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Studying Malaria Epidemic for Vulnerability Zones: Multi-Criteria Approach of Geospatial Tools

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Abstract

Introduction: Despite serious interventions worldwide, malaria remains a significant cause of global morbidity and mortality. Malaria endemic zones are predominant in the poorest tropical regions of the world, especially in continental Africa and South-Asia. Major Indian population reside in malaria endemic zones which are tribal dominated and inaccessible. Lack of suitable data, reporting and medical facilities in malaria vulnerable regions handicaps the decision makers in taking adequate steps. Natural resources were mapped to establish their possible linkage with malaria incidence and to delineate malaria hotspots using geo-spatial tools. **Methods:** Remote sensing data along with various ancillary data such as socio-economic (population in general, child population, tribal population, literacy), epidemiology (Malaria API and Pf cases) and environmental parameters (wetness, forest cover, rainfall, aspect, elevation, slope, drainage buffer, and breeding sites) were integrated on GIS platform using a designed weight matrix. Multi criteria evaluation was done to generate hotspot for effective monitoring of malaria incidences. **Results:** Various thematic layers were utilized for integrated mapping, and the final map depicted 59.1% of the study area is vulnerable to high to very high risk of malaria occurrence. Manoharpur Administrative Block consisted of 89% of its area under high to very high probability of malaria incidence and it needs to be prioritized first for preventing epidemic outbreak. Various village pockets were revealed for prioritizing it for focused intervention of malaria control measures. **Conclusions:** Geospatial technology can be potentially used to map in the field of vector-borne diseases including malaria. The maps produced enable easy update of information both spatially and temporally provide effortless accessibility of geo-referenced data to the policy makers to produce cost-effective measures for malaria control in the endemic regions.

Keywords

Geo-Spatial Tools, GIS, Integrated Mapping, Multi-Criteria Analysis, Remote Sensing

1. Introduction

Malaria and tuberculosis have global coverage and although no longer classified as Neglected Tropical Diseases (NTDs), share the characteristic of insufficient attention from the research community towards control and therapy. Tropical regions are home to both diversified natural resources and local populations from ancient times, allowing the development of traditional practices in disease control and management [1]. Malaria is a parasitic protozoal disease, caused by parasites of *Plasmodium* genus and transmitted to man by species of infected female Anopheles mosquito [2]. The parasite belongs to the diverse group of unicellular eukaryotes called protozoa. The genus has 250 *Plasmodium* species but *Plasmodium falciparum* and *Plasmodium vivax* are two key species found in the Indian sub-region [3]. Most prevalent among them is the *Plasmodium falciparum* which alone is responsible for the maximum deaths [4]. Falciparum malaria has the highest fatality rate worldwide [5]. It is estimated that 20% of the world population in tropical areas and the some of the poorest countries, are living under the high risk of malaria [6].

The spread of malaria depends on three important factors of malaria parasite, human host and the female Anopheles mosquito. The process begins when the germs enter the mosquito as soon as it bites a person infected with malaria. It sucks up its blood along with some germs, and the germs start growing in the body of a mosquito which takes about 7 - 10 days [7]. This is called the incubation period when the same mosquito bites a healthy person; it transfers some of the malarial germs into the new host thus causing infection. An exponential increase in mosquito-borne diseases has been reported in the recent past. It is primary because of the development of drug resistance in previously contained diseases and discovery of novel diseases.

Around 2.5 million malaria cases are reported annually from Southeast Asia, of which India alone contributes 76% [8]. Behind all statistics and graphs there exists the tragedy that malaria takes the life of an African child every minute. The tribal, hilly and remote places constitute a large part of the country's population (85%), and around 95% are found to reside in malaria endemic zones [9]. The cases of *P. falciparum* (53.7%) and *P. vivax* (46.3%) are observed to be widespread (both independently and together) in India, particularly in the north-eastern States and States of Jharkhand, Chhattisgarh, Madhya Pradesh, Rajasthan, and Orissa in India [10].

Various studies have been done on RS data and its malarial application and other vector-borne diseases over a period of time [11]. Using geospatial technology that is satellite images, Digital Terrain Model (DTM) and GPS superior spatial analysis was done for an effective environment strategy in urban areas of Dar es Salam by Dongus *et al.* [12]. In Venezuala, Delgado *et al.* [13] utilized geospatial technology to identify and delineate a malaria corridor. Areas which are vulnerable to vector habitat suitability have been assessed using satellite data at various resolutions such as IRS LISS I, LISS II and WiFS [14] [15] [16]. An integrated approach is required to tackle the above problem wherein the incorporation of latest technology is required to predict the problematic areas, spatial mapping and assessment of transmission risk. Further, reliable and accurate data is needed for vector control and vector borne disease control and management [17] [18].

A pivotal role is played by the forest ecosystems towards malaria transmission [19]. The suitable habitat for vectors is surface water for reproduction; humidity needed for adult mosquito survival, influence of temperature for developmental rates of both vector and parasite populations [20] [21]. Thus, the mosquito population varies according to the forest locality and their behavior is governed by forest microclimate, human population and social behavior. Forests with hilly areas and streams arising from slopes which provide efficient breeding sites are conducive for malaria vector growths [22]. Forest ecosystems were reported as meso-endemic to hyper-endemic to the conditions of malaria [23].

The advent of information processing tools which can be used to map natural resources, climatic factors, and disease epidemiology provides a powerful mechanism for identifying previously unknown disease causing factors and control mechanism. In order to understand the frequent malaria epidemics it is necessary that it is understood at large both spatially and temporally with respect to the various environmental parameters being an environmental disease [24]. Satellite data of various resolutions when coupled with geographic information system (GIS) provide huge scope to analyze large data at low cost, accurate and in an efficient manner. Such data have been employed to study the mosquitoes breeding habitats in India, where the remotely sensing (RS) data was found capable of mapping vector habitat areas, estimating vector abundance and vector density.

Landsat satellite data was used to predict Anopheles mosquito population dynamics in the coastal plain of Chiapas, Mexico, by integrating GIS and field research [25]. Landsat TM data was found useful in identifying Anopheles larva habitat sites in California [26]. It was also used in mapping rift valley fever vectors in Kenya, East Africa and image was classified and delineated roads, water, vegetation which helped in revealing habitat types which produced low, medium and high larva producing groups.

Direct observation of many vector diseases is not possible. Utilizing GIS and Landsat TM imagery, Wood *et al.* [26] identified mosquito producing fields in California, they were successful in correlating Anopheles larva density with reflectance of canopy growth in early season. Other parameters such as pastures with livestock, distance between rice fields and source of blood meal for mosquitoes were measured using GIS and it was concluded that rice fields located near pastures has more larval production than rice fields which were away from pastures.

Ahmed [27] used Multi criteria analysis (MCA) by integrating various thematic layers along with RS data and on GIS platform for malaria risk mapping for the district of Kersa in Ethiopia. Most of the natural factors involved were assessed and malaria risk maps were produced. Qayum *et al.* [28] incorporated various socio-economic, epidemiological and geographic features and integrated these datasets to identify malarial hotspots by using twelve thematic layers. Many tribal areas in India have been studied for malaria dynamics including Sonitpur district in Assam [5]; Koraput district in Orissa [29]; Mewat region in Harayana [30] and Udalguri district of Assam by Yadav *et al.* [31].

The present study was aimed for tribal dominated Indian State of Jharkhand, where malaria incidences are high yet sufficient database is lacking and malaria hotspots have not been identified so far leading to numerous problems in effective monitoring of the epidemic disease. The objectives of the current study was to apply GIS tools on RS and other ancillary data for visualizing and analyzing the various environmental, socio-economic and epidemiological data to reveal trends and interrelationships towards malaria incidences and to obtain a malaria risk map or vulnerability map of the target malaria endemic zone.

2. Materials and Methods

2.1. The Study Area

The present study area lies between the geographic coordinates of Latitude 22˚04'21"N to 22˚52'42"N and Longitude 84˚58'08"E to 85˚44'32"E and the total geographical area covered by it is approximately 355,136 Ha (**Figure 1**). It falls in Chakardharpur subdivision of the West Singhbhum district of the Jharkhand state in India. It is basically a tribal dominated subdivision. The range of elevation from the mean sea level differs from 170 m to 883 m. The forests of this area are best described by Champion and Seth (1968) [32], as moist peninsular valley *Shorea robusta* (Sal) under the category [3C/C2e (iii)]. Natural regeneration seems to be best seen here and disparity in tree structure and composition is found to be different with moisture because of variation in aspect and slope of the land. Other important features are hills alternating with valleys, steep mountains and dense forests on the mountain slopes. Besides, Asia's famous dense Sal forests are found in Saranda forests which form a part of the subdivision.

2.2. Data Preprocessing and Analysis

The data used for the analysis was Landsat OLI (Path: 140/44, Row: 140/45, dated 18-12-2015) having 30 m spatial resolution with UTM projection (Zone 45). The satellite data was downloaded from United States Geological Survey (USGS) portal and was obtained in 11 bands. The satellite images were radiometrically and geometrically corrected. Various individual bands were layer stacked to obtain a composite image for further analysis. Various scenes were mosaiced to obtain a single image. The vector layer of the study area was used to extract the false colour composite (FCC) from the larger mosaicked image.

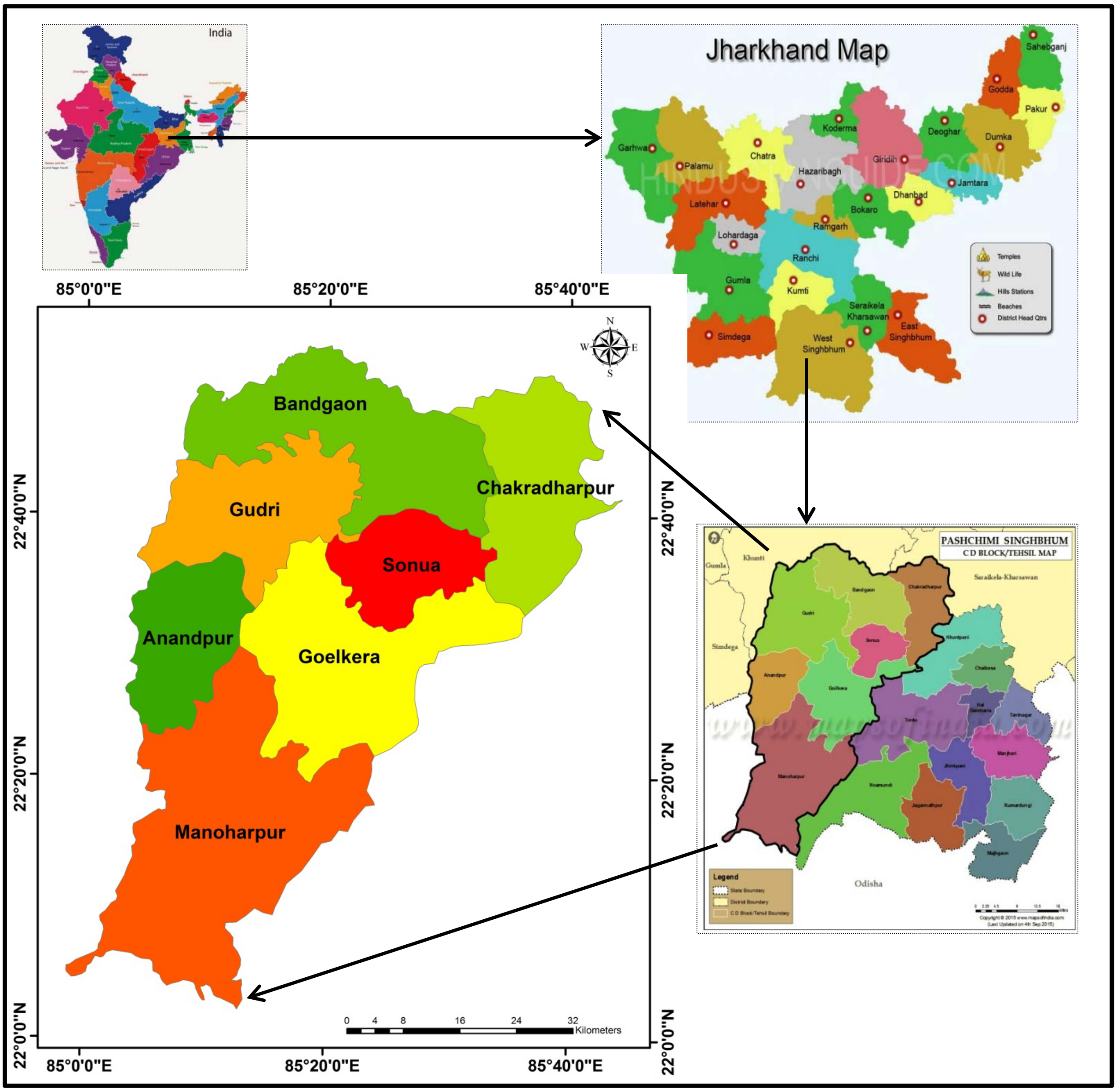


Figure 1. Study area (clockwise): → India → Jharkhand State → West Singhbhum district → Chakardharpur.

Digital elevation model (DEM) was downloaded from the USGS portal (ASTER DEM, resolution 30 m). Various obtained tiles were mosaicked and a subset was generated from the mosaic image using the vector layer for the study area. Thematic maps such as slope, aspect, elevation, drainage maps were generated using spatial analyst ArcGIS (10.1) and ERDAS Imagine software. Ancillary data such as rainfall, general population, child population, tribal population, literacy, epidemiology (Malaria API and Pf cases) were used to generate individual maps based upon interpolation technique and as per the schematic flowchart (Figure 2).

Three major layers of the mapping include environmental, socio-economic and epidemiology parameters with standard weights and ranks, which were decided based on various research findings (Figure 3).

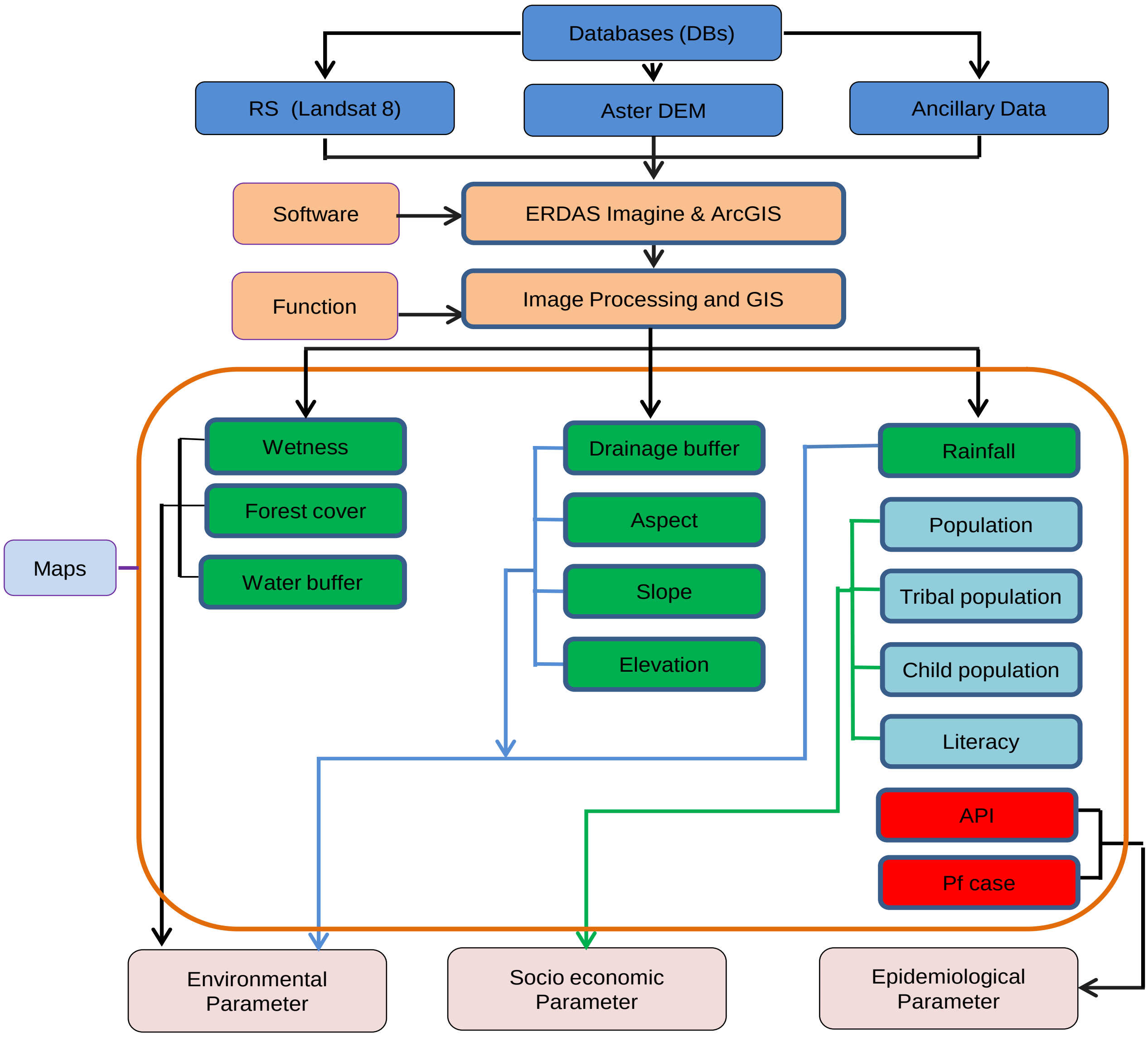


Figure 2. Flow chart showing the methodology.

2.3. Environmental Parameters

Malaria transmission is strongly associated with environmental parameters, which control mosquito breeding and parasite growth [33] [34]. Consequently parameters such as wetness index, forest cover, rainfall, aspect, elevation, slope, distance to stream (drainage buffer), breeding sites (water buffer) were considered in order of importance based upon findings of various research outputs and accordingly weights and respective ranks were provided for different thematic map and its significance towards malaria hotspot identification (Table 1 and Figure 4).

2.3.1. Wetness Index

This is one of the strong environmental parameters which provides suitable habitat for the malaria vectors to thrive [35]. Baig *et al.* [36] has developed the methodology to map wetness using Landsat 8 data and has developed the wetness

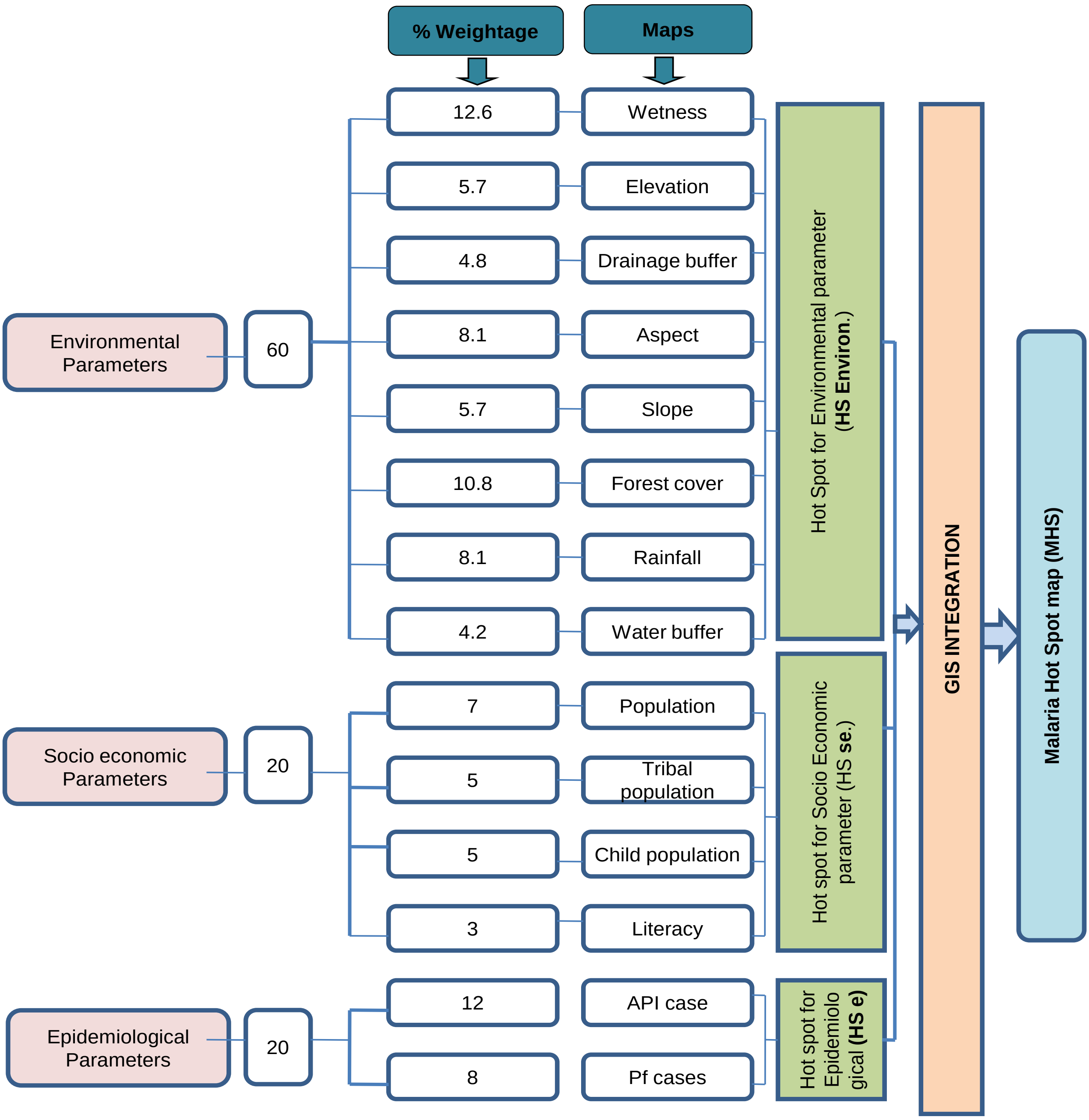


Figure 3. Schematic flowchart showing for malaria hotspot analysis.

coefficient for different bands (Table 2). The wetness map of the study area was generated using the coefficient of Table 2 and five classes (<1, 1 - 7, 7 - 23, 23 - 32, >=32) were identified and ranked as 1, 2, 3, 4, and 5 with respective degree of vulnerability as very low, low, moderate, high, and very high (Figure 4(a)).

2.3.2. Forest Cover

Forest ecosystems are one of the important parameters well known to support transmission of malaria [37]. Dense forest generates lot of leaf, which after decomposition produces litters with high moisture content which provides better environment for the mosquitoes to layeggs, development of larvae, pupae of

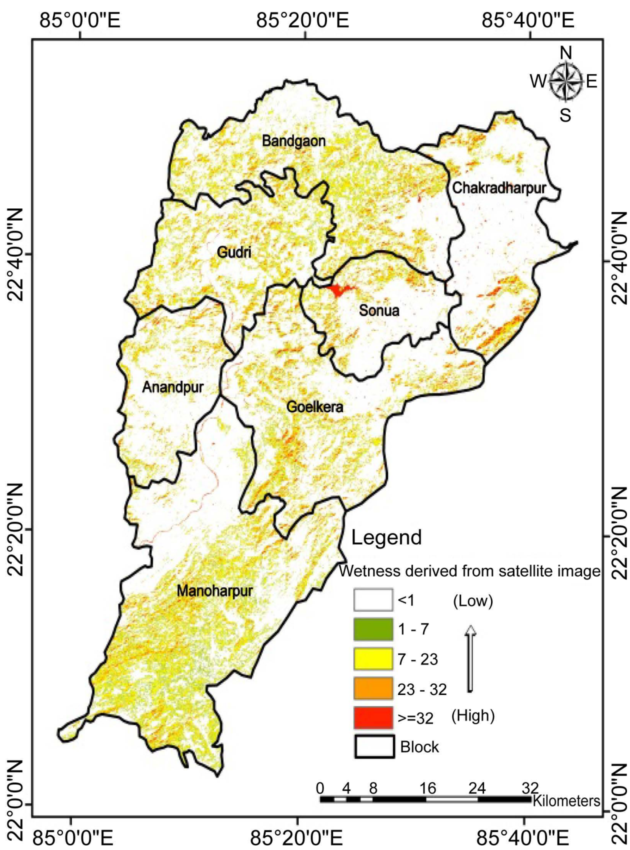
Table 1. Weight matrix for environmental parameters.

Environmental factor	Weight	Class interval	Ranks	Degrees of vulnerability
Wetness	12.6	<1	1	Very low
		1 - 7	2	Low
		7 - 23	3	Medium
		23 - 32	4	High
		>=32	5	Very high
Forest cover	10.8	Dense forest	5	Very high
		Medium forest	4	High
		Open forest	3	Medium
		Non forest	1	Very Low
Rainfall	8.1	<1257 mm	1	Very low
		1257 - 1264 mm	2	Low
		1264 - 1271 mm	3	Medium
		1271 - 1278 mm	4	High
		>=1278 mm	5	Very high
Aspect	8.1	Non shadow	1	Very low
		Shadow	3	Medium
Elevation	5.7	<200 meter	5	Very high
		200 - 400 meter	4	High
		400 - 600 meter	3	Medium
		600 - 800 meter	2	Low
		>=800 meter	1	Very low
Slope	5.7	<4	4	High
		4 - 9	3	Medium
		9 - 18	2	Low
		>=18	1	Very low
Drainage buffer	4.8	<250 meter	5	Very high
		250 - 500 meter	4	High
		500 - 750 meter	3	Medium
		750 - 1000 meter	2	Low
		>=1000 meter	1	Very low
Water buffer	4.2	<400 meter	5	Very high
		400 - 800 meter	4	High
		800 - 1200 meter	3	Medium
		1200 - 1600 meter	2	Low
		>=1600 meter	1	Very low

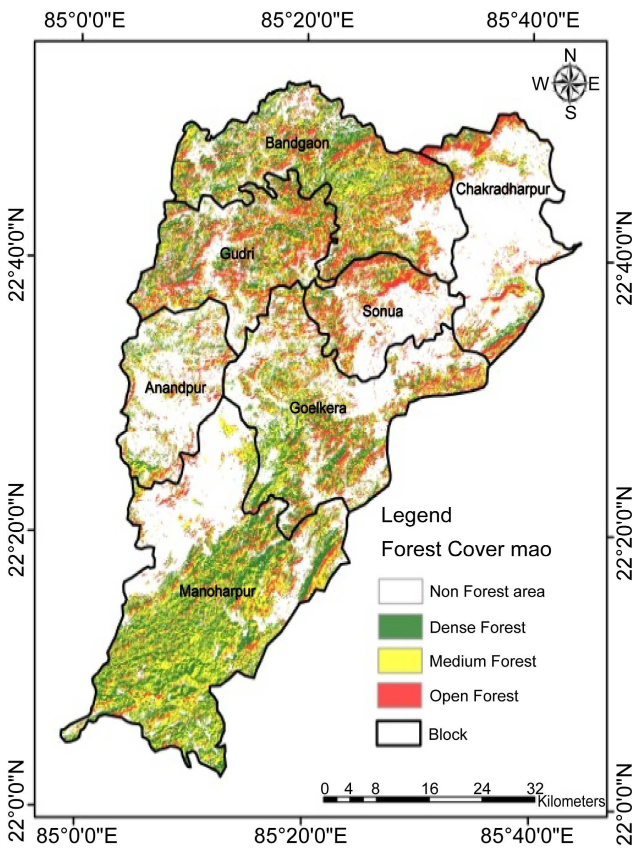
Table 2. Wetness coefficients for Landsat 8 OLI reflectance.

Band	Blue	Green	Red	NIR	SWIR 1	SWIR 2
Wetness	0.1511	0.1973	0.3283	0.3407	−0.7117	−0.4559

malaria vectors to grow in comparison with the open forest. The forest cover class of the study area was classified. The Normalized Difference Vegetation Index (NDVI) was executed and analyzed to get vegetation class and to produce a forest mask. NDVI was unable in delineating the shadow forest area. The shadow area in the image was later treated and delineated separately. Further, the forest mask image was classified using supervised classification (maximum likelihood technique). And, forest cover map with four classes namely dense, medium, open, and non-forest were delineated and ranked to 5, 4, 3 and 1 with description very high, high, moderate and very low, respectively (Figure 4(b)).


85°0'0"E
85°20'0"E
85°40'0"E
22°40'0"N
22°20'0"N
22°0'0"N
N
W
E
S
Bandgaon
Chakradharpur
Gudri
Sonua
Anandpur
Goelkera
Manoharpur
Legend
Wetness derived from satellite image
<1 (Low)
1 - 7
7 - 23
23 - 32
>=32 (High)
Block
0 4 8 16 24 32
Kilometers

(a)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Sonua
Anandpur
Goelkera
Manoharpur
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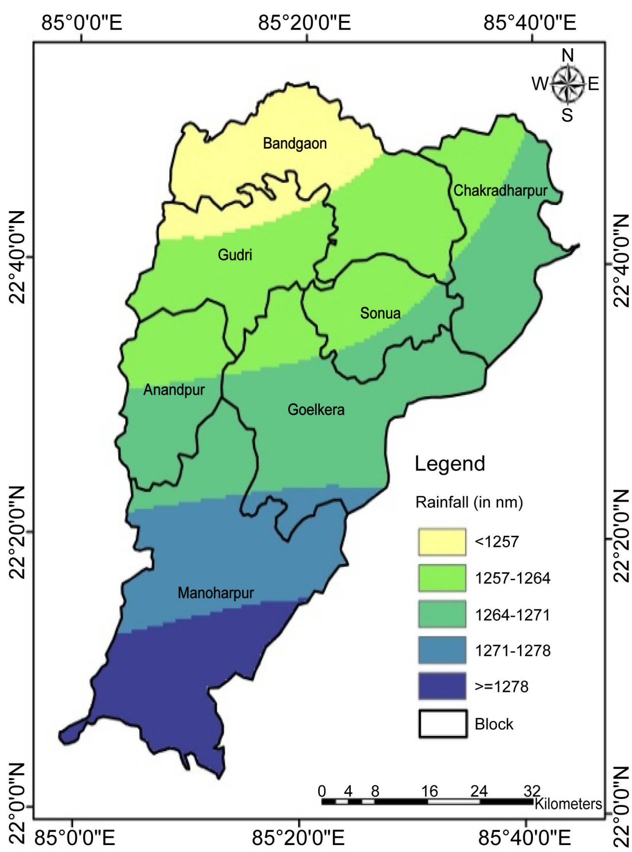
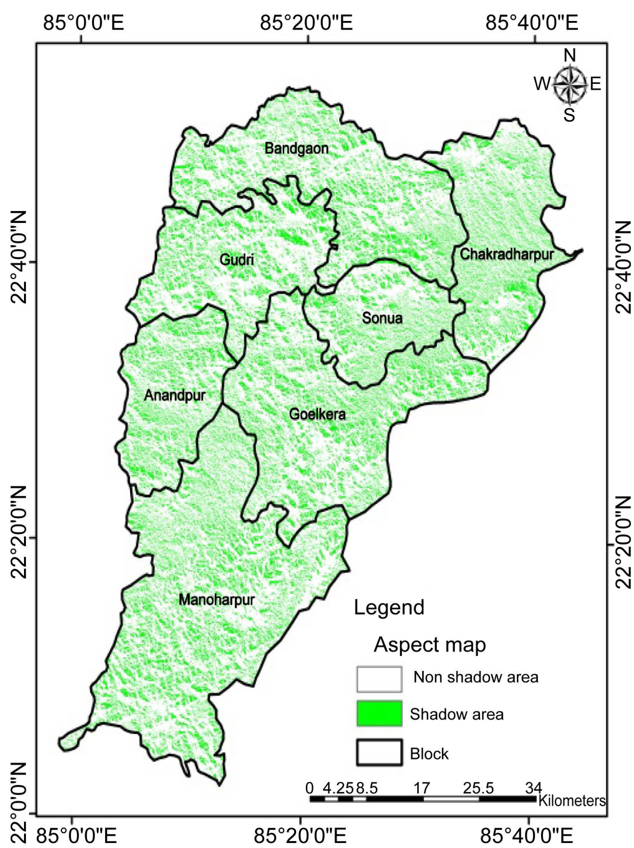
Forest Cover mao
Non Forest area
Dense Forest
Medium Forest
Open Forest
Block
0 4 8 16 24 32
Kilometers

(b)


85°0'0"E
85°20'0"E
85°40'0"E
22°40'0"N
22°20'0"N
22°0'0"N
N
W
E
S
Bandgaon
Chakradharpur
Gudri
Sonua
Anandpur
Goelkera
Manoharpur
Legend
Rainfall (in nm)
<1257
1257-1264
1264-1271
1271-1278
>=1278
Block
0 4 8 16 24 32
Kilometers

(c)


85°0'0"E
85°20'0"E
85°40'0"E
22°40'0"N
22°20'0"N
22°0'0"N
N
W
E
S
Bandgaon
Chakradharpur
Gudri
Sonua
Anandpur
Goelkera
Manoharpur
Legend
Aspect map
Non shadow area
Shadow area
Block
0 4.25 8.5 17 25.5 34
Kilometers

(d)

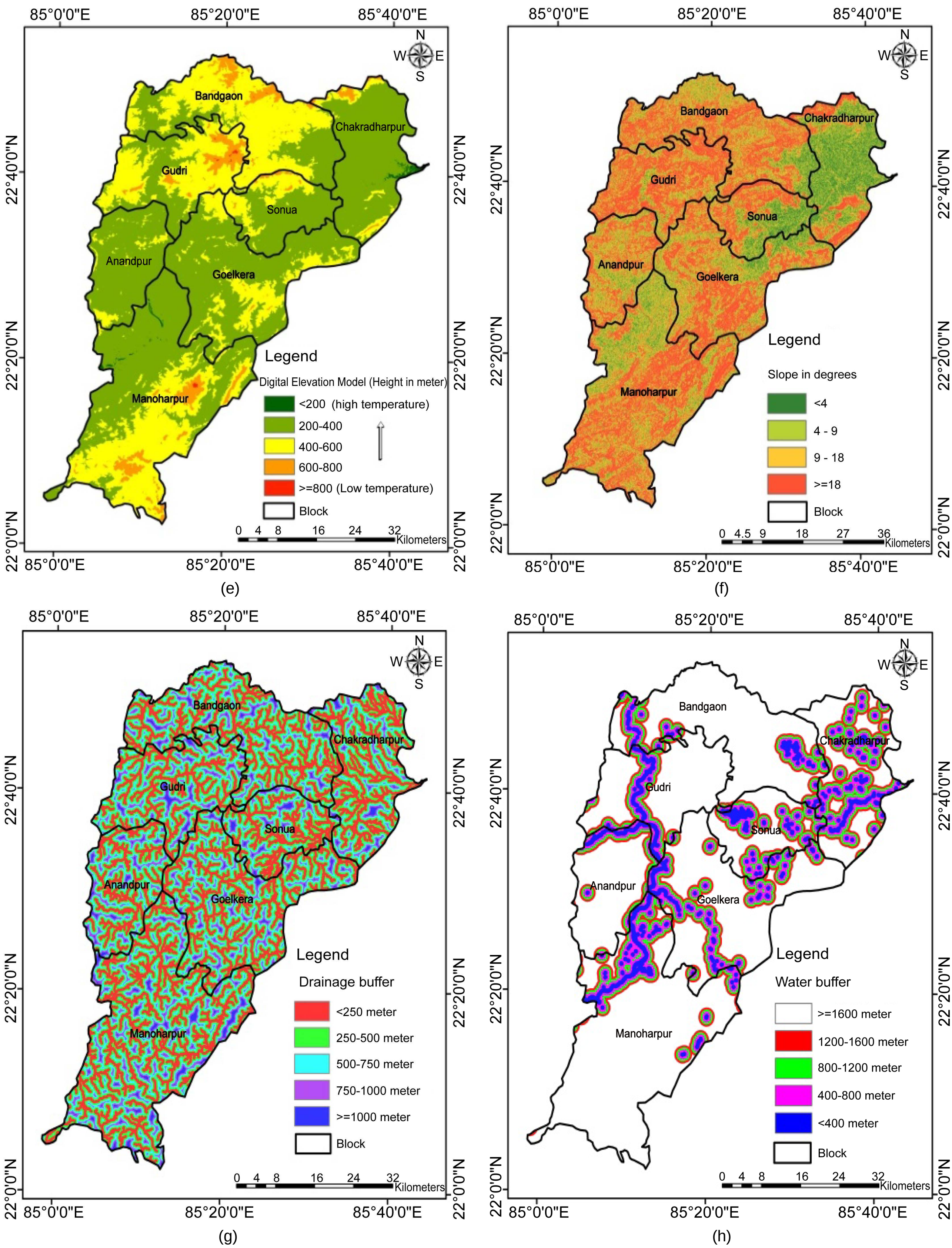


Figure 4. Maps of malaria affecting environmental parameters; (a) Wetness index map; (b) Forest Cover map; (c) Rainfall intensity map; (d) Aspect map; (e) DEM Map; (f) Slope map; (g) Drainage buffer map; (h) Water buffer map.

2.3.3. Rainfall Intensity

Rainfall is considered as the most important malaria triggering parameter and its spatial variation shows a heavy positive correlation with malaria incidence [38]. Several studies were done for malaria mapping in India and Africa. Qayum *et al.* [28] used rainfall data as one of the environmental parameters for GIS integration to generate malaria hotspots. Increase in precipitation increases the likelihood of increasing vector populations and increases the availability of anopheles breeding sites. The rainfall data from (1990 to 2002) was downloaded from the website [39]. The average (13 years) annual rainfall was used to generate spatial rainfall pattern (continuous surface) in Arc GIS by Kriging method of interpolation. The rainfall map was further classified into five classes (**Table 1**) based upon malaria risk level (**Figure 4(c)**).

2.3.4. Aspect

Aspect is another important parameter which affects malaria transmission [40]. The northern aspect ranges from NW340˚ to NE70˚ and is called as shadow area. In the shadow area due to lack of direct sunlight, moisture content is high as well as relatively dense vegetation is found when compared with the other aspects [41]. Shadow affects the larval distribution for the malarial risk [42]. Northern aspect (shadow area) is more susceptible to malaria. Aspect map was generated from DEM and reclassified into two classes of shadow and non-shadow and were ranked as 3 and 1 with description of moderate and very low, respectively (**Figure 4(d)**).

2.3.5. Digital Elevation Model (DEM)

As the elevation increases, temperature gradually decreases, which affects the mosquito breeding as the length of immature stage in life cycle [43]. At high temperatures, various stages like egg, larval and pupae, the time span will be shortened such that the turnover will be increased. DEM was reclassified into five sub groups at 200 meter interval and new values were re-assigned towards integrated (**Figure 4(e)**, **Table 1**).

2.3.6. Slope

It is one of the important topographic parameters, which can determine the existence of mosquito larval habitat [40]. It is described as the rate of change of elevation of the land per unit distance. The steeper slopes are known to allow faster movement of water and affects stability of aquatic habitats [44]. At gentle slopes surface water movement is nearly stagnant and this creates fertile situation for mosquito breeding sites. The slope was derived from aster DEM of the study area and reclassified in to four classes using standard reclassification technique (**Figure 4(f)**; **Table 1**).

2.3.7. Drainage Buffer (Distance to Stream)

It was reported that mosquitoes have typical flight ranges up to two kilometers depending upon the species [45] [46] and therefore the maximum flying distance of female Anopheles mosquito from the water stream was taken as two Km as basis for reclassification of the drainage layer. Flow distance-to-stream (drainage buffer) affected availability of the aquatic habitat and was calculated based upon creating multiple buffer of 250 meter distance using drainage layer. The drainage layer was derived from ASTER DEM using Spatial Analyst tool hydrology of Arc GIS (Figure 4(g)).

2.3.8. Waterbuffer (Distance to Breeding Site)

Wetlands provide habitats for the juvenile (immature) stages (egg, larvae, pupae) of the malaria vectors. Monitoring the state of small water bodies and wetlands using satellite data is therefore very useful in identifying the source of malaria vectors. Two-kilometer distance around wetlands was considered to be the maximum flying distance for the mosquitoes. Water bodies were extracted using the satellite map and multi water buffer with interval of 400 m was created. It was classified into five classes and was ranked as 5, 4, 3, 2, and 1 with description ranging from very high to very low (Figure 4(h)).

2.4. Socio-Economic Parameters

Socio economic parameter is another major layer in integrated mapping towards understanding the malaria transmission [47]. Both malaria incidences and transmission showed significant relationship with socio-economic parameter and accordingly weights for different sub-layers such as population, tribal population, child population, literacy were chosen (Table 3).

2.4.1. General Population

It is one of the most important socio-economic parameter which is directly related to the increasing risk of malaria. The population data of census 2011 [48] for the study area was interpolated in ArcGIS to create population map (Figure 5(a)).

Table 3. Weight matrix for socio-economic parameters.

SE factors	Weight	Class interval	Ranks	Degrees of vulnerability
Population	7	<63575	1	Very low
		63575 - 96180	2	Low
		96180 - 131341	3	Medium
		131341 - 166503	4	High
		>=166503	5	Very high
Tribal population	5	<41678	1	Very low
		41678 - 54694	2	Low
		54694 - 66054	3	Medium
		66054 - 77651	4	High
		>=77651	5	Very high
Child population	5	<9832	1	Very low
		9832 - 13126	2	Low
		13126 - 16489	3	Medium
		16489 - 20400	4	High
		>=20400	5	Very high
Literacy	3	<23287	1	Very low
		23287 - 35877	2	Low
		35877 - 48009	3	Medium
		48009 - 59455	4	High
		>=59455	5	Very high

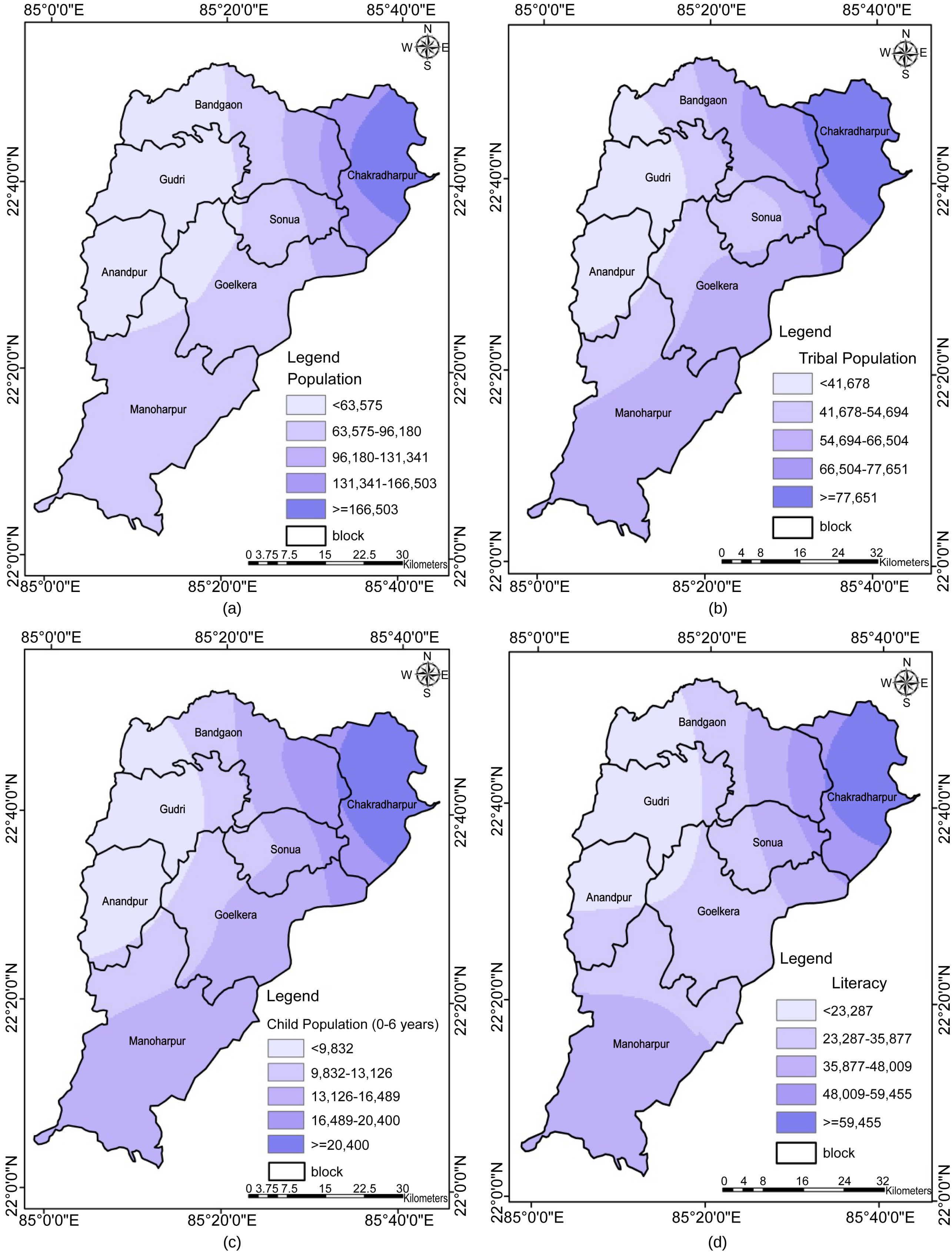


Figure 5. Maps of malaria affecting socio-economic parameters; (a) General population map; (b) Tribal population map; (c) Child population map; (d) Literacy map.

The map was further classified into five classes with ranks 1, 2, 3, 4, and 5 and description as very low, low, moderate, high, and very high, respectively.

2.4.2. Tribal Population

Tribal population usually stay in remote areas with limited means of communication and in difficult geographical conditions marked by the presence of forests, hills, valleys and perennial streams [49] with very low literacy rates [50]. The community prefers to go to spiritual healer for the treatment [51] or to untrained and unlicensed practitioners rather than a registered medical doctor and they are always at high malarial risk. Sharma *et al.* [52] analyzed the tribal population in India and concluded that malaria cases and malarial deaths were high when compared to other populations. Tribal population map was generated by method of interpolation using the census data 2011 (**Figure 5(b)**).

2.4.3. Child Population

The children population (0 - 6 year) as per data of census 2011 was interpolated for the mapping, which was further classified into five classes and was ranked as 1,2, 3, 4 and 5 with description very low, low, moderate, high, and very high, respectively (**Figure 5(c)**).

2.4.4. Literacy

Literacy enhances awareness towards better malaria control practices and measures towards prevention of the incidences [53]. Censes 2011 data of literacy was used for creating thematic map and the map was further classified into five classes varying from very low to very high (**Figure 5(d)**).

2.5. Epidemiological Parameters

Malaria distribution is strongly associated with spatial distribution pattern of epidemiological parameter, which provides the unique information on its importance for malaria hotspots. Accordingly, Annual Parasite Incidence (API) and *P. falciparum* cases were chosen with weights and ranks (**Table 4**).

2.5.1. Annual Parasite Incidence (API)

API data for the year 2010 of different districts in and around the study area was used for interpolation [54] and map was developed (**Figure 6(a)**).

Table 4. Weight matrix for epidemiological parameters.

Epidemiology factors	Weight	Class interval	Ranks	Degrees of vulnerability
API 2010	12	<7.7	1	Very low
		7.7 - 7.8	2	Low
		7.8 - 7.9	3	Medium
		7.9 - 8	4	High
		>=8	5	Very high
Pf case 2011	8	<2855	1	Very low
		2855 - 3596	2	Low
		3596 - 4338	3	Medium
		4338 - 5095	4	High
		>=5095	5	Very high

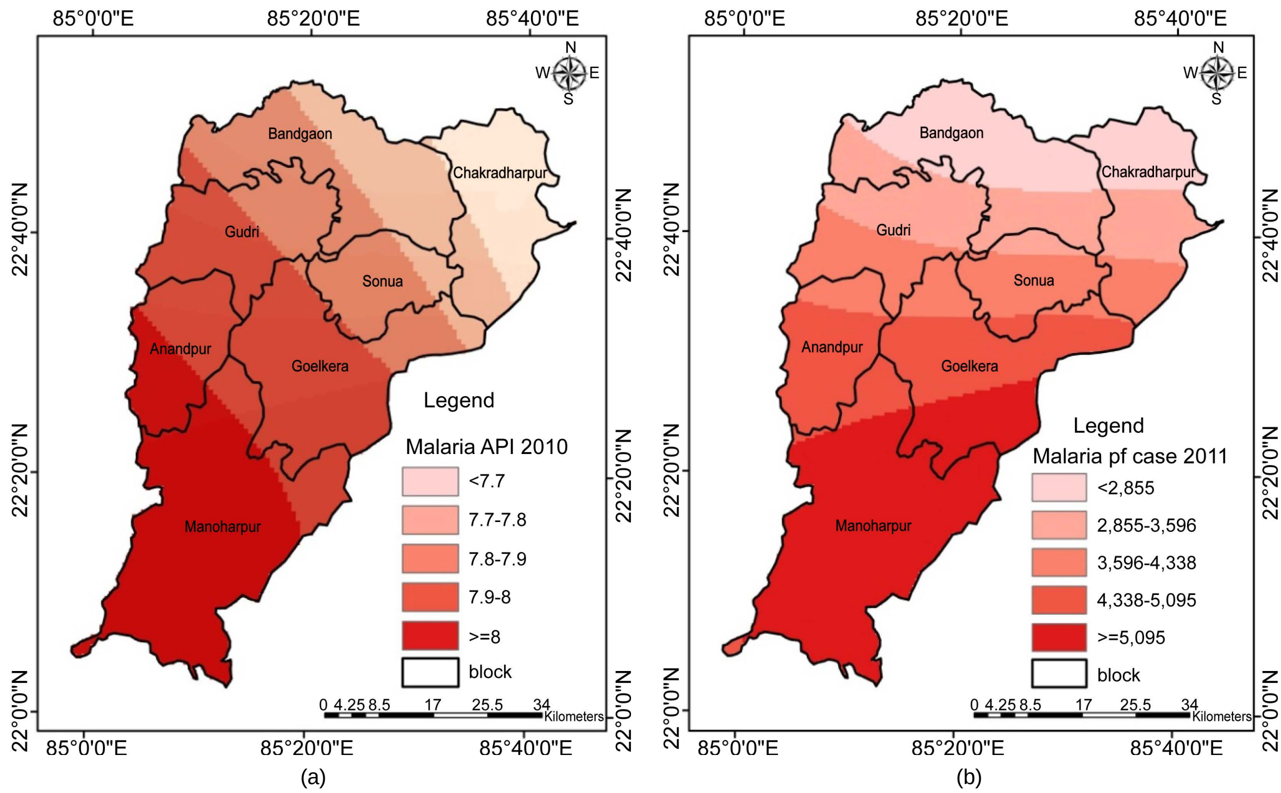


Figure 6. Maps of epidemiology parameters. (a) API 2010 map; (b) Malaria Pf cases map.

2.5.2. Pf Case

The data for total Pf cases for the year 2011 was reported by Ray [55] and it was interpolated to generate Pf 2011 map and classified into five varying from very low to very high based upon number of fatality cases due to Pf (**Figure 6(b)**).

2.6. Malaria Hotspot Identification

Malaria hotspot identification algorithm was used as it was done by Qayum *et al.* [28], which is:

$$\textbf{MHS} = \textbf{HS se} \times \textbf{HS epidemiology} \times \textbf{HS env;}$$

where, MHS = Malaria hotspot, HS_{se} is hotspot for socio-economic parameters, $HS_{epidemiology}$ is hotspot for epidemiology, HS_{env} is hotspot for environmental parameters. Malarial hotspot mapping was done using trio of environmental, socio-economic and epidemiological parameters with weights as per the schematic diagram (**Figure 3**).

3. Result and Discussion

For the malaria hotspot identification, it was observed that the dimensions considered are primarily interweaving factors of malaria incidences. The regions with water logging, high rainfall, and proximity to forest area supplemented with the poor socio-economic condition are the major hotspot regions. The work at the microscopic level is presented through a series of maps, tables, figures (**Figures 4-6**) and graphs to classify the entire area into "very high", "high", "moderate" and "low" category (Figure 7). "Very high" category of the area can be termed as hotspots which may be used to define government policy for the focused intervention towards malaria control measures.

3.1. Malaria Hotspot Analysis

The malaria hotspot for environmental parameters was computed using the chosen environmental variables such as topographic factors (elevation, aspect, slope, wetness and buffer distance to stream), forest cover, rainfall and breeding sites (buffer distance from water bodies) was developed and weighted using ERDAS Imagine and ArcGIS tool. Similarly, for socio-economic parameter, it was computed and weighted using socio-economic variables such as population, child population, literacy and tribal population. The malaria hotspot for epidemiological parameter (API and *P. falciparum* cases) shows strong correlation of spatial distribution pattern of it over the study area which was generated using spatial analyst module which provides valuable inputs for malaria hotspot identification. Weights were assigned to these parameters (environmental 60%,

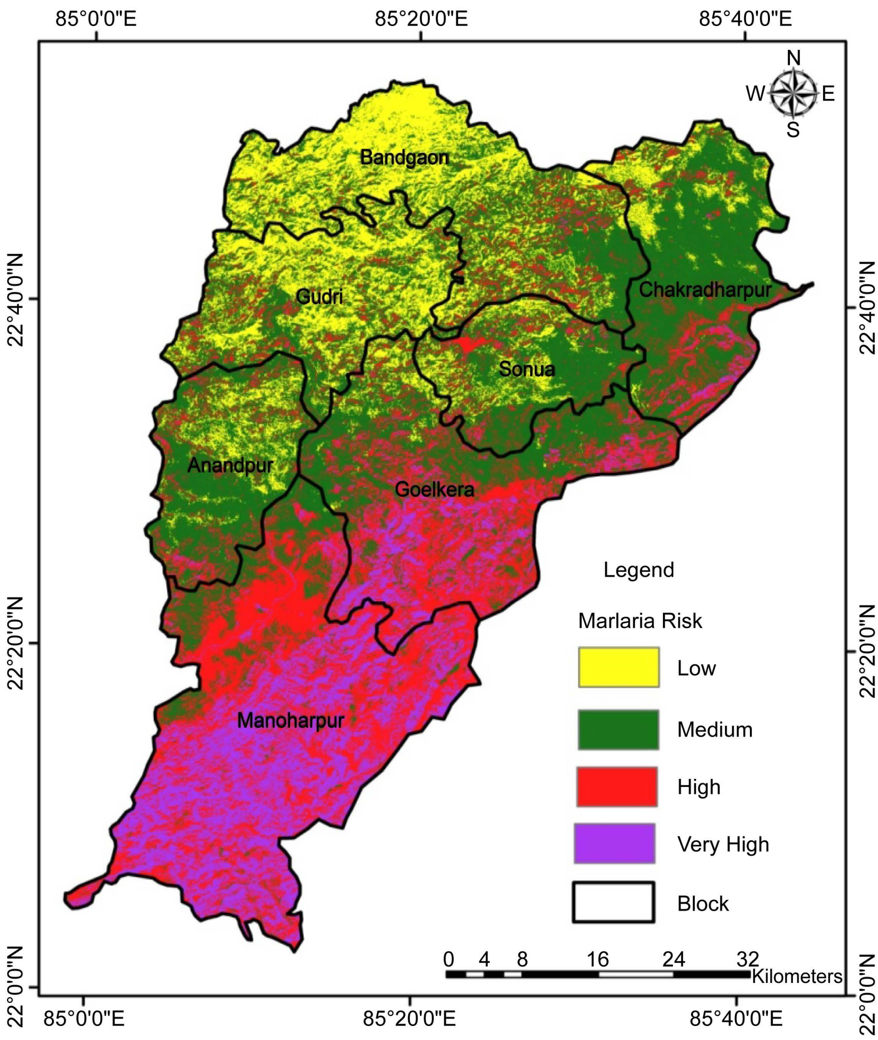


Figure 7. Malaria integrated risk map.

socioeconomic 20% and epidemiological 20%) for integrated mapping. These weights were in consonance with Qayum *et al.* [28] for the malaria hotspot identification.

The final output raster layer was reclassified according to the risk level in to four sub groups as very high, high, moderate and low hotspot areas (**Figure 7**). The results of the study showed 16.8%, 42.3%, 27.6% and13.3% area were subjected to very high, high, medium and low malaria hotspot rating, respectively (**Table 5**).

Various environmental and socioeconomic parameters are interrelated and influence the possibility of malaria outbreak. All such environmental parameters were incorporated in the present study to delineate areas suitable for mosquito growth. The result obtained was classified into four malaria hotspot rating:

Very high: These areas were found to be in southern part of the study area highly dominated by tribal population, covered with dense forest, high wetness, high rainfall with lot of perennial streams with gentle slope and moderate to low elevation provide most conducive environment for grow of malaria parasite. It surrounds 16.8% of total area amounting to 59,795.19 Hectares.

High: The high priority areas were found from north to southern part (very low concentration in north west part) of the study area, dominated with tribal population covered with dense to medium forest, moderate wetness, medium rainfall with streams with moderate to gentle slope and high to low elevation provides moderate favorable conditions for the parasite growth and accounted for 42.3% of total area (1,50,182.1 Hectares).

Medium: These areas were found in north (high concentration) to south part (low concentration) with moderate population in general and sparse to medium tribal population, covered with medium to open forest, moderate wetness, low to moderate rainfall with less streams, high to moderate slope and moderate to high elevation provides less moderate favorable condition for the parasite growth. This category accounts for 27.6% of total area (98,089.29 Hectares).

Low: Low priority areas were found to be more in north to central part of the study area (concentration is more in the north-west) with low population in general and low to sparse tribal population, covered with open forest to non-forest, low wetness, low rainfall, high slope and high elevation which provides less favorable condition for the malaria parasite to grow. It accounts for 13.3% of total area (47,069.55 Hectares).

Table 5. Malaria hotspot rating of study area with area statistics.

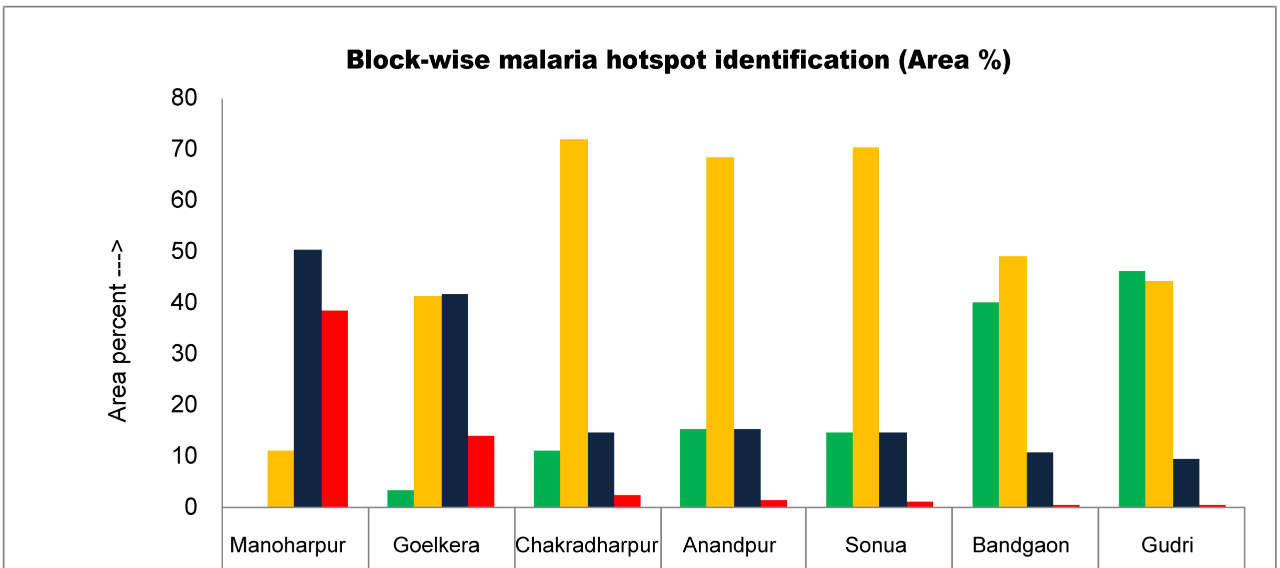
Malaria hotspot rating	Area in hectares	Percentage
Very high	59795.19	16.8
High	150182.1	42.3
Medium	98089.29	27.6
Low	47069.55	13.3

The identified hotspots ranking (block-wise) of the study area was presented through a bar diagram (**Figure 8**). Administrative Blocks such as Manoharpur, Goelkera, Chakadharpur, Anadpur, Sonua, Bandgaon and Gudricomprised of-more than fifty percent area under medium to very high hotspot ranking. However, Manoharpur, Goelkera Blocks consisted more than fifty percent of its area under high to very high hotspot ranking and Manoharpur block comprised of 89 percent of its area under high to very high malaria hotspot ranking which must be prioritized first for malaria control measures by the government agencies. And, from microscopic point of view the villages such as Holonguli, Thalkobad, Tinilposi, Baliba, Ankuwa and Chiria of Manohpur Block should be prioritized for an urgent policy intervention.

3.2. Geospatial Technology and Disease Management

The triangular relationship of climate change, the environment, and disease outbreaks is attaining importance and a need to address such issues through GIS based decision support system is increasingly gaining momentum. It could become an indispensable tool for disease management as it has inherent ability to manage spatial, non-spatial and temporal data [56]. GIS is intricately interconnected with several interfaces of human, data, server and tools and comprises a set of strategies and tools capable of integrating, storing, editing, analyzing and displaying geographically referenced information from various sources [29].

Malaria is a local and focal disease. Besides ecological parameters which influence the disease there are some important local factors such as socio-economic,



	Manoharpur	Goelkera	Chakradharpur	Anandpur	Sonua	Bandgaon	Gudri
Low MS	0.1	3.4	11.2	15.4	14.5	39.9	46.3
Medium MS	11.1	41.2	71.9	68.4	70.2	48.9	44.2
High MS	50.4	41.7	14.6	15	14.5	10.8	9.2
Very High MS	38.4	13.7	2.3	1.2	0.8	0.4	0.3

Figure 8. Block wise identified Malaria hotspot.

socio-cultural and behaviour patterns of the community which play a major role in disease transmission. If these parameters are to be used for decision-making, they must be well organized and managed. It can be accomplished by introducing a GIS for analysis and management. GIS mapping would make it easy to update information instantly and to identify the trouble spots at the village level, which is the lowest unit equipped with computer facilities and the information can reach instantly to state and the policy makers to formulate focused and cost effective malaria control strategy. Malaria is a complex disease and its distribution and intensity vary from place to place. Stratification of the potential disease causing factors has become an essential feature for the planning and development of a sound control strategy to maximize the utilization of available resources. It can also provide guidelines as to which strategy could be most suited and economical under the existing conditions. It is largely accepted that the current technology is becoming mandatory for economic and environmental planning especially for developing nations [57].

The present study utilized remote sensing data and multi-criteria analysis in GIS domain to achieve Malaria hotspot mapping. This area is reported to have meso-endemic to hyper-endemic conditions for malaria occurrence. A tribal dominated society, inaccessible forested areas, lack of infrastructure and in addition to these lack of suitable database creates an alarming situation towards an epidemic outbreak. A good database about malaria hotspot will guide the authorities to concentrate their limited relief measures and will guide for strategic use of resources. Thus, such databases can be used to control a priori-mosquito breeding sites and post outbreak, damaging the mosquito breeding sites. Geospatial technology has the capability to study spatially, in less time and with greater accuracy. Maps produced give adequate information for concerned authorities. Further, such epidemics can be monitored regularly at various time periods and data updating becomes much easy.

4. Conclusions

The results of the study illustrated that malaria is heavily influenced by major environmental parameters and socio-economic factors and these factors play a vital role either directly or indirectly in the occurrence of this vector-borne disease. The support of satellite data and integration of various parameters in GIS helps in delineating areas which needs priority in policy formulations and significant steps shall be taken to prevent the spread of disease in such priority areas. The developed database in this work will greatly assist the health department in fighting the malaria epidemic. The potential of geospatial data cannot be ignored, it is cost effective, accurate and less time consuming.

In order to address the malarial problem, it is necessary to interrupt one of the mediums of malaria parasite, human host and the female Anopheles mosquito thus preventing the spread. Identification of possible potential malaria prone areas is the first step in achieving this target. In the areas which were identified as malaria hotspot, it's the first step to determine the scale of risk and further decide on how the resources should be allocated to tackle malaria. This data provides guidelines to assess the progress of control and indicates which geographic area should be prioritized. The present study has made an attempt to develop a hotspot map of malaria that would support malaria related decision making process Chakardharpur subdivision of west Singhbhum District. Geospatial technology can be used in the field of vector-borne diseases including malaria. The malaria risk maps enable easy update of information and effortless accessibility of georeferenced data to policy makers to produce cost-effective measures for malaria control in the endemic regions. Computerized spatial database and GIS mapping software provide powerful tools for the management and analysis of malaria control programs.

Ethics Approval and Consent to Participate

Not applicable.

Consent for Publication

Not applicable.

Availability of Data and Materials

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request. And, most of the data generated or analysed during this study are included in this published article.

Competing Interests

The authors declare that they have no competing interests.

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No funding in any form has been received by any of the author for current work.

Authors' Contributions

FA proposed the idea and analyzed the satellite and ancillary data in GIS domain, LG supervised the analysis and drafted the manuscript. AQ made critical evaluation towards malarial suitability of geospatial technology and provided continuous feedbacks. All authors read and approved the final manuscript.

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