# GEOGRAPHIC INFORMATION SYSTEM AS A TOOL TO STUDY MALARIA RECEPTIVITY IN NADIAD TALUKA, KHEDA DISTRICT, GUJARAT, INDIA

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**Abstract.** Nadiad taluka, Kheda district, Gujarat State, India, comprising of 100 villages with unstable malaria and periodic epidemics, was selected for the study. Using topo sheets and satellite imageries thematic maps on water table, water quality, hydro-geomorphology, soil type, relief, irrigation channels, were prepared, overlaid and integrated sequentially using ArcInfo software. The composite map resulted in 13 stratification classes. Stratification classes 1-12 fell in non-irrigated tracts and exhibited 95% matching of areas of high receptivity as revealed by geographical information systems (GIS) and annual malaria parasite incidence (API). Stratification class 13, an irrigated area, showed poor matching but the ground verification established low receptivity of the area. Thus the study resulted in complete reconciliation of cause and effect relationship as established as per GIS in explaining malaria epidemiology. In general, the study revealed that high malaria in villages of Nadiad is mainly due to high water table, soil type, irrigation and water quality. Based on local malaria transmission determinants, a revised malaria control strategy has been suggested.

## INTRODUCTION

In India in 1964 there were 0.1 million cases of malaria and deaths due to malaria were completely eliminated. This was followed by a period of resurgence and in 1976 the National Malaria Eradication Program (NMEP) reported 6.4 million cases.

Since the early 1980s malaria incidence has stabilized at about the 2 million level (Sharma, 1995). In spite of the best efforts of the NMEP malaria incidence could not be reduced further. This is mainly due to the development of vector resistance to insecticides, parasite resistance to anti-malarial drugs and aversion in the community to chemical interventions, and to behavioral, social and operational problems (Sharma, 1996 a,b). These problems are not peculiar to India but have adversely affected malaria control in other countries as well. In order to improve the malaria situation the World Health Organization (WHO) launched a revised malaria control strategy in 1992. This strategy was adopted in WHO regions (WHO, 1993). The important components of the Global Malaria Control Strategy are (i) preventive and selective vector control and (ii) reassessment of each country's malaria situation regularly, in particular the ecological, social and economic determinants of the disease. Unlike the past, this approach to vector control requires a sound knowledge of the local transmission dynamics of malaria. Improved information management techniques, *viz* integrating remote sensing and geographical information systems (GIS), may lead to rapid data analysis in establishing a local disease profile to assist the control of malaria. A study was therefore undertaken using GIS as a tool to identify determinants of malaria receptivity and vulnerability, in Nadiad taluka, Kheda district, Gujarat State.

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## MATERIALS AND METHODS

Gujarat is one of the leading industrial states of the country. It tops the list in projects encompassed under the mining and manufacturing sector. There are 1,500 large/medium and 152,000 small-scale industries. The area under the Sardar Sarovar Irrigation Project (SSP) consists of 3,393 villages in 62 talukas of 12 districts in Gujarat State and 75,000 hectares in arid areas of Barmer and Jaisalmer districts in Rajasthan State (Ministry of Information and Broadcasting, 1994). Half of Nadiad taluka falls under right bank of the Mahi river command area (Ashok Raj and Nathan, 1983). In Kheda district, agriculture is well developed due to fertile soil, good annual rainfall and an excellent network of canals and distributaries. Almost all villages have an approach road and small industrial units that attract migrant laborers.

Gujarat State is endemic for malaria. In 1994 about 250,000 malaria positive cases were reported. Kheda has been the worst affected district with an average annual parasite incidence (API) of 12.97 (1976-1991). In 1991, 34.9% *Plasmodium falciparum* cases were recorded in the taluka (NMEP, 1991). Villages of Nadiad taluka has reported a high incidence of deaths due to malaria. In 1981, in Bamroli village there were 32 unusual deaths, the majority of which were attributed to falciparum malaria (Sharma and Sharma, 1986). In 1995, in Kheda district there were 12,000 positive cases, including 1,225 falciparum cases (NMEP, 1995, provisional data).

Nadiad taluka is one of ten talukas of Kheda district in Gujarat, India. It is situated at 70°45′ - 73°15′ E longitude and 22°30′ - 23°00′ N latitude. It consists of 100 villages with a total area 662.3 $km^2$ and about 0.5 million population. Half of the taluka is canal irrigated, villages in the area are surrounded by a network of canal distributaries and drainage systems. Forty-three villages falling under this network system are grouped and named as irrigated villages. In the remaining area, *ie* in 57 villages, agriculture is rain-fed or lift-irrigated, and these villages have been grouped in the category of non-irrigated villages. There are two seasonal rivers, Shedi and Mohar: the latter dries up completely during summer whereas excess water passing through escape channels is released into the Shedi river (Bhatt *et al*, 1991).

Anopheline fauna of Kheda district consist of 16 species which include *An. culicifacies* as the major vector of malaria (Yadav *et al*, 1989). In irrigated areas *An. culicifacies* breeds in irrigation canals, channels, drains, seepages, ponds, rain water collections, paddy fields, etc. In non-irrigated areas ponds, pools, river margins and riverbed pools are the major breeding sources. Wells and domestic water containers also provide opportunity for mosquitos to breed throughout the year. *An. culicifacies* has shown resistance to DDT, HCH and Malathion (Sharma and Sharma, 1989).

Topo sheets (1981) of Nadiad taluka on the scale of 1 : 50,000 were obtained from Survey of India, and were used to digitize base maps. A matrix consisting of attribute data for each theme, namely water table, water quality, soil type, hydro-geomorphology, relief, irrigation channels, streams and surface water bodies was prepared to generate thematic maps. Remote sensing data was obtained from the National Remote Sensing Agency (NRSA), Hyderabad and the Space Application Center (SAC), Ahmedabad. It was rectified with respect to topomaps by generating a second order polynomial transformation model using necessary ground control points. The rectified data was re-sampled to 30 x 30 ground pixel size. Digital classification was performed on sun elevation angle corrected data using a maximum likelihood algorithm. Care was taken to identify homogeneous and evenly distributed training samples all over the area. The images were analyzed on a 512 x 512 pixel frame; each pixel corresponds to 30 x 30 m after re-sampling. Surveys were conducted to verify thematic maps on water table, soil type, water salinity, water bodies and irrigation networks. The area under different classes was calculated as 30 m x 30 m x no. of pixels.

Each thematic map was stratified in three potential zones *ie* high, medium and low according to favorable conditions for water logging and, in turn, mosquito breeding. Overlaying operations included superimposition, proximity searches, topography analysis and aggregation of areas. Though attribute data was available village-wise, the ecological data do not have conformity with political boundaries for overlying of maps, so village boundaries were merged. For selection of high-, medium- and low-potential areas in overlaid maps three steps were followed: (1) a simple intersection of areas with common conditions in two overlaid maps were selected; (2) in stratification classes where different situations in the two overlaid maps exist, conditions high, medium and low of the dominant parameter for promoting vector breeding were taken; (3) the resultant map was prepared by union of the areas in steps 1 and 2. Here 'Intersection' and 'Union' have been taken in the truly mathematical sense, *ie* intersection C of two areas A and B is the area consisting of pixels belonging to both areas A and B, whereas union 'C' is the area consisting of pixels belonging to areas A and/or B. Thematic maps were used to prepare three sets of overlaid maps, namely (i) water table and water quality, (ii) soil type and hydro-geomorphology, and (iii) relief, irrigation channels, streams, surface water bodies, etc. Overlaying these three sets resulted in 13 stratification classes. In the composite map village boundaries were superimposed to find the status of each village. A few villages falling into more than one stratification class were considered in a specific stratification class, if more than 50% of its area fell into that stratification class. The area under each category of each parameter was estimated to study the disease spatial distribution pattern with reference to these parameters. Annual Parasite Incidence (API, number of cases/1000 population/year) data for 1987 to 1991 was procured from Directorate of Health Services, Gujarat State for validation of the technique.

GIS software ArcInfo version 6.0 for Work Stations and ArcInfo version 3.4 for PC were used to digitize, integrate and analyze thematic maps. The area falling in each zone - high, medium and low - in thematic maps and the integrated maps was estimated using ArcView version 1.0.

## RESULTS AND DISCUSSION

The areas estimated under high, medium and low breeding potential are given in Table 1 and will be discussed in association with subsequent thematic and overlaid maps.

### Thematic maps

Soil maps were prepared using toposheets and later matched with the remote sensing imagery. Four types of soil with the local names Chaklasi - CKS, Anki - ANK, Ratnapur - RTP and Matar - RTP are present in Nadiad taluka. In the northern part, soil ranging from sandy loam to loam is found. The soil consists of non-calcareous, mixed type coarser particles, inherently porous and permeable, hence internally well drained. This portion of Nadiad has been considered to be a low water holding area (72.8 km$^2$. The soil becomes deeper and darker in color towards the west and the texture changes to medium/fine medium and consequently acquires moderate to poor internal drainage. Thus the middle region of Nadiad with mixed and fine loamy soil (ANK) has been taken as a medium breeding potential zone. Also, a small region in southern Nadiad with sandy and loamy soil (MTR) has been taken to be a medium breeding potential zone. The total area of medium breeding potential zones is 228.8 km$^2$. In the southwestern part of Nadiad the soil (ANK) is mainly fine clay, loam and non-calcareous, allowing water stagnation (Yadav *et al*, 1983). Therefore this area of 357.3 km$^2$ has been designated as a high breeding potential zone.

An area having a high water table < 3 m (Bhatt, 1991) has been taken as a high water stagnation zone because the high water table reduces the rate of water percolation, promoting water stagnation. This constitutes an area of 339.7 km$^2$. A water table of 3-15 m, consisting of an area of 177.8 km$^2$ has been taken as moderate potential zone and the remainder, 141.5 km$^2$, was taken as a low breeding potential zone. Two types of water quality *ie* saline and potable were found in Nadiad. The saline water belt passes through the center of Nadiad and a pocket in the northeast constituting a total area of 145.2 km$^2$. The rest of Nadiad has potable water (513.6 km$^2$) which provides favorable breeding grounds and in the study has been taken as a high breeding potential zone.

The area has a slope from northeast to southwest, with an average gradient of about 1 to 1,600 towards the gulf of Cambay. However, there are some isolated local high spots and ridges that determine the courses of natural streams and their tributaries. Half of Nadiad (the southern part) is on the right bank of the Mahi river command area with a good network of irrigation system. On the basis of topography the southwest (232.73 km$^2$) Nadiad has been considered as high potential zone, whereas the remaining 426.37 km$^2$ has been taken as a medium potential zone. There are numerous ponds and tanks in Nadiad, every village has a pond but these are generally infested with vegetation (Bhatt *et al*, 1991) and largely do not support vector breeding. The ponds help in maintaining high humidity, and in extending vector longevity and transmission of the disease. The flood plain exists around Shedi and Mohar rivers. To designate the flood plain a buffer zone of 79.1 km$^2$ was created around the rivers. Malaria is generally low in flood plains unless these are modified by man.

### GIS analysis

Overlaying of water table and water quality maps resulted in 11 stratification classes, of which 5 were in low, 4 in medium and 2 in high breeding potential zones. The total areas under high, medium and low strata were respectively found to be 297.1 km$^2$, 135.5 km$^2$ and 226.3 km$^2$ (Table 1). The soil and hydro-geomorphology combined map, when overlaid with the previous map, resulted in 18 stratification classes, 4 having high breeding potential, 7 each having medium and low breeding potential, with total areas of 347.8, 94.9 and 216.3 km$^2$ respectively. Finally, the relief map combined with streams, irrigation networks, surface water bodies, etc was overlaid on the integrated map (soil + water table + water quality + hydro-geomorphology). The composite map resulted in 13 stratification classes (Fig 1). The sums of areas under high, medium and low zones were 416.1, 111.0 and 131.8 km$^2$, respectively (Table 1).

Average API for each stratification class when compared with the GIS analyzed map established 95% (288.8 km$^2$) matching of the areas in non-irrigated zone (Fig 1). The breeding potential of stratification class numbers 6 and 10 situated on inter-taluka boundary did not match with average API is due to migration from nearby areas. For example in

Table 1
Areas under different categories of thematic maps as estimated by GIS analysis.

| Parameters | Area (km²) | | | |
|---|---|---|---|---|
| | Low | Medium | High | Total |
| Soil | 72.82 | 228.82 | 357.33 | 658.98 |
| WT | 141.50 | 177.81 | 339.65 | 658.97 |
| WQ | 145.17 | - | 513.80 | 658.97 |
| Relief | - | 426.37 | 232.73 | 659.11 |
| GMOR | 79.12 | - | 580.34 | 659.47 |
| WT+WQ | 226.33 | 135.52 | 297.12 | 658.97 |
| WT+WQ+Soil+HGM | 216.31 | 94.90 | 347.75 | 658.97 |
| Composite map | 131.84 | 110.99 | 416.13 | 658.97 |

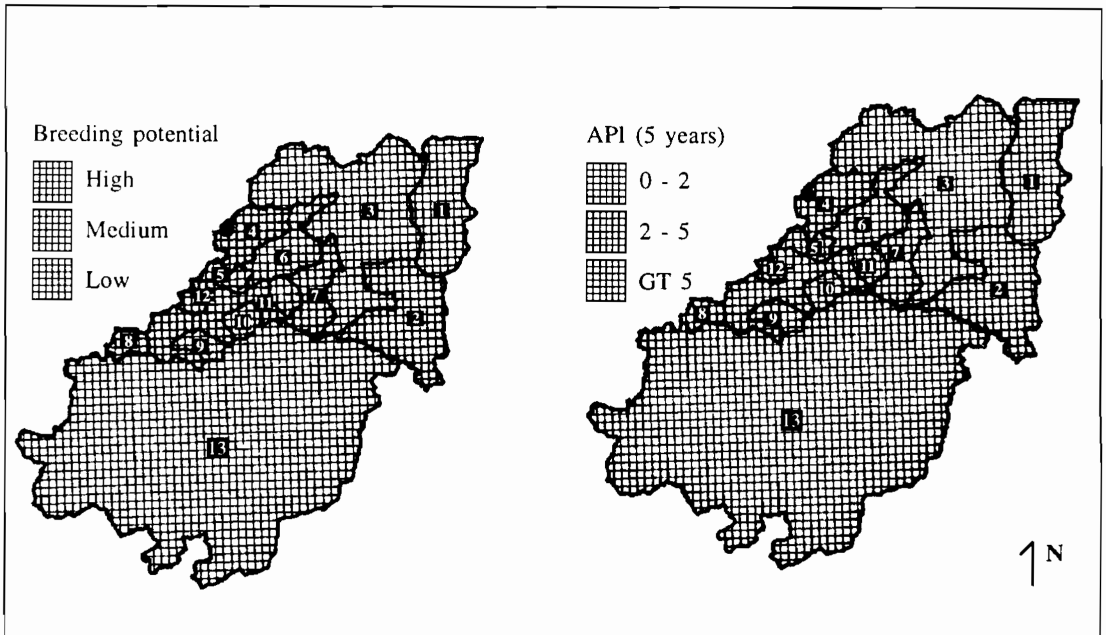


Fig 1–The two maps showing malaria receptivity as predicted by GIS and ground reality. Ground verification reveals complete reconciliation of the two.

the village with code number 15 breeding potential was low whereas, malaria was high as a result of migration due to weekly market (Table 2). A study on imported malaria in Kheda district revealed that annual falciparum incidence in migrant labor was 2 to 5 times higher than in local population (Sharma and Sharma, 1988).

In irrigated area *ie* stratification class 13 breeding potential and API did not reconcile. Studies on ground truth verification revealed that after implementation of the Mahi irrigation project at one time there was an acute problem of high subsoil water, water logging resulting in rise in salinity and loss of agriculture production. These situations provided optimal conditions for mosquito proliferation and there were several out breaks and epidemics in the command area. To increase agriculture production the Mahi irrigation authorities undertook various measures such as alternating 10 days dry and wet canal system, completion of drainage network, perennial irrigation was restricted to class I and II soil categories. Also, more than 10,000 wells were dug for conjunctive use of water to increase rice cultivation.

Table 2
Determinants of malaria receptivity and selective control strategy proposed for Villages of Nadiad taluka.

| Classes | No. Vil | Avg API (1987-91) | Results of GIS | Reasons for malaria situation in each geographical area | Recommendations for control |
|---|---|---|---|---|---|
| 1 | 3 | 8.13 | High | High water table, slow flowing streams and water bodies | BC |
| 2 | 7 | 2.8 | Medium | Natural streams, water bodies and river bank | BC |
| 3 | 20 | 1.84 | Low | No evidence of transmission | EDPT |
| 4 | 2 | 4.8 | Medium | Non-porous, soil and surface water bodies | BC |
| 5 | 2 | 7.8 | Low | Cases due to migration | EDPT |
| 6 | 2 | 5.5 | Medium | Soil type, water quality and cases due to migration | EDPT |
| 7 | 10 | 4.2 | Medium | Natural streams, water bodies and soil | BC |
| 8 | 1 | 1.0 | Low | No evidence of transmission | EDPT |
| 9 | 1 | 7.6 | Low | River taking a bend along village boundary leaving more area for water logging | BC |
| 10 | 1 | 1.9 | Low | No evidence of transmission | EDPT |
| 11 | 1 | 1.3 | Low | No evidence of transmission | EDPT |
| 12 | 1 | 2.8 | Low | No evidence of transmission but cases due to migration | EDPT |
| 13 | 49 | 5.0 | High | Conjunctive use of water *ie* canal and tube well and selective wells, improved drainage, environmental use of insecticide control strategy during 1983-86 resulted in successful control of malaria and its vectors. | BC |

For comparison API < 2 is taken as low, 2-5 as medium and >5 as high
EDPT - Early detection and prompt treatment; BC - Bioenvironmental control
Vil - villages

Besides this an alternate strategy known as bioenvironmental control of malaria was launched in Nadiad taluka, Kheda district in 1983. Initially it was started in seven villages (26,000 population) in the irrigated zone and showed spectacular success in malaria control; the study was extended to cover a total of 21 villages, mostly in irrigated zone in 1985. The vector densities of *An. culicifacies* and *An. stephensi* were greatly reduced in these villages. The incidence of malaria also started to go down in successive years. Low malaria was substantiated by reduction of spleen enlargement in children and low sero-positivity rate. In 1986, the study was extended to cover the entire taluka comprising 100 villages with a population of 350,000. The results in the entire taluka were equally spectacular with general improvement in the environment. Major emphasis in this project was on introduction of larvivorous fishes, most of the village ponds were converted to hatcheries. These larvivorous fishes multiplied and helped in maintaining low vector densities (Sharma, 1991; Sharma and Sharma, 1989; Sharma *et al*, 1986).

The measures taken by Mahi irrigation authorities lowered the subsoil water and water logging whereas implementation of bioenvironment strategy resulted in source reduction of vectors and helped in maintaining low vector density and malaria incidence. It may be mentioned that agriculture production mainly rice cultivation was increased to the extent that the Mahi irrigation authorities were awarded a National Productivity Council prize (Kalra, 1994); rice fields have poor relation with malaria (Sharma *et al*, 1993). This ground realities established low receptivity of stratification class 13 and thus the study resulted in complete reconciliation of cause and effect relationship as established through GIS in explaining malaria epidemiology.

The areas with high breeding potential in water table and water quality thematic maps were estimated as 339.65 and 513.80 $km^2$, respectively (Table 1). Overlaying of these two maps resulted in reduction of high potential breeding area to 297.12 $km^2$. When this map was overlaid on soil and hydrogeomorphology combined maps, the area under high breeding potential zone increased to 347.75 $km^2$. In the composite map total area under high potential zone increased to 416.13 $km^2$. Thus, adding of a new theme may result in change in breeding potential of an area depending upon the conditions of the theme for breeding. Or in other words, for each smallest unit, say pixel, the condition for breeding is dependent on the conditions of overlaid themes which vary spatially and temporally. Thus, the conditions for breeding potential may vary from pixel to pixel, thus making the disease as local phenomenon. The successive overlaying thus revealed spatial dynamics of breeding potential/disease distribution pattern. It also substantiates the thesis that each of the parameters considered in the study plays a role in modifying malaria receptivity in geographical realm.

Overlaying of each thematic map and API was done for estimating percent matching of low, medium and high areas (Table 3). It exhibited maximum matching of API with water table (37%) of villages followed by soil (26%), irrigation (24%) and water quality (21%) as given in Table 3. Streams and relief thematic maps exhibited only 14% and 11% matching with the API map, respectively. It shows that out of all parameters considered, water table and soil type play a major role in governing malaria receptivity in Nadiad taluka. Soil type is more or less a stable parameter whereas water table keeps changing with irrigation, rainfall and ground water exploitation. The roles of other parameters in different stratification classes in Nadiad are given in Table 2. Based on the local malaria transmission determinants, a revised malaria control strategy has been suggested. Adoption of this strategy would control malaria on a long term basis at low cost. The methods suggested are environmentally friendly and have the scope of community participation and intra-sectoral coordination.

Table 3
Percentage reconciliation of villages in each category of breeding potential with API.

| Themes | Low % | Medium % | High % | Total % |
|---|---|---|---|---|
| Soil | 5 | 13 | 8 | 26 |
| WT | 16 | 11 | 10 | 37 |
| WQ | 10 | - | 11 | 21 |
| IRRI channels | 3 | 13 | 8 | 24 |
| Streams | - | 8 | 6 | 14 |
| Relief | - | - | 11 | 11 |

Total number of villages = 100

## ACKNOWLEDGEMENTS

The authors are thankful to Director, NISTAD for providing basic remote sensing data and support in the initial stages of the studies. Thanks are also due to Mr PK Pujara, retired entomologist, Gujarat State for providing malaria data and other ground information. We are grateful to Mr NL Kalra and Dr MS Malhotra for fruitful discussions.

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