Cristina, G. M. S. and Rosane, M. P., *Molecules*, 2013, **18**, 7609–7630.
8. Ooi, V. E. C., *Phytotherapy Res.*, 1996, **10**, 536–538.
9. Alam, N., Yoon, K. N. and Lee, T. S., *Afr. J. Biotechnol.*, 2011, **10**(11), 2978–2986.
10. Adriana, F., Mariana, M., Carmen, M. D. and Sophie, L., *J. Nutr.*, 2008, **138**(12), 2309–2315.
11. Warjeet, L. S., Rajkumar, Y., Satyabhama, A. D. and Sujata, W. D., *Indian J. Nat. Prod. Res.*, 2013, **4**(1), 67–72.
12. Sujata, W. D. and Warjeet, L. S., *Indian J. Nat. Prod. Res.*, 2012, **3**(2), 184–188.
13. Sujata, W. D., Radhapiyari, W. D., Brajakishore, C. S. and Warjeet, L. S., *J. Adv. Chem.*, 2014, **8**(1), 1523–1532.

ACKNOWLEDGEMENTS. We thank DBT, New Delhi for DBT RA Fellowship; Mr Nahakpam Surjit Singh for technical support and Physics Department of Manipur University for EDX analysis.

Received 23 November 2015; revised accepted 24 August 2016

SUJATA DEVI WANGKHEIRAKAPAM[1,3,*]
JOSHI DEVI DATT[2]

[1]*Institute of Bioresources and Sustainable Development, Imphal 795 004, India*
[2]*Department of Biotechnology, Govt of India, Takyelpat, Imphal West 795 001, India.*
[3]*Present address: Chemistry Department, NIT Manipur, Langol 795 004, India*
**For correspondence.*
e-mail: wangkheimayums@yahoo.com

Malaria risk mapping: a study of Visakhapatnam district

Malaria is a vector-borne disease and endemic in degraded environments, especially in tropical and subtropical ecosystems[1]. Globally, malaria is the third leading cause of death among infectious diseases in children under five years of age[2]. Even though the number of malaria deaths declined by 48% during 2000–2015, ~0.4 million deaths occurred globally in 2015 (ref. 3). The intensity of malaria transmission depends on factors related to the parasite (*Plasmodium* species), the vector (mosquitoes), the human host and the environment. Thus, malaria risk is not uniform throughout a given region[4]. The local heterogeneity of the disease motivated the epidemiologists to generate maps for understanding the local disease ecology, which is necessary for targeting the preventive measures. Although efforts were made to map the malaria risk for over a century, proper understanding of malaria distribution has been achieved only during the past few decades, stemmed from the necessity to develop better public health tools[5]. At present, geospatial technologies are extensively used globally to identify the malaria risk zones for targeting malaria eradication programmes[6].

We used statistical techniques for malaria risk mapping in a study of Visakhapatnam district. Covering an area of 11,161 sq. km in the north coastal Andhra Pradesh, Visakhapatnam district exhibits two distinct physiographic regions – the eastern coastal region and the western hilly region (Figure 1). The coastal region covers 44% (4928 sq. km) and lies below 100 m elevation with only a few isolated hills rising above 300 m. The hilly region, which forms a part of the Eastern Ghats, is above 600–1500 m elevation and covers 56% (6233 sq. km) area of the district. The annual rainfall in the coastal region is 1178 mm and in the hilly region it is 1322 mm. The coastal region experiences semi-arid climate with relatively higher mean annual temperature (26–28°C) than in the dry subhumid hilly region (26°C). The district is divided into 43 revenue 'mandals' (tehsils): 32 in the coastal region and 11 in the hilly region. Out of the 4.29 million (2011 Census) population of the district, the coastal region accounts for 3.69 million (86%) and the remaining 0.60 million (14%), mostly scheduled tribes, are from the hilly region. The average density of the population in the district is 343 persons per sq. km, with higher density of 829 per sq. km in the coastal region against 112 per sq. km in the hilly region.

Of the five malaria-causing species of the parasite, *Plasmodium* – *P. falciparum*, *P. vivax*, *P. ovale*, *P. malariae* and *P. knowlesi* – *P. falciparum* is responsible for a majority of malaria deaths globally[7], while, among other four types of the parasite, *P. vivax* is widespread in the temperate and subtropical zones causing large-scale morbidity[8]. Although malaria prevails almost throughout the year, *P. falciparum* malaria is most common during July–January, whereas *P. vivax* malaria proliferates during February–June[9]. As mosquitoes (the carriers of malaria-causing parasites) need stagnant water to breed, the incidence of malaria is mainly associated with rainy season when the mosquitoes proliferate. However, periods immediately following heavy rainfall are associated with low malaria incidence because of temporary flushing of mosquito breeding grounds[10].

Data on malaria cases recorded during 1999–2011 at 72 Primary Health Centres spread over 43 mandals showed that both *P. falciparum* and *P. vivax* malaria are prevalent in Visakhapatnam district although with significant spatial variations. Of the total 160,970 malaria cases, 109,312 cases were from the hilly region and 51,658 from the coastal region. The *P. falciparum* cases were relatively high (94,031) in the hilly region than those in the coastal region (13,717). But, *P. vivax* malaria cases were higher (37,941) in the coastal region than those in the hilly region (15,281). However, the annual average share of *P. falciparum* cases in the hilly (coastal) region was 1.20% (0.03%) over a range of 0.38–2.42% (0–0.39%) and that of *P. vivax* cases was 0.19% (0.08%) over a range of 0.01–0.54% (0–0.24%) (Figure 1), clearly indicating the relatively higher rate of incidence of both types (*P. falciparum* and *P. vivax*) of malaria in the hilly region.

The malaria risk analysis was carried out to identify malaria intensity levels among various mandals in Visakhapatnam district. For this purpose, mandal-wise yearly data on malaria cases during 1999–2011 were analysed using location quotient (LQ) method, which is a ratio of proportions that illustrates the relative incidence of malaria by mandal. The formula for deriving LQ of a mandal is

$$\mathrm{LQ} = \frac{\mathrm{N_{mandal}}/\mathrm{P_{mandal}}}{\mathrm{N_{district}}/\mathrm{P_{district}}}$$

where $\mathrm{N_{mandal}}$ and $\mathrm{N_{district}}$ represent number of malaria cases in the mandal and the district respectively, and $\mathrm{P_{mandal}}$ and $\mathrm{P_{district}}$ represent the total population of

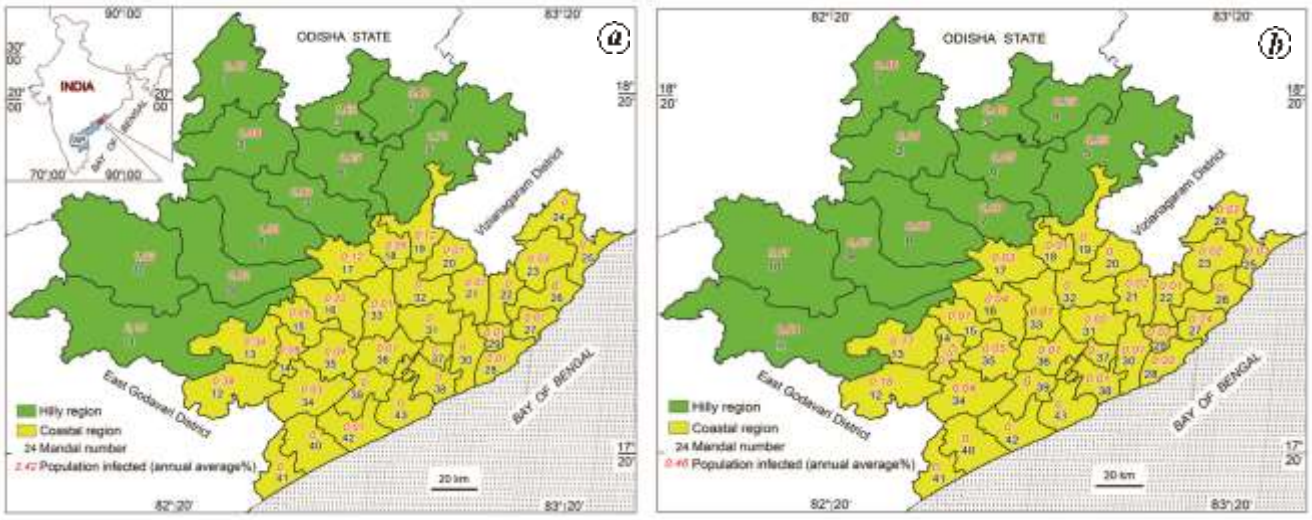

Figure 1. Population infected (annual average %) by *P. falciparum* (***a***) and *P. vivax* (***b***) malaria in Visakhapatnam district (inset map in (***a***) shows the location). Names of the mandals are given in Tables S1 to S4 (see supplementary material online) against the respective numbers.

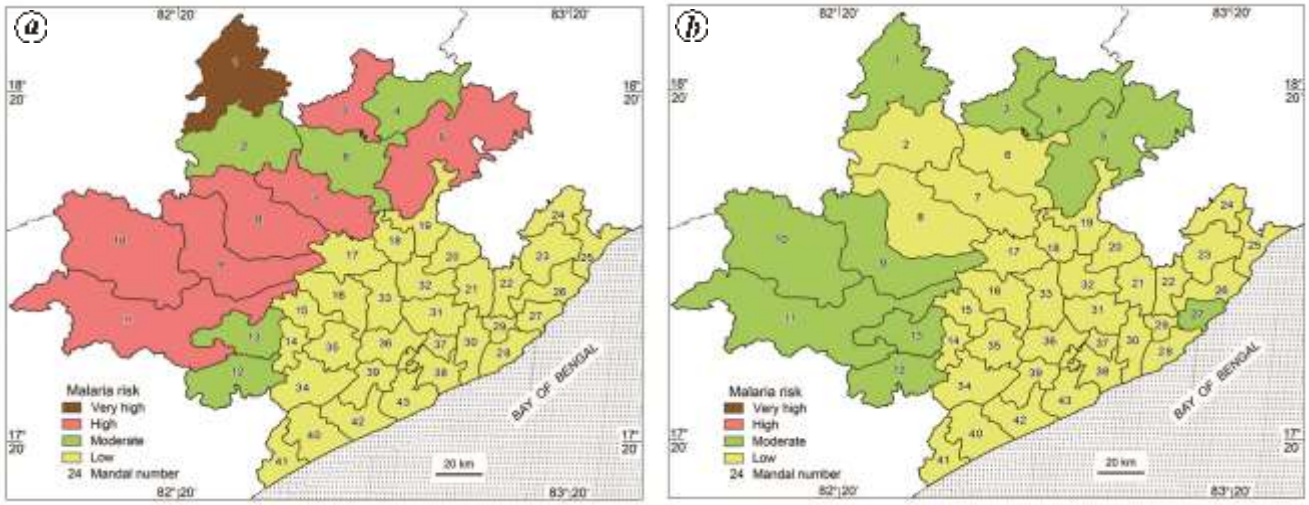

Figure 2. Variations in the risk levels of *P. falciparum* malaria (***a***) and *P. vivax* malaria (***b***) in Visakhapatnam district.

the mandal and the district respectively. An LQ greater than 1 indicates that the given mandal has more than its share of malaria cases relative to its population size.

The annual average LQ values of *P. falciparum* (*P. vivax*) malaria in the hilly region ranged between 0.39 and 2.62 (0 and 0.41), and those in the coastal region between 0.01 and 0.53 (0 and 0.24) (Figure 1). On the whole, *P. falciparum* malaria was at higher levels in the hilly region as 7 out of the 11 mandals showed annual average LQ values more than 1. On the other hand, the average LQ values of *P. falciparum* malaria were less than 1 in all the mandals of the coastal region. The annual average LQ values of *P. vivax* malaria, however, were less than 1 almost throughout the district during the 13-year period, except in 5 mandals in the hilly region that too only during 1999 (mandal-wise yearly LQ values and the annual average LQ of *P. falciparum* and *P. vivax* malaria are shown in Tables S1 and S2 respectively (see supplementary material online).

As the LQ values do not show the subtle variations in malaria intensity among mandals, we refined the LQ values by assigning relative weightages. Thus, the weighted LQ values are computed for estimating the mandal-wise malaria-risk factors. For this purpose, the yearly LQ values of each mandal were ranked into five levels: rank 1 (LQ value <0.5), rank 2 (0.5–1.0), rank 3 (>1.0–2.0), rank 4 (>2.0–3.0) and rank 5 (>3.0).

The frequency of all the rank values (i.e. during how many years each rank value repeated) is counted for all the mandals (Table S3 for *P. falciparum* and Table S4 for *P. vivax* in the supplementary material online). The rank frequencies were then multiplied by their respective rank values to obtain the weighted LQ value of that malaria intensity level. For example, for Dumbriguda

mandal (Sl. # 3 in Table S3, in the supplementary material, online), the frequency of rank 1 is 4 and hence its weighted LQ value is 4 (4 × 1 = 4). Similarly, the frequency of rank 2 is 2 and its weighted LQ value is 4 (2 × 2 = 4). The frequency of rank 3 is 2 and its weighted LQ value is 6 (2 × 3 = 6). Rank 4 repeated three times and hence its weighted LQ value is 12 (3 × 4 = 12) and the frequency of rank 5 is 2 and its weighted LQ value is 10 (2 × 5 = 10). The sum of the five weighted LQ values is 36 (4 + 4 + 6 + 12 + 10 = 36) for Dumbriguda mandal for the entire period. This was divided by 13 (the total number of years) to obtain the annual average weighted LQ value for the mandal (36/13 = 2.77).

The annual average weighted LQ values are then grouped into four malaria risk categories: low risk (annual average weighted LQ value ≤1.0), moderate risk (range of average weighted LQ values: >1 to 2), high risk (>2 to 3) and very high risk (>3).

Geospatial maps are prepared showing the distribution pattern of malaria risk for both *P. falciparum* and *P. vivax* (Figure 2). The *P. falciparum* malaria risk level is higher in the hilly region with one mandal (Munchingi Puttu) in the very high risk category, seven mandals (Dumbriguda, Ananthagiri, Paderu, G. Madugula, Chintapalle, G. K. Veedhi and Koyyuru) under the high risk category and the remaining three mandals (Pedabayalu, Araku Valley and Hukumpeta) in the moderate risk category (Figure 2 *a*). Almost all the mandals of the coastal region are under low risk category except Nathavaram and Golugonda mandals, which are in the moderate risk category (Figure 2 *a*). Similarly, *P. vivax* malaria risk is also on the higher side in the hilly region with seven mandals (Munchingi Puttu, Dumbriguda, Araku Valley, Ananthagiri, Chintapalle, G. K. Veedhi and Koyyuru) coming under the moderate risk category and the remaining four mandals in the low risk category (Figure 2 *b*). In the coastal region, *P. vivax* malaria risk is relatively higher with three mandals, Nathavaram, Golugonda and Visakhapatnam (U) in the moderate risk category (against two in the case of *P. falciparum* malaria), but definitely lower when compared to the hilly region (Figure 2 *b*).

The study showed that malaria in Visakhapatam district is caused by *P. falciparum* and *P. vivax* parasites and the hilly region is at higher risk, especially to *P. falciparum* type of the disease indicating that 8 out of 11 mandals in the region are endemic to malaria. Although the *P. vivax* malaria cases are more in absolute numbers in the coastal region, its ratio to total population is high in the hilly region. Thus the study showed the advantage of weighted LQ analysis and geospatial mapping for highlighting the malaria risk zones.

1. Snow, R. W., Guerra, C. A., Noor, A. M., Myint, H. Y. and Hay, S. I., *Nature*, 2005, **434**, 214–217.
2. Buonsenso, D. and Cataldi, L., *Italian J. Pediatr.*, 2010, **36**, 58.
3. Cibulskis, R. E. *et al.*, *Infect. Dis. Poverty*, 2016, **5**, 61; doi:10.1186/s40249-016-0151-8.
4. Bejon, P., Williams, T. N., Nyundo, C., Hay, S. I., Benz, D. and Gething, P. W., *Elife*, 2014, **3**, e02130; doi:http://dx.doi.org/10.7554/eLife.02130.001
5. Schlipköter, U. and Flahault, A., *Public Health Rev.*, 2010, **32**, 90–119.
6. Bautista, C. T., Chan, A. S., Ryan, J. R., Calampa, C., Roper, M. H., Hightower, A. W. and Magill, A. J., *Am. J. Trop. Med. Hyg.*, 2006, **75**, 1216–1222.
7. Kantele, A. and Jokiranta, T. S., *Emerging Infections*, 2011, **52**, 1356–1362.
8. Andrade, B. B. *et al.*, *Malaria J.*, 2010, **9**, 13; doi:10.1186/1475-2875-9-13
9. Singh, N., Mishra, S. S., Singh, M. P. and Sharma, V. P., *Ann. Trop. Med. Parasitol.*, 2000, **94**, 101–112.
10. Hema Malini, B., In *Disasters, Environment and Development* (ed. Singh, R. B.), Oxford and IBH, Delhi, 1996, pp. 395–406.

ACKNOWLEDGEMENTS. We are grateful to the anonymous reviewers for their valuable suggestions. B.H.M. and K.N.R. thank UGC for Emeritus Fellowships during 2014–2016 and 2015–2017 respectively.

Received 5 November 2015; revised accepted 27 October 2016

B. HEMA MALINI[1,*]
B. VISWESWARA REDDY[2,3]
M. GANGARAJU[1]
KAKANI NAGESWARA RAO[2]

[1]*Department of Geography, and*
[2]*Department of Geo-Engineering,*
Andhra University,
Visakhapatnam 530 003, India
[3]*Present address:*
Aditya Institute of Technology and Management,
Tekkali 532 201, India
**For correspondence.*
e-mail: bhmalini@yahoo.com