTRODUCTION

Malaria is the major parasitic disease that causes of morbidity and mortality in developing countries due to its highest transmission rates [1]. The disease causes widespread immature death and miserable, baronial financial asperity on poor menaces, and holds back economic growth and transmutations in living standards. It is basically an environmental disease as vectors and parasite population require specific habitats with surface water for reminiscence, wetness [2]. The present malaria risk maps have restricted operational usage to sustenance programmatic undertakings since they were created at coarse spatial scales, based on definite geo-reference point prevalence data [3,4], entomological parameter that are not effusively confirmed [5].

The Murshidabad district is historically prevalent with both the *Plasmodium falciparum* and *Plasmodium vivax* [6,7]. In the district, out of twenty six blocks, twenty blocks are worstly affected by the disease. Although the burden of malaria transmission in the Murshidabad district is less and often seasonal, inter-annual variations in micro-environmental characteristics can enhance transmission rates and trigger devastating epidemics [8]. The climatic suitability depends on the ecology of the dominant malaria vector species, and therefore varies with geographic region. A National Malaria Elimination Programme (NMEP) was formulated by the Ministry of Health, Govt. of India.

During the last three decades, the development of space technology and geographic information system (GIS) have made it possible to make crucial progress in the monitoring of the ecological and anthropogenic factors which influence the reduction or the re-emergence of the disease [9]. Spatial-temporal epidemiology of malaria has provided us a beneficial system to comprehend the spatio-temporal configurations of malaria epidemics, evaluating vicissitudes in malaria transmission and recognizing the high threat areas and periods with higher risk at larger scale [10,11]. Spatial technology has clearly defined the epidemiology of the disease *vis-a-vis* environmental factors by identifying the spatial limits of the disease prevalence and risk mapping with relevant risk factors. Spatial technology helps systematic and regular monitoring of the earth's environmental condition furnishing large amounts of spatial and temporal data [12,13]. Such information composed with proper field studies can demonstrate very prolific for early detection and suitable response to disease control. This tool is aided in the identification of hotspots of malaria prevalence and spatial of the disease [14].

In this study, the space, times of malaria cases were investigated at the block level in Murshidabad district between 2009 and 2016. Present study also describes the temporal and spatial analyses of both *P. falciparum* and *P. vivax* malaria using GIS techniques to apprehend the trend and dynamics of transmission.

2. MATERIALS AND METHODS

2.1 Study Area

Murshidabad district is extended between 87º49′09″ to 88º44′ E longitudes and 23º43′30″ to 24º52′N latitudes, which is located in the eastern part of the West Bengal, India, covered with an area of about 5316.11 sq km. The major river in the study area is the river Ganges and its distributaries, of which the most significant are Bhagirathi, Jalangi, and Bhairab. The river Bhagirathi, flowing from north to south through the district, extensively separated into four zones – rarh, barendra, bagri and vanga. Soils of the district are taxonomically characterized into three orders i.e. Alfisols, Inceptisols and Entisols. Physiographically the entire district comes under the plain region. The average elevation of the district is 300 meter. An alluvial plain is the main physiography of the district followed by marshy land. District Murshidabad goes to humid tropical monsoon climatic region, where the mean maximum temperature is 25°C in the winter season and average annual rainfall is 1.90 cm. In summer season, the mean maximum temperature is recorded as 39.86°C and mean minimum temperature is 22.43°C. The average annual rainfall of the district is 11.68 cm. According to 2011, the total population of Murshidabad district was recorded as 7,102,430.

2.2 Malaria Incidence Data

National Vector Borne Disease Control Programme (NVBDCP), Govt. of India is responsible for monitoring and implementing the malaria control programmes and archiving the malaria data. The monthly and provincial malaria incidence data's were collected from the district Malaria Office, Murshidabad, West Bengal. This study evaluated block-wise malaria incidence dynamics during the period between 2009 and 2016. These data's are based on passive case detection, mainly confirmed malaria cases reported by hospitals and clinics. Malaria cases from the two most prevalent parasite species (*P. falciparum* and *P. vivax*) were further divided and used for the subsequent spatial and temporal analysis. Historical demographic data of Murshidabad district for the period of 2009-2016 were obtained from the district statistical handbook. Block-wise malaria incident rate was calculated per 10,000 individuals based on malaria incidence [15] and population data for the past eight years. The district was categorized into several classes based on geometric interval of malaria incidence rate/10,000 individuals.

2.3 Geo-database Preparation and Data Analysis

A personal geodatabase was prepared in ArcGIS environment based on Universal Transverse Mercator (UTM) projection system and World Geodetic System - 84 (WGS-84) datum. The administrative boundary of block was digitized on the referenced co-ordinate system and the label was created for each block. The malaria incidence data at block level was integrated into the GIS based layer for further processing and analysis. For each year three columns was generated for total annual incidence *P. falciparum* and *P. vivax* incidence. The annual malaria incidence at the block level for each year was determined to assess the malaria spatial distribution.

2.4 Spatial Correlation Analysis

The local spatial auto-correlation [16] was investigated using Local Moran's *I* statistics in ArcGIS software v9.3 (ESRI Inc., Redlands, CA) to examine the presence or absence of local spatial auto-correlation using the incidence of malaria cases between pairs of blocks for the eight years period. The local Moran's *I* statistics is calculated as:

$$I_i(d) = (x_i - \bar{x})\sum_{j=1}^{n} W_{ij}(d)(x_j - \bar{x}), j \neq i$$

Where, $\bar{x}$ is the average number of malaria cases in blocks; x_i and x_j are the number of malaria cases at block *i* and *j* respectively; W_{ij} is the spatial weight matrix reliant on the well-defined distance lags (in km) between blocks *i* and block *j* (where $W_{ij}(d)$ = 1 if the distance between blocks *i* and *j* is within *d*; otherwise $W_{ij}(d)$ = 0). The local Moran's *I* values vary from -1 to 1. Positive values point out the incidence of significant clustering, negative values (less than zero) designates the divergent or inconstant patterns, and values equivalent to zero signpost incidence of random spatial pattern [17,11].

2.5 Spatial Cluster Analysis

The incidence of spatial cluster existence was intended for each block from 2009 to 2016. The local Getis-Ord G statistics (G_i^*) statistics were estimated for each block based on the spatial weights using dissimilar threshold spaces (*d*) as designated as follows:

$$G_i^*(d) = \sum_j \frac{W_{ij}(d)x_j}{\sum_j x_j}$$

Where, W_{ij} is a spatial weight matrix at assumed distance lag in kilometers (*d*) ($W_{ij}(d)$) is 1 when the distance from block *j* to *i* is within *d*, or else $W_{ij}(d)$ is 0). The occurrence of local grouping of malaria cases in the study blocks was dogged using z-score values. The higher positive Z score value, >1.96 signpost that the block *i* is encircled by comparatively high malaria occurrence blocks, whereas a high but negative Z-score value specify that the block *i* is bounded by somewhat low malaria incidence block. Z-score values ≥ -1.96 and ≤1.96 directs incidence of a malaria or random distribution [18].

3. RESULTS

A descriptive characteristic of malaria incidences/10,000 individuals during the period between 2009 and 2016 is illustrated in Table 1. The maximum annual malaria incidence rate was recorded as 6.05/ 10,000 individuals in 2009 whereas, the low incidence rate was recorded in 2016 (2.28/ 10,000 individuals). Malaria incidence rate per year progressively decrease (except in 2012). Moreover, the highest *P. vivax* incidence/10,000 individuals was recorded in 2010 (4.55/10,000 individuals) and the lowest incidence rate was recorded in 2016 (1.84/10,000 individuals). The maximum *P. falciparum* incidence /10,000 individuals was recorded in 2009 (1.18/10,000 individuals) and less incidence rate of *P. falciparum* was estimated in 2013 (0.40/10,000 individuals). Even though the occurrences of *P. falciparum* malaria were typically 3 ~ 5 times lower than those of *P. vivax* malaria incidence in every consistent year, the disparity in annual incidence of the disease was essentially steady with that of *P. vivax* malaria (Fig. 1).

Malaria incidence rates in Murshidabad district showed an overall tendency of decline over the past eight years (2009-2016) (Fig. 1). Both the species had similar trends to decline, although annual *P. vivax* malaia case numbers have decreased at a faster rate since the early 2009s. In 2013, the incidence rate was slightly lower for both the species. The incidence ratio of malaria during the period between 2009 and 2016 was 2.99. The incidence ratio of *P. falciparum* and *P. vivax* were calculated as 3.12 and 2.70 respectively. Meanwhile, the incidence ration of *P. vivax* malaria was higher compare to the *P. falciparum* malaria. A significant correlation between the incidence rates of malaria caused by the two most parasite prevalent parasite species, *P. falciparum* and *P. vivax* was analyzed. The highest significant correlation was observed in 2010 (r = 0.90, P <*0.001*) and the lowest correlation was observed in 2013 (r = 0.47, P <*0.008*).

Table 1. Descriptive statistics of the malaria incidence / 10,000 individuals in Murshidabad district from 2009 to 2016

Year	Mean	Median	Standard deviation	Kurtosis	Skewness
Annual malaria incidence/10,000 individuals					
2009	6.05	3.84	7.59	1.31	1.47
2010	5.71	2.0	8.02	2.44	1.74
2011	3.99	1.1	6.08	3.39	1.6
2012	3.4	0.91	5.67	5.07	2.29
2013	3.02	1.36	4.15	3.62	1.95
2014	3.42	2.09	4.21	1.98	1.68
2015	2.81	1.8	3.32	3.67	1.97
2016	2.28	1.47	2.81	3.58	2
Pv incidence / 10,000 individuals					
2009	4.41	2.57	5.64	0.76	1.38
2010	4.55	1.82	6.55	2.47	1.79
2011	3.25	0.81	5.17	3.43	2
2012	2.78	0.88	4.8	5.31	2.37
2013	2.60	1.1	3.86	4.31	2.14
2014	2.95	1.72	3.63	1.4	1.57
2015	2.41	1.46	3.03	4.07	2.07
2016	1.84	1.23	2.41	3.73	2.07
Pf incidence / 10,000 individuals					
2009	1.18	0.66	1.51	4.18	1.87
2010	0.82	0.3	1.1	2.09	1.61
2011	0.58	0.22	0.92	6.37	2.41
2012	0.33	0.04	0.54	5.1	2.23
2013	0.29	0.15	0.37	0.95	1.32
2014	0.57	0.41	0.69	9.64	2.64
2015	0.4	0.25	0.45	1.53	1.42
2016	0.44	0.16	0.6	6.26	2.27

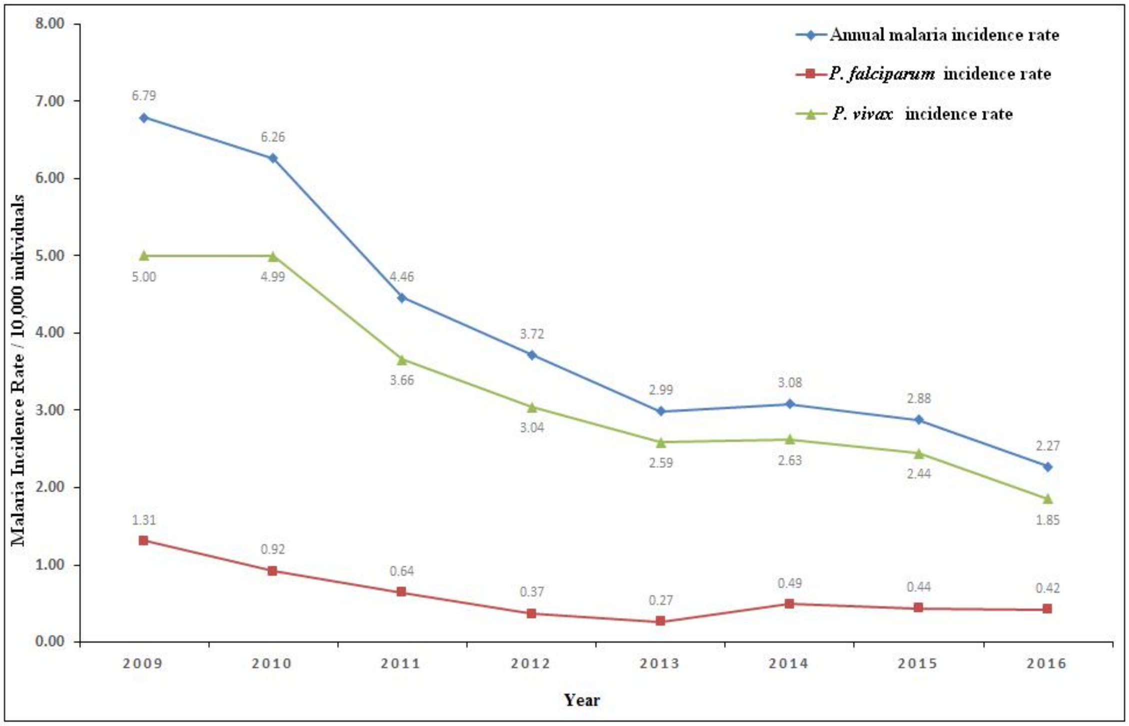


Fig. 1. Malaria incidences in Murshidabad district for the period of 2009 - 2016

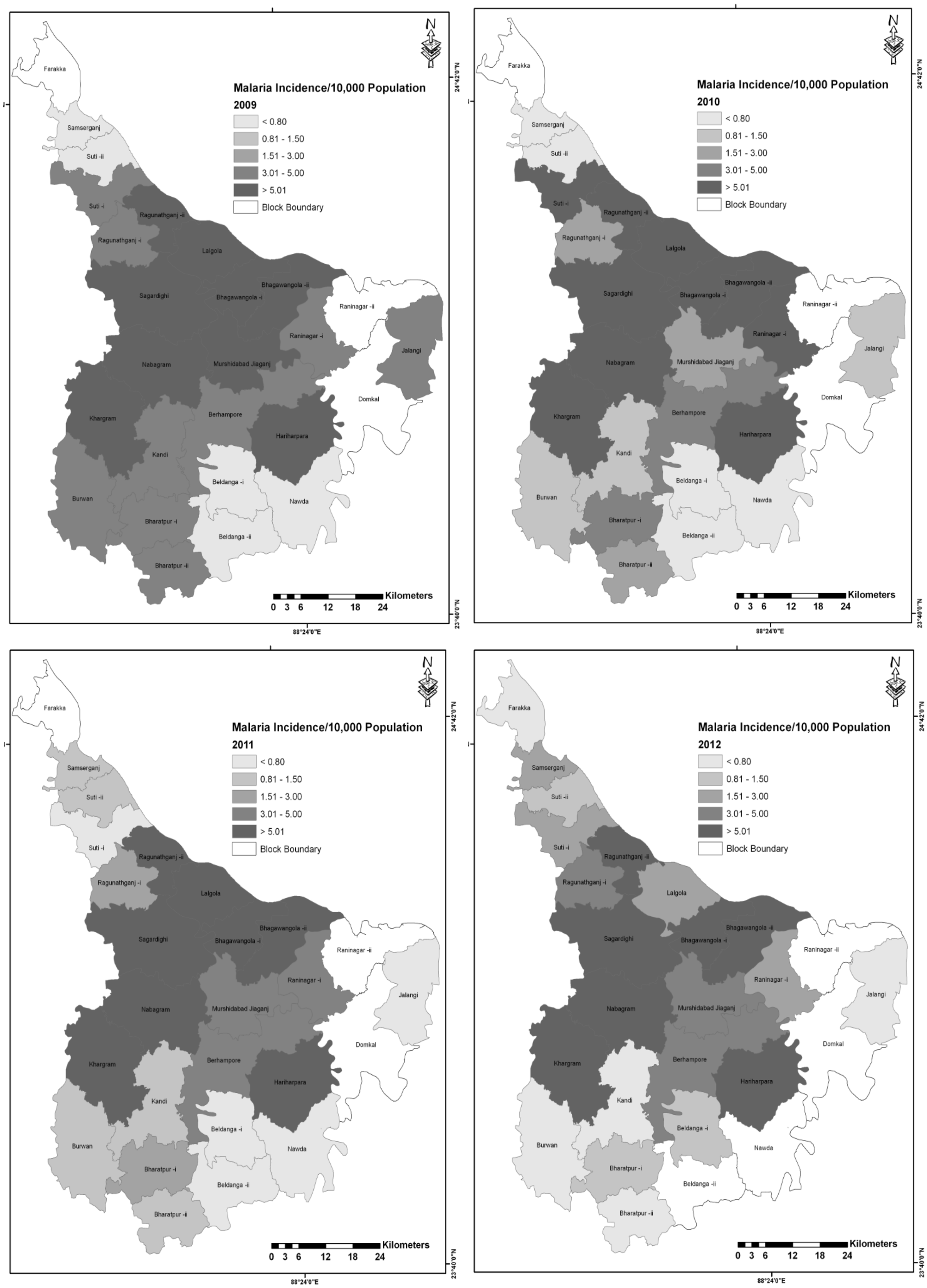
3.1 Patterns of Annual Malaria Incidences in Murshidabad District

The entire district was divided into five categories based on the incidence statistics (Fig. 2). The blocks having no malaria case was excluded in this analysis. The darker shades represented high incidence rate and lighter shades indicated the low incidence rate. Moreover, class I, indicate the low incidence rate and class V, indicated the high incidence rate. The central part of the district was highly affected by the disease in comparison to its surrounding areas. No malaria cases were recorded from the Farakka, Raninagar-ii and Domkal block for the period between 2009 and 2011. From 2012 to 2014, malaria incidence rate were very less, almost negligible in Beldanga, Jalangi and Nawada block. In between 2015 and 2016, Bhagwangola, Hariharpara and Nabagram block showed the highest malaria incidence rate. Furthermore Suti, Raghunathganj, Behrampur, Raninagar, Jiaganj, and Sagardighi block portrayed the moderate incidence rate during the entire study period. Bharatpur, Burwan, Kandi, Samserganj and Khargram block showed medium to low incidence rate for the period between 2009 and 2016.

3.2 Spatial Patterns of *P. vivax* Malaria Incidences

In general, Murshidabad district had higher *P. vivax* malaria the incidence rate (3.28/10,000 individuals) than the *P. falciparum* malaria incidence (0.61/10,000 individuals) over the eight year period ($t = 7.85$, degrees of freedom [df] = 6, $P < 0.0001$). At the block level, *P. vivax* and *P. falciparum* malaria exhibited disseminated spatial patterns and temporal dynamics. Analysis of the data from 2009 to 2016 showed a mean correlation of 0.88 ($P<0.007$) between two species.

The entire district has been divided into five categories of *P. vivax* malaria incidences (Fig. 3). The darker shades showed the higher incidence rate and vice-versa. Spatial patter of *P. vivax* malaria incidence showed that rate was higher in the central part of the district and the lower incidence rate was observed in the south-east and northern blocks. Raninagar i, Bhagwangola, Sagardighi, Nabagram, Hariharpara, Raghunathganj blocks were portrayed the higher incidence rate of *P. vivax* during the entire study period. Furthermore, Khargram, Suti, Samserganj, Berhampur, Raninagar blocks were high to moderate *P. vivax* incidence rate. Nawada, Domkal, Lalgola and Farakka blocks were moderate to low *P. vivax* incidence rate.



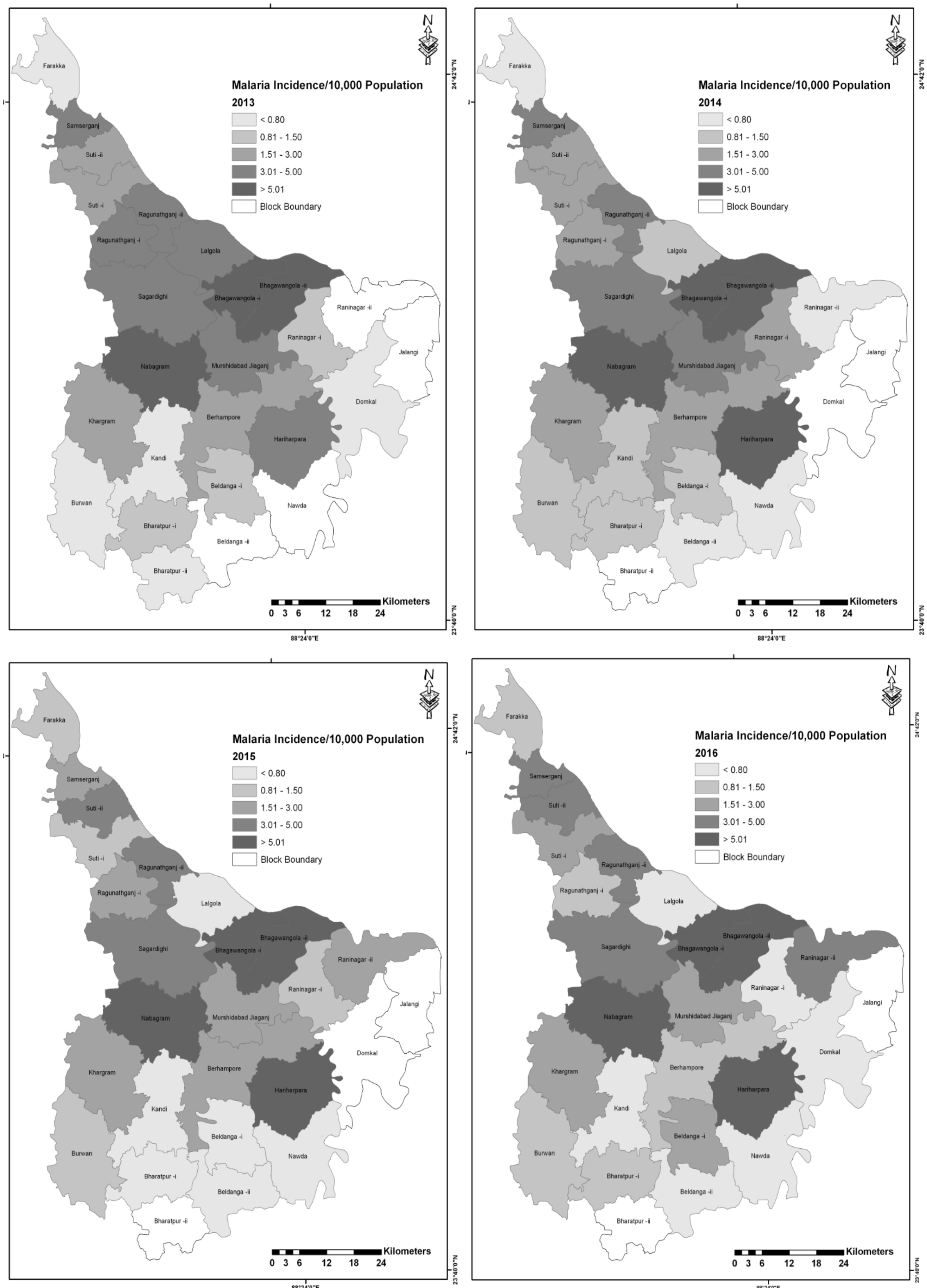
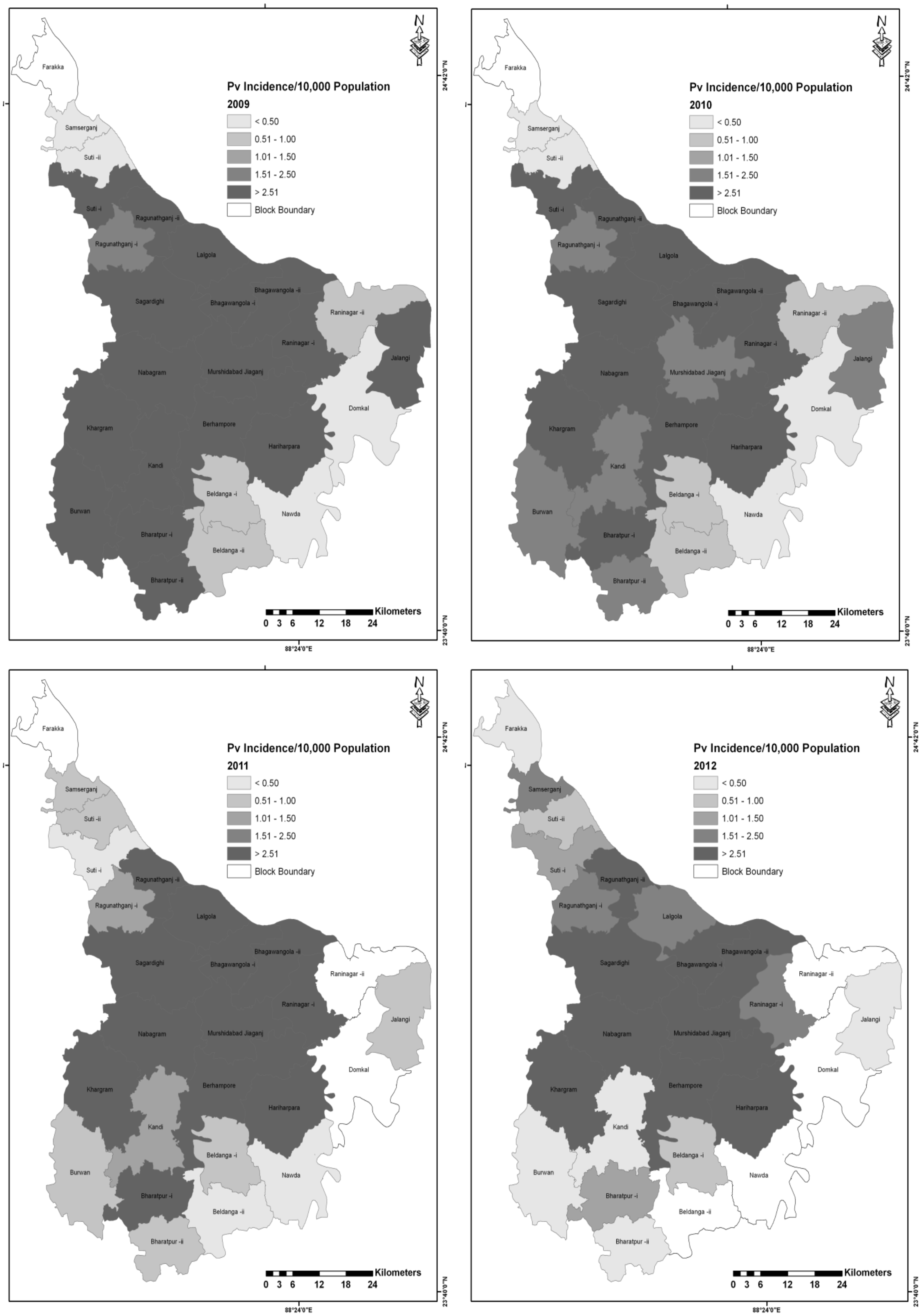


Fig. 2. The annual malaria incidence rate / 10,000 individual of Murshidabad district during the period between 2009 and 2016


Pv Incidence/10,000 Population
2009
< 0.50
0.51 - 1.00
1.01 - 1.50
1.51 - 2.50
> 2.51
Block Boundary
Farakka
Samserganj
Suti -ii
Suti -i
Ragunathganj -ii
Ragunathganj -i
Lalgola
Sagardighi
Bhagawangola -i
Bhagawangola -ii
Raninagar -ii
Raninagar -i
Jalangi
Nabagram
Murshidabad Jiaganj
Domkal
Khargram
Berhampore
Hariharpara
Kandi
Beldanga -i
Nawda
Burwan
Bharatpur -i
Beldanga -ii
Bharatpur -ii
Kilometers
0 3 6 12 18 24
24°42'0"N
23°40'0"N
88°24'0"E
Pv Incidence/10,000 Population
2010
Pv Incidence/10,000 Population
2011
Pv Incidence/10,000 Population
2012

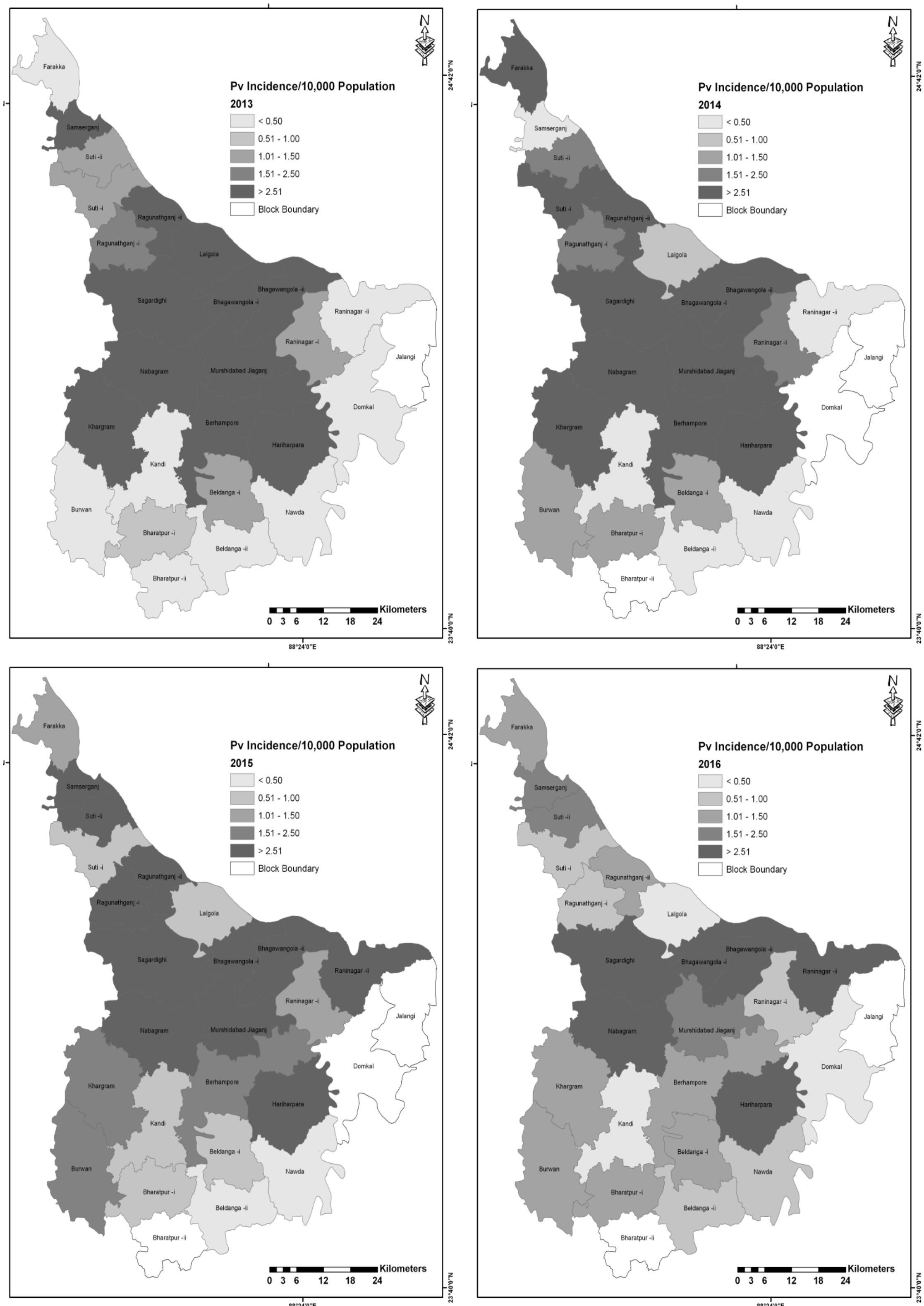


Fig. 3. The annual *P. vivax* malaria incidence rate / 10,000 individual of Murshidadad district during the period between 2009 and 2016

3.3 Spatial Patterns of *P. falciparum* Malaria Incidences

The heterogeneous pattern of *P. falciparum* malaria distribution was observed in the study area and also the rate of incidence rate was lower in comparison to *P. vivax* malaria incidence rate (Fig. 4). Generally, in Murshidabad district, the study blocks had higher *P. falciparum* malaria incidence rate in 2009 than 2016 (t = 3.29; *P<0.002*). The study blocks were also categorized into five classes based on the geometric interval in ArcGIS software v 9.3. The higher *P. falciparum* malaria incidence rate was recorded for the Nabagram and Bhagwangola block during the period between 2009 and 2016. The lowest incidence rate was observed in the south-east, southern and northern part of the district. The central part of the district portrayed high to moderate *P. falciparum* malaria incidence rate.

3.4 Distribution of Malaria Spatial Auto-correlation

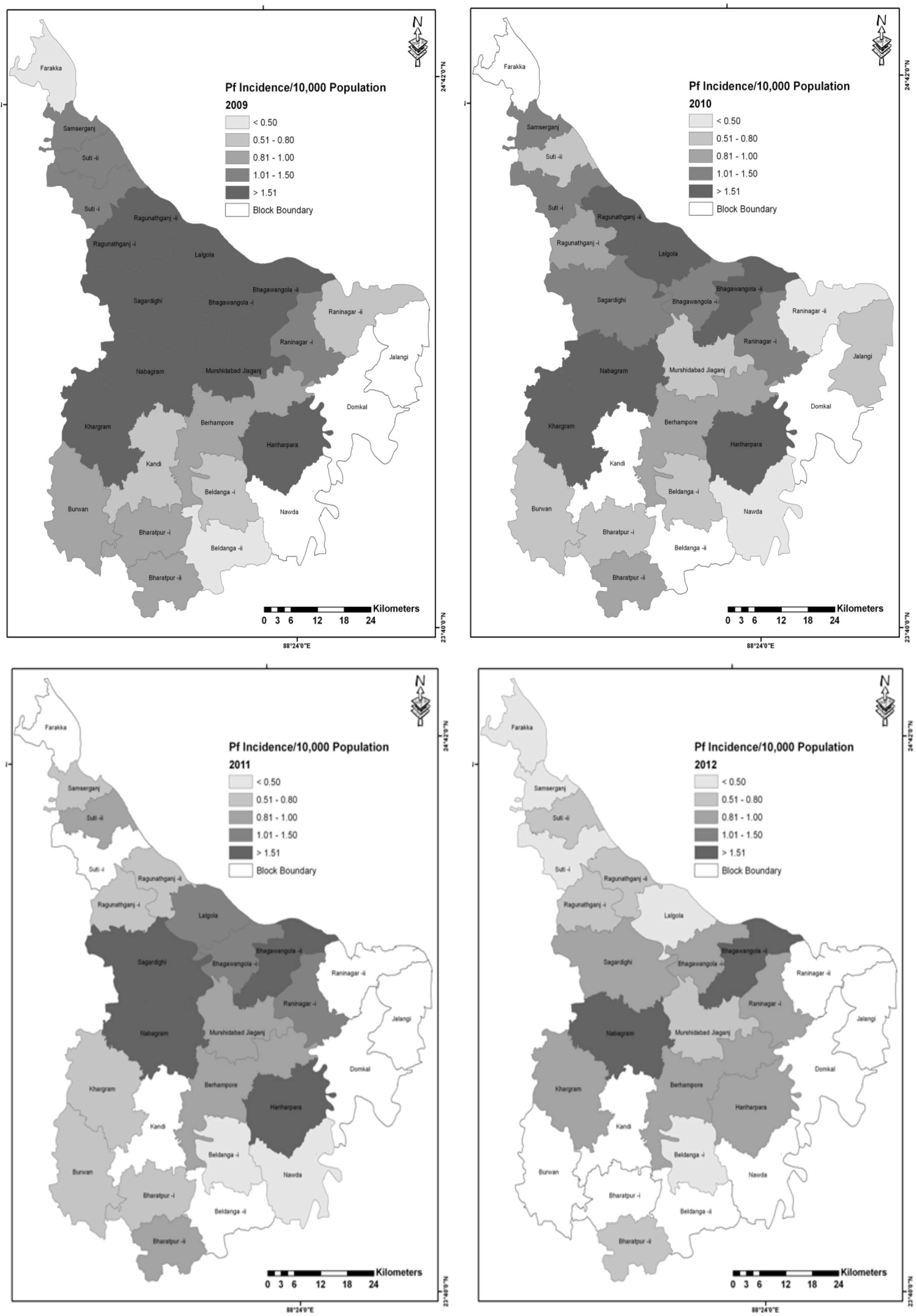
To understand the spatial auto-correlation quantitatively, Moran's I analysis was performed and results illustrated in Fig. 6. The spatial auto-correlation analysis for the annual malaria incidence, *P. falciparum* malaria incidence and *P. vivax* malaria incidence in Murshidabad district showed that Moran's *I* values were statistically significant (Table 2). The results inferred that malaria dissemination was usually auto-correlated in space in the district. The Moran's *I* values of total annual incidence rate decreased from 2009 to 2011, then increased until 2013, and dramatically increased afterward. The Moran's *I* values for *P. falciparum* malaria were remarkably fluctuant and generally higher than those *P. vivax* malaria, representing that the *P. vivax* malaria epidemic area was more concentrated than *P. falciparum* malaria. Consequently, the Moran's I value for *P. vivax* were concurrently fluctuant with the annual malaria incidence rate. The highest value of Moran's *I* for *P. falciparum* malaria was recorded in 2013 (0.94), whereas, the lowest value of Moran's *I* was recorded in 2012 (0.53).

3.5 Distribution of Spatial Cluster of Malaria

The results of the analysis were interpreted within the context of the null hypothesis. Using the block level incidence rate of malaria spatial cluster analysis (based on Getis-Ord G statistics) was performed in each year for the total annual incidence of malaria, *P. vivax* malaria and *P. falciparum* malaria (Fig. 5). The analysis of the results showed that high malaria incidence affected blocks were clustered in some particular area. The results showed statistically significant high-low clustering pattern for both the malaria cases in 2012 and 2013 (Table 3). As the *P-value* is less than 0.5 for both the *P. vivax* malaria and *P. falciparum* malaria, and the z-score is positive, indicated spatial distribution of high incidence block in the district was more spatially clustered than would be expected if underlying spatial processes were truly random. The details description of 'high-low clustering pattern of malaria in Murshidabad district is represented in Table 3.

Table 2. Spatial auto-correlation of malaria incidences in Murshidabad district during the period between 2009 and 2016

Year	*Moran's I*	Z-Score	*P-value*
Total malaria incidence			
2009	0.795	4.678	0
2010	0.72	4.21	0
2011	0.69	4.05	0.0005
2012	0.74	4.35	0.00013
2013	0.728	4.28	0.00028
2014	0.638	3.78	0.0005
2015	0.67	3.95	0.0008
2016	0.74	4.39	0.0001
***P. Falciparum* incidence**			
2009	0.74	4.36	0.00013
2010	0.65	3.81	0.0001
2011	0.63	3.76	0.0004
2012	0.52	3.15	0.0001
2013	0.94	3.49	0
2014	0.84	4.79	0.0002
2015	0.74	4.29	0.0001
2016	0.91	5.39	0
***P. vivax* incidence**			
2009	0.81	4.76	0.0002
2010	0.73	4.27	0.0002
2011	0.66	3.91	0.0009
2012	0.73	4.3	0.0017
2013	0.72	4.3	0.00009
2014	0.66	3.91	0.0003
2015	0.67	3.96	0.0001
2016	0.77	4.32	0.000


Pf Incidence/10,000 Population
2009
< 0.50
0.51 - 0.80
0.81 - 1.00
1.01 - 1.50
> 1.51
Block Boundary
Farakka
Samserganj
Suti -ii
Suti -i
Ragunathganj -ii
Ragunathganj -i
Lalgola
Bhagawangola -ii
Bhagawangola -i
Sagardighi
Raninagar -ii
Raninagar -i
Jalangi
Nabagram
Murshidabad Jiaganj
Domkal
Khargram
Berhampore
Hariharpara
Kandi
Beldanga -i
Burwan
Nawda
Bharatpur -i
Beldanga -ii
Bharatpur -ii
Kilometers
0 3 6 12 18 24
88°24'0"E
24°42'0"N
23°40'0"N
Pf Incidence/10,000 Population
2010
Pf Incidence/10,000 Population
2011
Pf Incidence/10,000 Population
2012

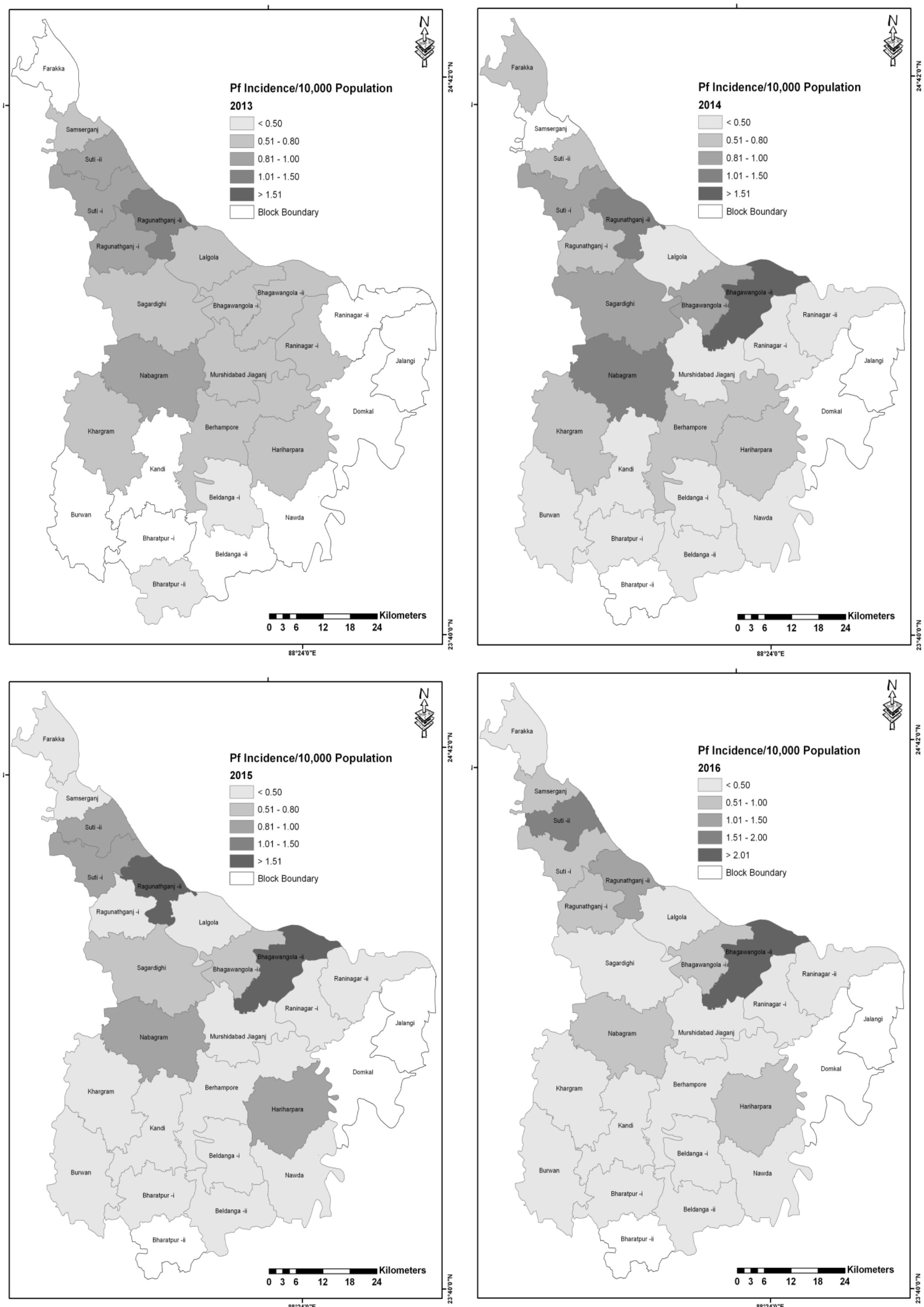


Fig. 4. The annual *P. falciparum* malaria incidence rate / 10,000 individual of Murshidabad district during the period between 2009 and 2016

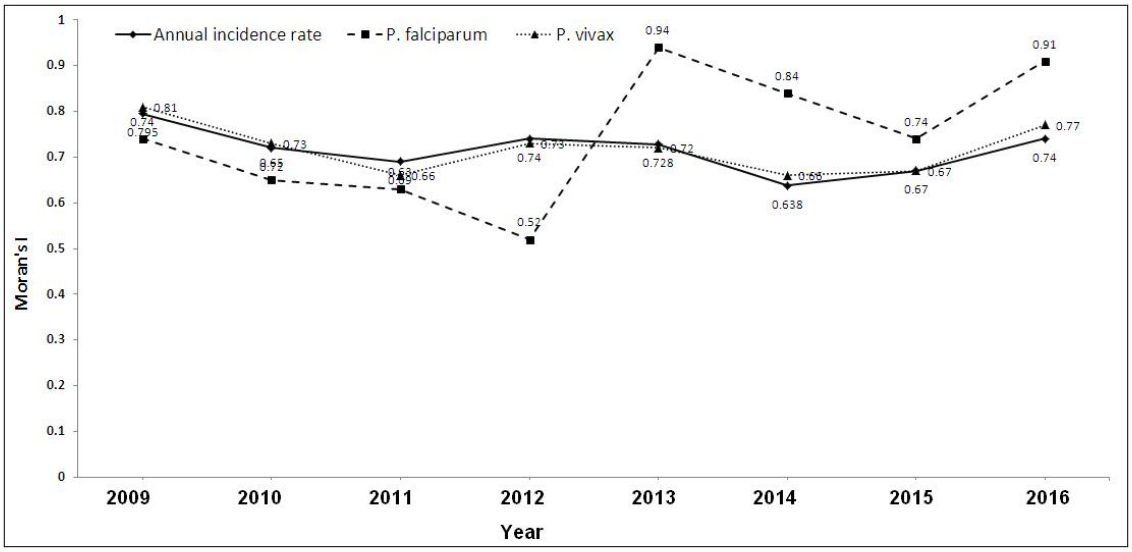


Fig. 5. Yearly spatial auto-correlation of malaria incidence rate (per 10,000 individuals) in Murshidabad district for the period 2009 – 2016

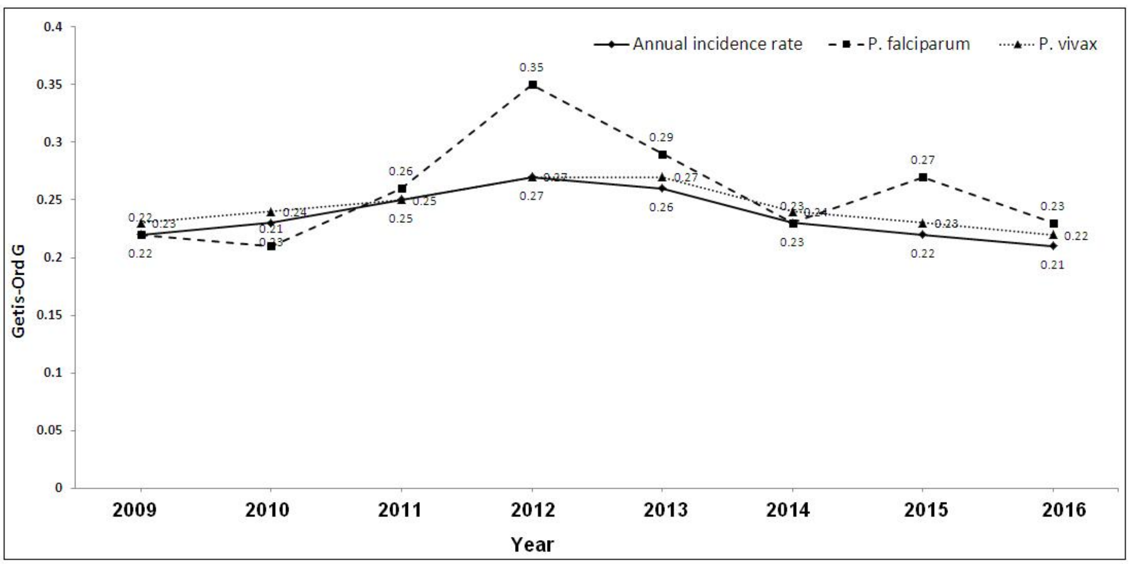


Fig. 6. Yearly temporal clustering pattern of malaria incidence rate (per 10,000 individuals) in Murshidabad district for the period 2009 – 2016

4. DISCUSSION

Recognition and treatment of the infectious reservoir is precarious to the accomplishment of malaria elimination crusades [19]. Here, we executed the retrospective analysis of malaria incidence data for the past 8 years in Murshidabad district and the findings denote that malaria remains a severe health menace in the Murshidabad district. While a regular diminution in block-wise malaria cases has been perceived over the study period, there was a high geographical dissimilarity in malaria incidence rate across the district. The regions are situated in environmentally favorable region and this accelerates in vector multiplication [20]. The variations in annual incidences of both *P. vivax* and *P. falciparum* malaria mainly charted the similar patterns demonstrating that definite aspects rather than biological characteristics of parasites regulate the propagation of the disease. High incidence blocks were concentrated in the central part of the district. The adjacent Birbhum district on the western side has suitable environmental condition of lower Gangetic plain could have impacted on the population at risk and the incidence of reported cases [21,22]. Cross-border malaria could be other causes since borders are quite open and people of either Bangladesh or adjacent regions can easily cross the border [20]. Moreover, the higher human migration from Bangladesh on the eastern side of the district perhaps indicates higher levels of malaria transmission to seek the malaria treatment [23].

Table 3. High-low clustering of malaria incidences in Murshidabad district during the period between 2009 and 2016

Year	Getis Ord G	Z-Score	*P-value*
Total malaria incidence			
2009	0.22	4.17	0.00031
2010	0.23	4.18	0
2011	0.25	4.73	0.002
2012	0.27	4.86	0.001
2013	0.26	4.6	0.0004
2014	0.23	4.48	0.00007
2015	0.22	4.19	0.0002
2016	0.21	3.81	0.0001
***P. falciparum* incidence**			
2009	0.22	3.475	0.0005
2010	0.21	3.719	0.0002
2011	0.26	4.38	0.0001
2012	0.35	5.49	0.0000
2013	0.29	3.89	0.0009
2014	0.23	3.47	0.0005
2015	0.27	3.07	0.002
2016	0.23	2.82	0.004
***P. vivax* incidence**			
2009	0.23	4.35	0.0009
2010	0.24	4.29	0.0008
2011	0.25	4.8	0.0005
2012	0.27	4.88	0.007
2013	0.27	4.79	0.0001
2014	0.24	4.75	0.0001
2015	0.23	4.46	0.0008
2016	0.22	4.29	0.0018

Spatial auto-correlation analysis revealed that spatial association of malaria affected blocks were not randomly distributed in the study area, proposing that malaria transmission in one block is directly or indirectly linked with the transmission in adjacent block. Getis-Ord G further confirmed that malaria cases clustered in the district. This may be because of the local resemblances in climatic and environmental factors that are interconnected to the dynamics of vectors. Additionally, the clustering of high incidence block may be associated to the socio-economic factors that shake the effectiveness of vector control programme [11,24]. A previous investigation has evidently shown that malaria is directly connected to socio-economic factor in West Bengal. It is perceived that in certain high-incidence area, malaria control programme contain government aided public health centers and local vector control exertions [25] and the disease persists in the rural and boarder areas which promote stress the requirement for a sustained and fortified malaria control programme. Therefore, significant enhancements of malaria prominence in the central regions and likelihoods for perfections in the bordering endemic regions.

Here, two cluster recognition methods were used to delineate the different types of malaria clusters, suggested by other researchers [10,13]. The analysis using the geospatial and spatial statistical technique could investigate the spatial and temporal dissemination of malaria and recognize times and extents of increased risk in Murshidabad district, where both *P. vivax* and *P. falciparum* malaria are predominant. The results also showed in a sharp decrease in *P. falciparum* malaria, but *P. vivax* malaria incidence rate showed only a slight decline. Hence, *P. vivax* became the most prevalent malaria parasite in Murshidabad district. Such a difference response to control measure may be directly linked to the intrinsic biological properties of *P. vivax* [26,15]. Present study suggests that appropriate countermeasures should target high threat areas accordingly and the undelaying sources of increased risk in the recognized areas.

Malaria distribution patterns in Murshidabad district have altered. The epidemics of both the *P. vivax* and *P. falciparum* malaria are changed. The environmental factors are exceedingly persuading malaria transmission that could be measured for further research. Spatial cluster of *P. vivax* and *P. falciparum* malaria rehabilitated with time, which were primarily placed in the central part of the district and the Bhagirathi river basin. The result derived in this study should be considered in imminent malaria prevention and control and in the expansion of spatio-temporal models of malaria transmission in Murshidabad district as well.

5. CONCLUSION

Spatial analysis of malaria incidence through GIS tool facilitated in documentation, depiction, monitoring and instituting relationship between malaria incidence and other potentially related factors. Despites its restraint which are the no taking in account the environmental factors, the present work delivers valuable evidence on the local distribution patterns of malaria in Murshidabad district. Consequently, the spatial statistical analysis contributed to identify the presence of spatial and spatio-temporal clusters of *P. vivax* and *P. falciparum* malaria in Murshidabad district. Although a gradual reduction in malaria cases throughout the district had been perceived over this period, there were substantial spatial and temporal heterogeneity at the block level. However, further studies should be carried out to identify the malaria epidemics and risk factors of malaria transmission within the study area.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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