Public health | water borne diseases | malaria | environmental effects

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WATER-RELATED ENVIRONMENTAL FACTORS AND MALARIA TRANSMISSION IN MAHI KADANA, GUJARAT, INDIA

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Summary

In this paper an assessment is made of the spatial and temporal relationship between malaria incidence and selected water-related environmental parameters within the Mahi Kadana Irrigation Scheme in the state of Gujarat, India. The analysis is based upon the use of secondary information. A geographical information system (GIS) was used to generate input into a statistical analysis and to map out the parameters for a visual analysis. The paper discusses the quality of the data used and describes the possibilities for using GIS in health-related research. The analysis for the whole study area was carried out on an annual basis for 2 years, 1981 and 1982. For the period July 1990 to June 1993 the analysis was carried out for a selected part of the study area. The annual number of positive blood films per 1000 population for each of the health centers under analysis were used as an indication of malaria incidence. For the year 1981 rainfall variation explained 60 percent of the variation in malaria incidence among the primary health care centers located throughout the whole study area. Variation in rice intensity, depth to groundwater, and irrigation density did not contribute to explaining the variation. For the year 1982 none of the water-related environmental parameters analyzed contributed to explaining the variation in malaria.

When the analysis was performed on a seasonal basis for one selected administrative unit, rainfall and rice intensity explained most of the variation in malaria. It was only for the selected administrative unit that the analysis showed that factors under irrigation management control were of importance in explaining the variation in malaria incidence. The analysis was weakened by the incomplete information obtained in relation to malaria cases. The differences in treatment-seeking behavior across the study area, differences in diagnostic and reporting practices among the centers, and the degree of underreporting may have disguised the real difference in malaria incidence in various parts of the study area. The GIS provided key inputs into the statistical analysis by generating average values for the parameters under study for the catchment areas of the health care centers. The GIS was also useful for performing the interpolations of rainfall for the whole study area.

BACKGROUND

Irrigation development has, for centuries, been linked to the spread of malaria as an effect of the ecological changes induced by the systems and because of population movements often associated with irrigation development. However, studies seeking to examine the relationship between malaria and irrigation have revealed a complex picture with a high degree of site-specificity. In some situations, incidence of malaria is increasing while in others it is decreasing or remains unchanged following irrigation development. The different *Anopheles* mosquitoes that transmit malaria have different preferences in breeding sites, with some species favoring the new opportunities created within the irrigated area while other vectors may find lesser opportunities. The impact of irrigation development will therefore be highly dependent upon the malaria vector present in the area. Also, in some areas where irrigation is promoted, the number of mosquitoes that transmit malaria is already so high that an increased number of mosquitoes will not lead to an increase in the number of malaria cases since the level of transmission is already much higher than needed to maintain effective transmission (Bradley 1988).

In some areas, irrigation may only have a seasonal effect by extending the transmission season into the dry season, while the contribution from irrigation during the rest of the year may be limited in comparison to the mosquito breeding habitats created by precipitation. Variations in irrigation water management practices and differences in design of irrigation infrastructure will also create very different breeding opportunities. A number of design and management measures have been suggested to reduce mosquito breeding within an irrigated area including, for example, precision or intermittent irrigation practices to reduce standing water in the fields, lining of canals to reduce seepage pools, improved on-farm water management to reduce the amount of drainage water, irrigation water rotations making it possible to dry out canals on a weekly basis, and releasing fingerlings into irrigation reservoirs to reduce the mosquito larvae abundance.

Increased knowledge will need to be generated, on the basis of case studies, to determine the contribution of irrigation to the overall transmission of malaria within a given area. Some of the factors determining transmission will be manageable and could be integrated into the normal irrigation routines or may even improve irrigation performance while other factors will be outside the control of irrigation managers.

Objectives

In this paper an effort is made to find out to what extent irrigation and water-related environmental parameters may explain the variation in malaria transmission within an irrigated area. The case study is based upon available data making it possible to discuss the usefulness of secondary information as an input into an analysis making use of geographical information systems (GIS) and traditional statistical methodologies. The specific objectives of this paper are to:

1. Asses the spatial and temporal relationship between malaria incidence and selected water-related environmental parameters within the Mahi Kadana irrigation scheme in Gujarat, India, and

2. Produce case study material to describe the use of GIS in the field of environmental health and irrigation.

Malaria in India

Large parts of India are endemic to one or both types of malaria parasites prevalent in the country, *Plasmodium vivax* and *Plasmodium falciparum,* and more than 350 million people in India are at risk of infection. The main control measures are spraying of residual insecticides and treatment of cases. The growing resistance of *Plasmodium falciparum* to the commonly used drugs and the problem of growing resistance among mosquitoes against a range of the insecticides used for mosquito control have made malaria control interventions very costly and difficult to sustain. Therefore, there is a growing interest in using alternative means of vector control interventions, often referred to as environmental management measures for disease vector control. However, before such interventions can be effective, substantial knowledge has to be generated to i) identify the most important environmental parameters determining the transmission of the disease, ii) identify factors under irrigation managers' control, and iii) further assess the feasibility and cost-effectiveness of such interventions.

Geographic Information System Technology to Monitor and Control Diseases

A study carried out by John Snow is often cited as an example of the importance of understanding the spatial dynamics of diseases, and the use of maps to describe and analyze them. *More than a century ago,* Snow hypothesized that cholera may be spread by infected water supplies. The hypothesis was generated by using maps to demonstrate the spatial correlation between cholera deaths and contaminated water supplies in the area of Soho in London 1854. Over the past 20 years, researchers have been developing automated tools for the efficient storage, analysis and presentation of geographic data. This rapidly evolving technology is known as 'Geographic Information Systems' (GIS).

GIS, resulting from the demand for data and information of a spatial nature, is widely used across varied scientific and management fields. The ability to use topological information and spatial analysis functions distinguishes GIS from a number of other information systems (Bretes 1994). A great deal of information is necessary for most aspects of malaria control and research programs. GIS offers the ability to process quantities of data beyond the capacity of manual systems. Data are stored in a structured digital format which permits rapid data retrieval and use. In addition, data may be quickly compiled into documents, using techniques such as automatic mapping and direct report printouts (Bretes 1994). Further, a number of specific spatial analysis methods can be applied on data stored in a GIS. Among these methods are computation of distance and area and identifying the most efficient routes of importance for the planning and operation of malaria control programs. Interfaces between satellite remote sensing (SRS) and GIS open new avenues for researchers to overcome the problems related to data collection using conventional techniques over large land areas which are labor-intensive and therefore costly. In addition to control aspects, SRS and GIS allow for entomology-related studies identifying areas with high potential mosquito density by using physical characteristics such as temperature, rainfall, humidity, aridity, water stress, and waterlogging.

Description of Water-Related Variables

Variation in water status has a profound effect on the breeding potential of the mosquito and may determine the level and seasonality of malaria transmission. In this study, four factors were selected to describe variations in water availability. One of the factors, rainfall, is outside irrigation management control whereas the other three factors are fully or partly under irrigation management control, i) rice intensity, ii) depth to groundwater, and iii) irrigation density.

Rainfall

The amount and the seasonality of rainfall are obviously important parameters in determining the status of mosquito breeding habitats and therefore also important in determining the total density of adult mosquitoes and the seasonality of transmission. In many malaria areas the peak of transmission is known to follow the rainy season and the length of transmission may be determined, among other things, by the balance between precipitation and evaporation. During periods of heavy rainfall, breeding may be hampered for a short time by flushing pools and by transforming small streams into rapid torrents. Periods with low rainfall may, in certain areas, induce mosquito breeding. For example, by turning rivers into a string of pools in which certain anopheles would breed in profusion, as is the case of species belonging to the *Anopheles culcifacies* complex including some of the major vector of malaria in India. In this study, rainfall is taken as annual or monthly values in millimeters.

Rice Intensity

Rice cultivation may create favorable conditions for mosquito breeding during certain stages of its growth when water is stagnant in the fields and the rice has not yet developed a closed canopy. Also, mosquito breeding will depend on the temperature and turbidity of the water in the fields. Further, the total mosquito production within an area of rice cultivation will depend on the duration and synchronicity of flooding (Bradley 1988). Thus an area with rice cultivation divided into very small plots and cultivation taking place in a nonhomogeneous manner with crops at various stages are likely to increase the length of time that the rice area contributes to vector breeding. Without information on the homogeneity of rice cultivation, only rice intensity as a whole had been taken in to account in this study given as a percentage of command area under rice cultivation per year.

Depth to Groundwater

Shallow groundwater favors the establishment of surface water pools and following light rains it may be an important factor in determining the mosquito abundance. However, various studies have given different results between the relationship of depth to groundwater and malaria (Donnelly et al. 1996). These results have been attributed to the difference in ecology of the different malaria vectors. Depth to groundwater, in this study is given in three different ranges: below 3 meters, between 3 and 1.5 meters, and above 1.5 meters.

Irrigation Density

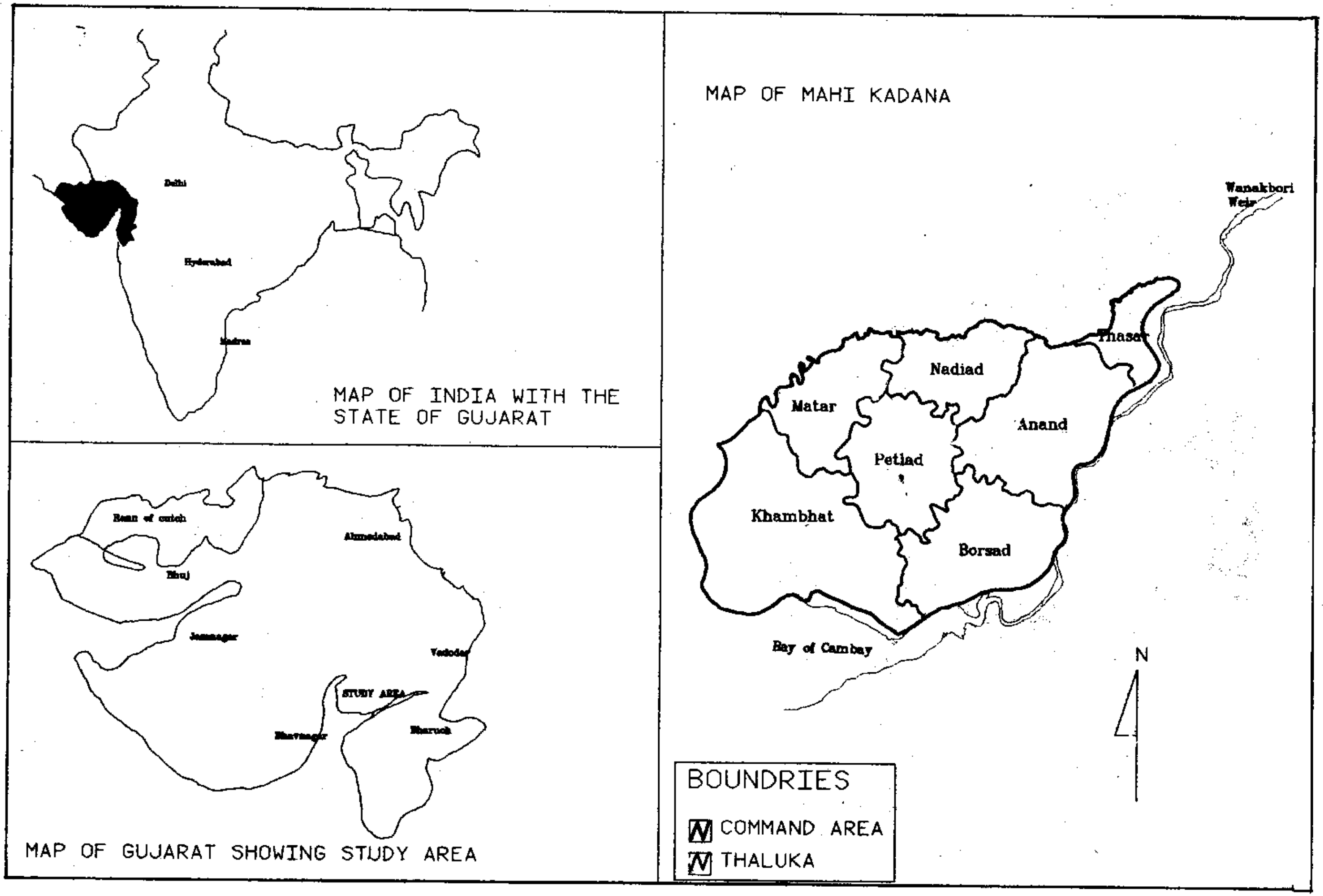
Early work on malaria and irrigation showed that increased irrigation intensity could lead to an increased incidence of malaria (Gill 1930; Russel, Menon, and Rao 1938). An increased area under irrigation may increase the density of malaria-transmitting mosquitoes by increasing the area favorable to breeding resulting from, for example, pooling within the fields, seepage from canals, or stagnant water in the drainage. Also, dry season irrigation may extend the transmission season where the irrigation water supplied to an area is the only breeding source available. Various types of irrigation water management practices may have different impacts on the breeding potential of a given area; however, this factor is not considered in this study. Irrigation intensity is usually defined as a percentage of irrigable area under irrigation. In this study, it was necessary to define a new parameter, irrigation density, since the exact size of the irrigable area is not known. Irrigation density was defined as the percentage of area under irrigation of the geographical area, including irrigated and nonirrigated areas, as an annual average for each of the distributary command areas. Only areas supplied via canal irrigation were included since it was not possible to obtain figures for tube well irrigation for the different distributaries. However, it was estimated, in 1991, that the amount of irrigation water from groundwater equaled approximately one third of the water supplied through the canal irrigation system (Narayanamurthy, personal communication).

THE STUDY AREA

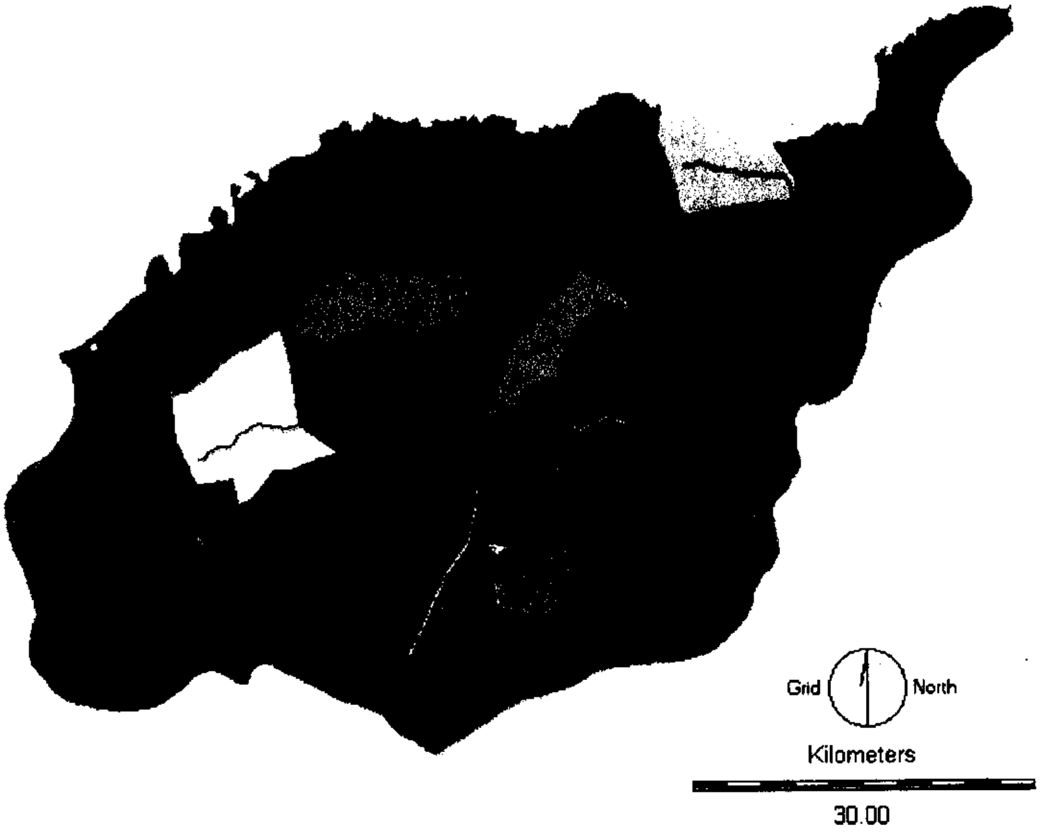
The Mahi Kadana Irrigation Project in the State of Gujarat has been developed in two phases. The first phase related to the construction of a diversion weir across the Mahi River at Wanakbori in the Kheda District and the second phase related to the construction of a dam at Kadana in the Panchmahal District. The area is divided into seven *thalukas* (administrative units): Thasar, Nadiad, Anand, Petlad, Borsad, Matar, and Khambhat (map 1) with a total population of 1.2 million. The cultivable command area of the project is estimated at 212,000 hectares covering either whole or part of the 7 thaluka units of the Kheda District. Each thaluka has two or three parent primary health care centers (PPHC) with each PPHC having three to five minor PHCs within its catchment area.

The distribution system of the Mahi Kadana irrigation project consists of the main canal and 39 distributors (map 2) and farm-level field channels. Tube wells are used increasingly to supply irrigation water from groundwater. The diversion weir allows for intensive irrigation in *kharif* (the monsoon season from 15 June to 15 November) and for limited irrigation in *rabi* (the winter season from 15 October to 15 March) and during the third, hot weather, season from 15 February to 15 June, depending on river flows.

Map 1. India, Gujarat, and Mahi Kadana.



Map 2. Distributary canals with command areas.



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The area under study is one of the most developed areas in the State in terms of agricultural practices and cooperative ventures such as milk processing. The upper and the upper middle parts of the command area (Thasra and Nadiad thalukas) have the most fertile land of the area, viz., sandy loam to sandy. The lower middle part of the area (Anand, Petlad, and Borsad thalukas) is of medium black soil type. The tail part of the area (Matar and Khambhat thalukas), which is mostly coastal saline, is poorly drained and less fertile. From

1980 to 1989 the district received an annual rainfall of between 386 mm and 1,173 mm with an average of 779 mm. Except for the occasional showers in winter, rainfall is restricted to the period between June and October. Rice, pearl millet, and pulses are the important kharif crops of the upper and middle areas. Tobacco is grown extensively in this area as a kharif-cum-rabi crop, accounting for 40 percent of the gross cropped area. The exclusive rabi crops are wheat and potato. During the hot weather, pearl millet and fodder sorghum are grown. The tail part of the project area is essentially a rice growing area in kharif , with no major crop in rabi. More than two seasons of irrigation in the upper and middle parts of the command area in recent years have resulted in an increased area under waterlogged conditions. To arrest this unfavorable development, a massive draining program has been undertaken.

The Nadiad thaluka was selected for a more detailed study. This thaluka consists of 102 villages. Part of the thaluka belongs to the Mahi command area and is canal-irrigated while the other part is not. There are two PPHCs in the Nadiad thaluka, One, Alindra, is in the irrigated area and the other, Mahuda, is in the nonirrigated area. There is one rain gauge in the thaluka.

Malaria Transmission in the Mahi Kadana Area

The primary malaria vector identified in the command area of Mahi Kadana is *An. culcifacies*. Available literature on malaria states that this species occurs in fresh water and in sun-exposed habitats. A study done by Yadav et al. from 1985 to 1988 in the Mahi Kadana area to identify the breeding habitats of Anophelines showed that *An. culcifacies* preferred to breed in canals, rivers, irrigation channels, riverbed pools, and rice fields. The compositions of *An. culcifacies* in total adults that emerged from the sample taken from these habitats were 45.55 percent, 36.46 percent, 26.9 percent, 7.32 percent, and 7.23 percent, respectively. Also identified was a marked variation in seasonal prevalence during the year and between different areas of the Kheda District. It has been shown that in non-canal irrigated areas mosquito densities remained very low from January to June, a period with no or little rainfall. However, in canal-irrigated and riverine villages mosquito densities showed a peak in this period. This peak was due to extensive canal irrigation, rice cultivation, and the formation of riverbed pools. For both areas, mosquito densities showed a peak following the onset of the monsoon in June.

Antimalarial Program during the Period of Data Collection

Following the serious outbreak of malaria in 1976, disease control and prevention measures were stepped up under the leadership of the local self-government organization known as District Panchyat, which is the main body responsible for development and social infrastructure in the Kheda District. These include public health programs and the control and prevention of epidemic diseases. The District Health Officer, an official of the District Panchyat, was in overall charge of the malaria control and eradication program, assisted by a special officer known as the District Malaria Officer. Under the District Panchyat there were 19 parent primary health care centers (PPHCs) which offered malaria treatment. Of these 15 PPHCs fall within the irrigated area of the Mahi Kadana system. These clinics had laboratory facilities for testing blood smears and they had stocks of medicine for the treatment of malaria. In addition to the malaria clinics of the PPHCs multipurpose health workers, community health visitors, and auxiliary nurse midwives also provided services such as the distribution of drugs to the patients, free of charge. In addition to these, a Fever Treatment Depot also functioned in the bigger villages, with a population of more than 5,000. These depots functioned under the guidance and control of the PPHC. This arrangement had been made with a view to circumvent the difficulty of traveling to the main PPHC, with its catchment up to 20 km, and to provide simple drugs, as far as practicable, in the village itself. Further, there were private doctors and pharmacists who ran their own treatment centers.

METHODOLOGY

Data Sources and Collection of Data

Malaria incidence, expressed as annual parasite incidence (API, annual number of positive blood films per 1,000 population per year), had been collected for the period 1981 to 1992 at the level of PPHC for the whole Mahi River bank area. The API was calculated on the basis of the blood film confirmed malaria cases registered at each PPHC, divided by the population living in the villages within the official administrative boundary of the PPHC demarcated by the malaria control program. In addition, monthly malaria incidence was calculated for the period 1990 to 1993 for a selected thaluka, Nadiad, within the Mahi Kadana command area. The monthly malaria incidence figures were calculated by dividing the number of malaria cases registered at the PPHC by the population within the catchment. The government health statistics were obtained from the Malaria Research Centre in Nadiad.

Maps indicating depth to groundwater (Post-monsoon maps from 1988 and 1992), irrigation infrastructure, and distributor command area were obtained from the State Irrigation Department and Water and Land Management Institute (WALMI). Annual figures on irrigated crops for each of the distributors of the Nadiad thaluka for 1983 to 1994 were provided by the State Irrigation Department and WALMI. Rainfall data had been accumulated on an annual basis for the seven stations (map 3) within the command area from 1981 to 1992 by the Department of Meteorology in India. Monthly rainfall data for the Nadiad thaluka were also obtained from the same source for the period 1989 to 1994.

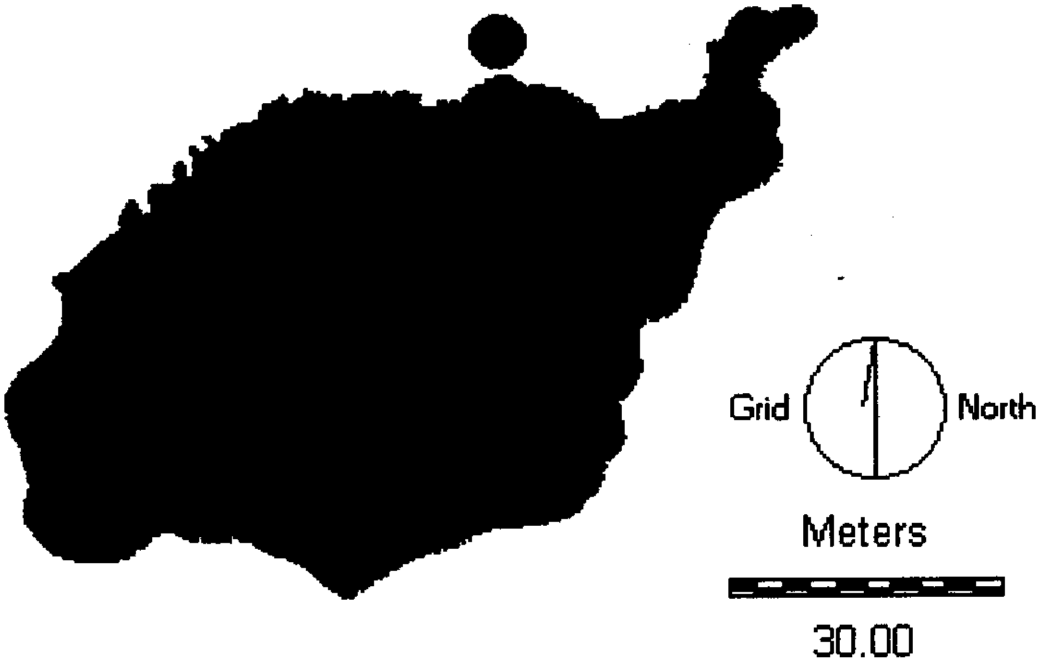
Spatial Data Processing and Analysis

All information was included in geographic information system software, Arc-Info and Idrisi, to facilitate visual interpretation and to carry out the interpolations necessary for further analysis.

Three different GIS and statistical capabilities were used in the analysis to identify the most important factors for the transmission of malaria:

- a visual spatial comparison between all variables
- a composite vulnerability analysis based on independent variables overlay
- a multiple regression analysis based on spatial aggregation of independent variables

Map 3. PPHCs (red) with catchment area and rainfall stations (black).



PPHC Catchment Areas

The actual catchment of a PPHC was likely to be different from the catchment defined on the basis of an administrative boundary since people were free to seek treatment at any government center. For the spatial analysis carried out in this study it was decided to estimate the catchment areas of the PPHC on the basis of distances from a PPHC by using the Thiessen polygon technique. This implies that any point within the catchment of a PPHC is closer to that PPHC than to any other PPHC. In this way, the definition of the PPHC catchment area may not overlap with the catchment area defined by the official administrative boundaries, and the API values are only a best approximation of the malaria transmission for a given PPHC catchment area.

Spatial Aggregation of Environmental Information

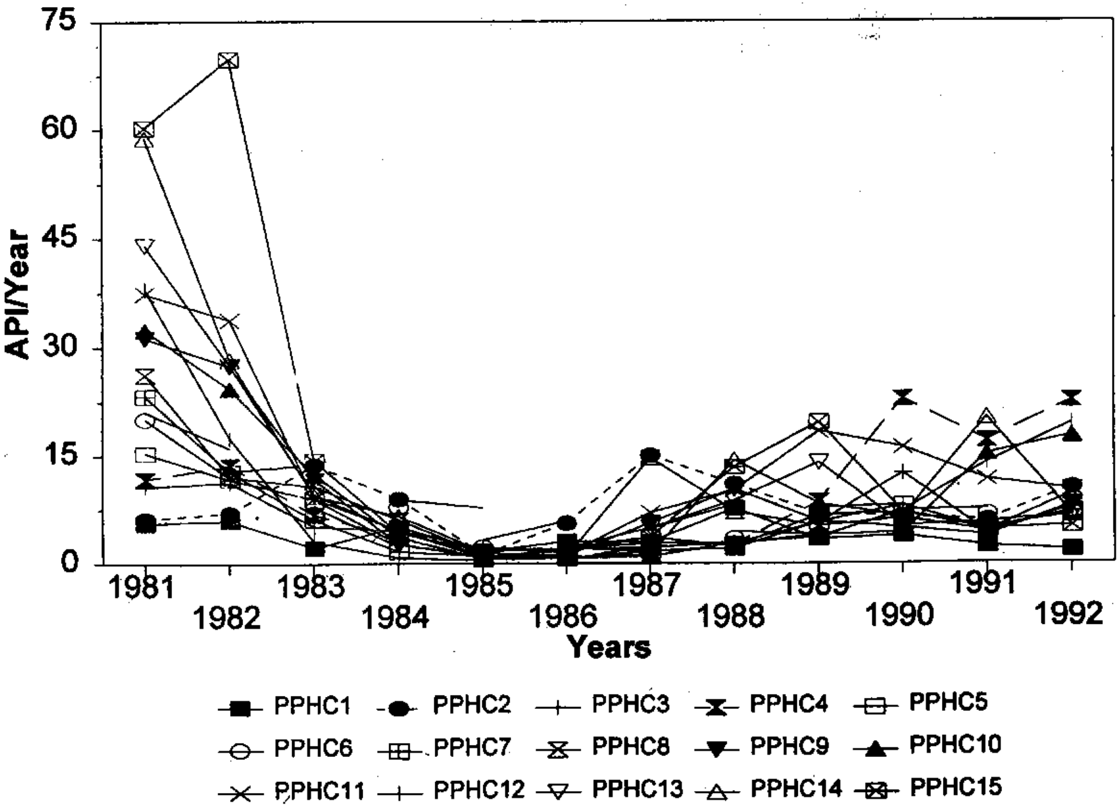
For each catchment area of the 15 PPHCs within the irrigated command, defined by the Thiessen polygon, average values of rainfall, depth to groundwater, rice intensity, and irrigation density were calculated. This was done by making use of the facilities available in Idrisi, the GIS software used in this study, where each of the variables is spatially aggregated for each polygon and average values calculated. Further, the interpolation of rainfall for the whole command area, based on the values recorded at the rainfall stations in seven different locations, was done by using the inverse distance technique available in Idrisi.

ANALYSIS AND RESULTS

Aggregation of Data for the Whole Command Area

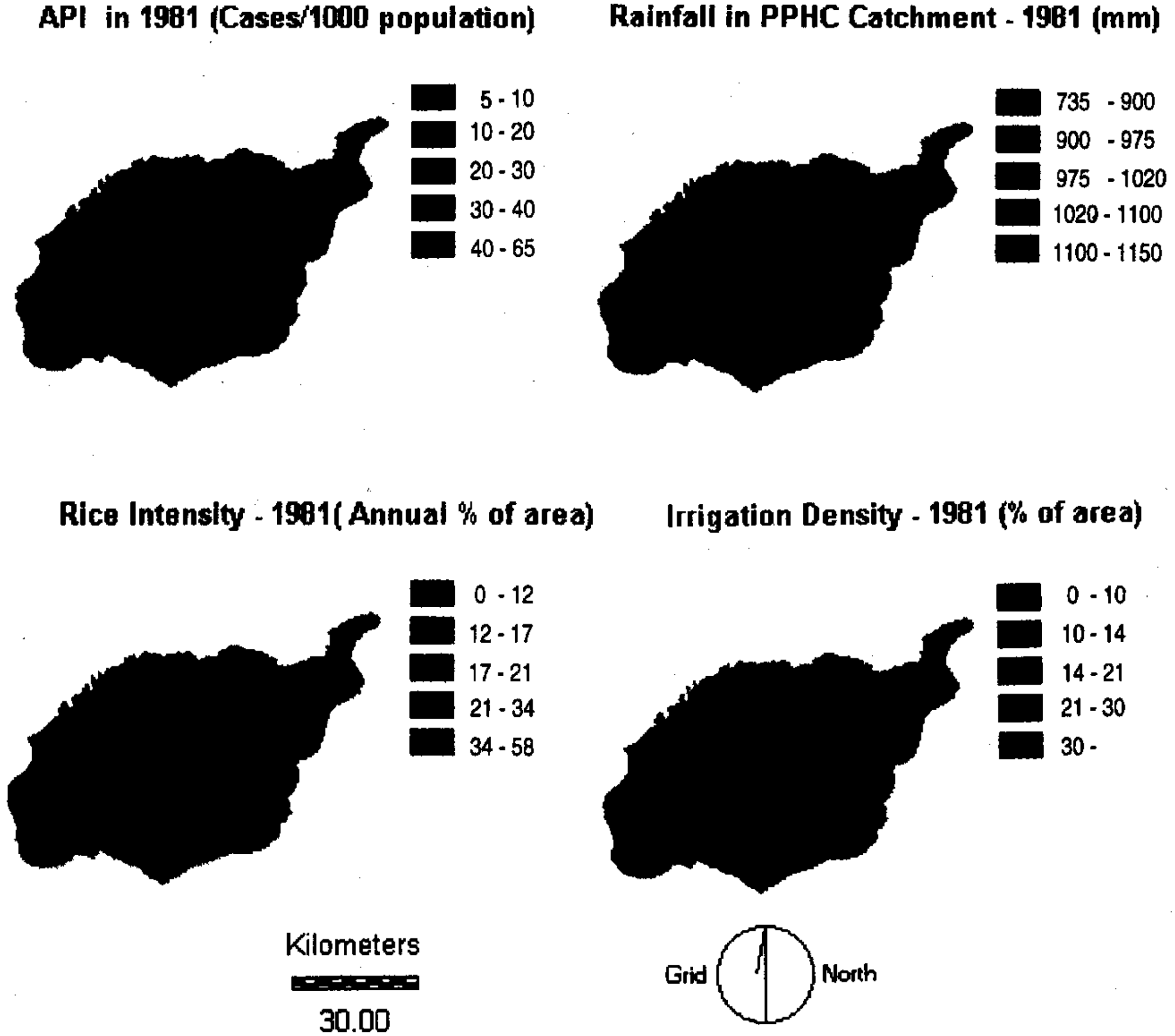
The first year of the data collection was 1981. As shown in figure 1, relatively high API values were identified in 1981 and 1982. Also high variations of API with respect to the PPHCs were identified in these years. The other years did not have the same high API values and the variation between the PPHC was very small. Therefore, only data for 1981 and 1982 were initially included in the analysis of the relationship between API and factors such as rainfall, irrigation density, and rice intensity. However, since no groundwater maps were available for 1981 and 1982, the 1988 map was used. The variation of the different factors within the study area are shown below. The analysis of the data for the year 1981 is used as an example and the analysis for 1982 is presented without a step-by-step explanation.

Figure 1. API values with respect to the PPHC.

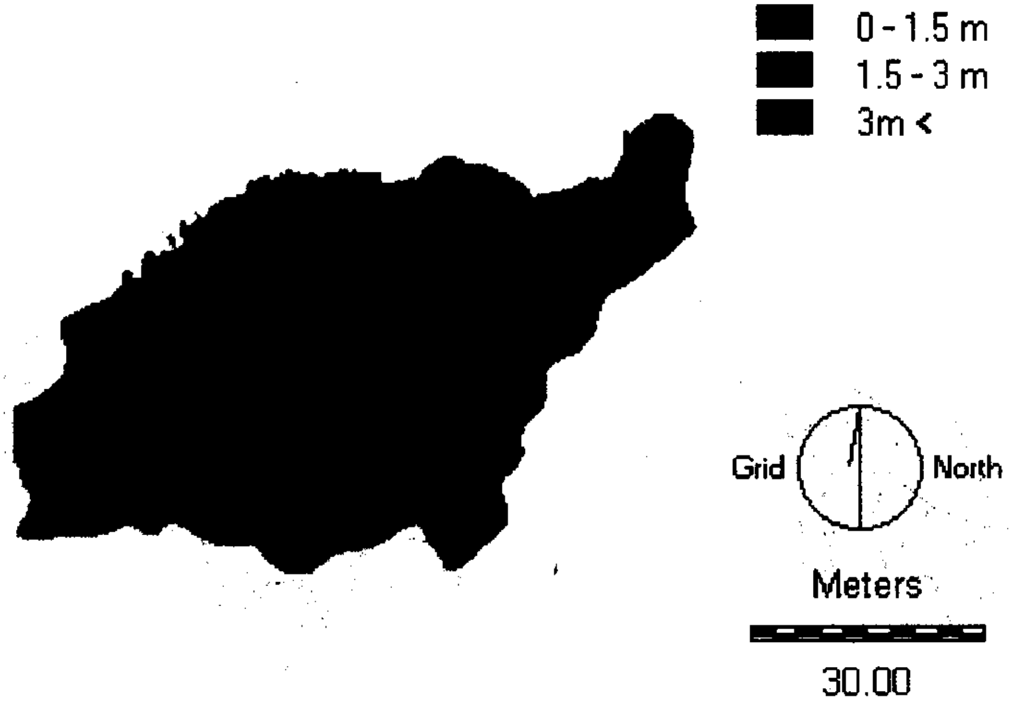


Maps 4a through 4d display the 1981 spatial distribution of API, average rainfall values, irrigation density values, and annual rice intensity. All the parameters are presented as values for PPHC catchment area (Thiessen polygon) and reclassified into 5 categories. Black lines indicate the PPHC catchment area boundary.

Map 4. Spatial distribution of API, average rainfall values, irrigation density values, and annual rice intensity, 1981.



Map 5. Depth to groundwater classification, 1988.



Map 5 displays depth to groundwater in 1988 divided into 3 categories.

Data Analysis for the Whole Command Area

Visual Analysis

Maps 4a through 4d are presented side by side allowing for a visual analysis. Although no quantification can be carried out on the basis of these four maps it still indicates a correlation between the selected water-related environmental parameters and malaria, supporting further analysis.

Composite Vulnerability Analysis (Overlay Process)

A map was produced in an overlay-weighted process indicating the potential risk of malaria at any point within the study area in relation to rainfall, depth to groundwater, irrigation density, and rice intensity. To create the risk or vulnerability index for the map, each variable was reclassified into three classes 1, 2 , and 3 corresponding to low-, medium- and high-risk, respectively. Equal weight was assigned to each of the variables in the computation procedure: Vulnerability Index = Rainfall Index (1-2-3) + Irrigation Index (1-2-3) + Rice Intensity Index (1-2-3). Map 6 shows a three-dimensional display of the estimated vulnerability index with the API values superimposed on the map using the drape function of the GIS. Although it is far from a perfect fit, map 6 does indicate some correlation between the water- related environmental parameters and malaria, supporting further analysis.

Map 6. Malaria vulnerability.

Spatial Aggregation Processes

A more classical statistical analysis was performed on the basis of data generated for 1981 and 1982, using data spatially aggregated at PPHC catchment areas. Based on the scatter plots it was found that the independent variables were highly associated with the natural logarithm of API. Tables 1 and 2 give the correlation coefficients between the logarithm of the dependent variable (Ln API) and the independent variables.

Table 1. Correlation coefficients between variables aggregated at PPHC catchment for 1981.

	Rainfall	Irrigation density	Rice intensity	Depth to groundwater
Ln(API)	0.77 (P= .001)	0.412 (P= 0.127)	0.56 (P = .028)	0.18 (P= 0.519)
Rainfall		0.327 (P= 0.234)	0.49 (P= .063)	0.16 (P= 0.560)
Irrigation index			0.283 (P=0.080)	0.07 (P= 0.802)
Rice intensity				0.67 (P= 0.006)

Note: P indicates the level of significance, e.g., P=0.001 means the correlation is significant with a probability of 99 percent, whereas P=0.234 refers to a probability of 76.6 percent. Also the level of significance is taken as follows: 99 percent and above—significant; 80 - 99 percent—marginally significant; Below 80 percent—not significant.

Table 2. Correlation coefficients between variables aggregated at PPHC catchment for 1982.

	Rainfall	Irrigation density	Rice intensity	Depth to groundwater
Ln(API)	0.3619 (P=0.185)	0.0766 (P=0.786)	0.3619 (P=0.185)	0.1817 (P=0.517)
Rainfall		0.482 (P=0.864)	0.1767 (P=0.529)	0.5899 (P=0.021)
Irrigation density			0.4080 (P=0.131)	0.1024 (P=0.717)
Rice intensity				0.6506 (P=0.009)

As shown in table 1, rainfall and rice intensities correlated significantly with the dependent variable. No significant correlation was found for depth to groundwater and irrigation density with the dependent variable. In addition, there were marginally significant correlations between some of the independent variables. Therefore, they cannot be considered as truly independent. Consequently, partial correlation coefficients were considered to control the association between variables. The rainfall, when controlled for the influence of the other variables, gave the partial correlation coefficient of 0.5642 and a probability of significance, P= 0.052, leading to consider the correlation as marginally significant. The other two partial correlation coefficients for irrigation density and rice intensity when controlled for other variables were not even marginally significant. Therefore, for the 1981 data, only rainfall was retained to explain the variation of API between the PPHCs.

Regression analysis was performed to see what percentage of API variation is explained by rainfall in 1981. In this analysis the natural logarithm of the API value was considered as a dependent variable. According to this analysis, 60 percent of the variability of the dependent variable can be explained by the rainfall. Finally, according to the regression analysis, API could be expressed as Ln(API) = -2.203 + 0.005 (Rainfall).

As shown in table 2 none of the independent variables were significantly correlated with Ln(API) and therefore, these did not explain the variation of API in 1982. One possible explanation for the difference in the impact of rainfall between 1981 and 1982 could be the changes in the pattern of precipitation. A comparison of rainfall values between these two years shows that the mean rainfall in 1981 (993 mm) was significantly (P=0.0001) higher than that in 1982 (602 mm) although the coefficient of variation was about the same (0.1) for both series. Also, the year 1981 is different from 1982 in the spatial distribution of precipitation across the study area with low values along the coast (735 mm) and with the highest values inland (1,139 mm) whereas the rainfall pattern for 1982 was more evenly distributed.

Due to low values of API and low variability of API between PPHCs for the data covering 1983 to 1991 it was impossible to detect a significant association between API and the independent variables for this period and no further analysis was done.

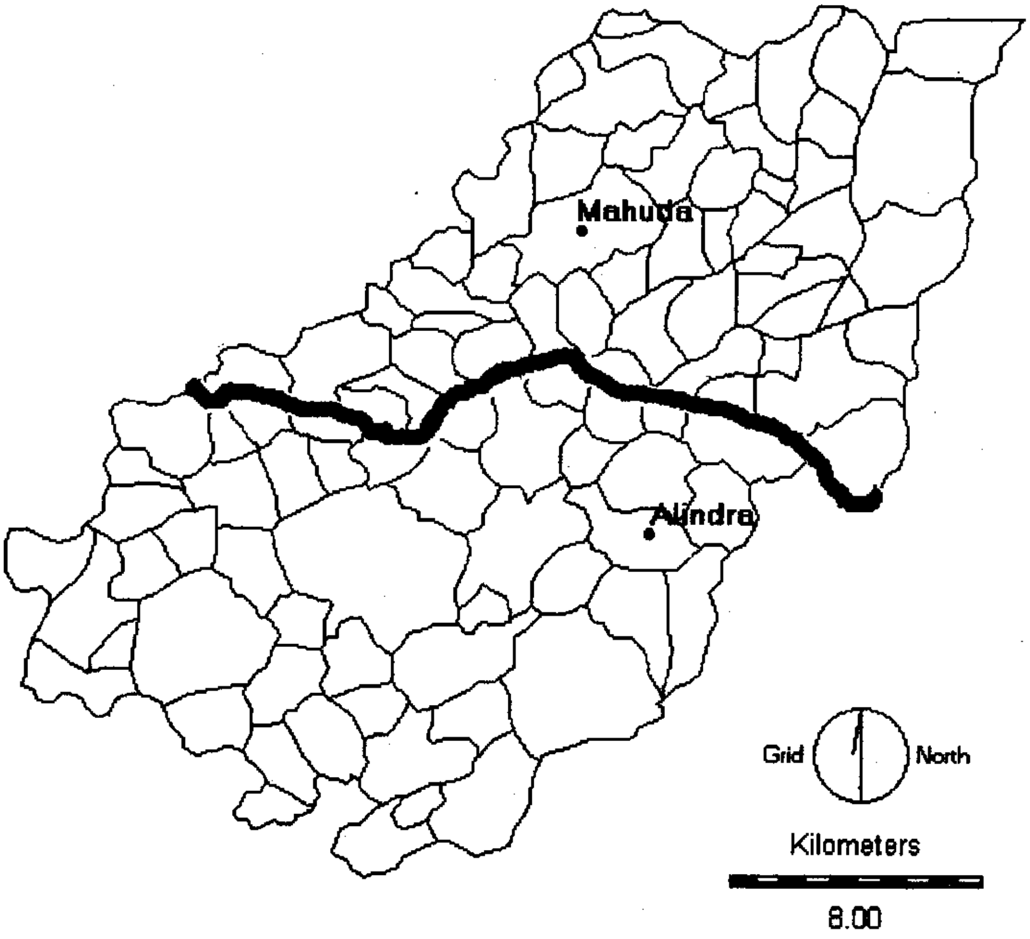
Timely Analysis of Data for Nadiad Thaluka

Regression analysis was performed to examine the seasonal variation for one PPHC over the period July 1990 to June 1993. Since information was not available for all the variables on a monthly basis it was decided to do a seasonal analysis following the three major cropping seasons. Malaria incidence values were taken from PPHC Alindra which was situated in the canal-irrigated part of the Nadiad thaluka (see map 7). In this analysis, the dependent variable used was seasonal parasite incidence (SPI, number of positive blood films per 1,000 population per main agricultural season) figures and the independent variables were rainfall (ranging from 0 to 1,160 mm), and rice intensity (ranging from 0 to 12%). Rainfall was the main factor explaining malaria transmission in the Nadiad thaluka and the next important variable was rice intensity. The rainfall and rice intensity explains 97 percent of the seasonal malaria incidence. Finally, according to the regression analysis seasonal malaria incidence could be expressed as:

$\text{SPI} = 0.26 + 0.0013\ (\text{Rain}) + 0.023\ (\text{Rice intensity})$.

Mann Whitney's non-parametric test was used to compare seasonal parasite incidence values between irrigated and nonirrigated areas in the Nadiad thaluka by using data from Alindra and Mahuda PPHCs which are situated in a nonirrigated area for the period 1990 and 1993. It showed that the median SPI value in the irrigated area (174) was marginally higher than that in the nonirrigated area (110) ($p = 0.057$).

Map 7. Nadiad thaluka with PPHCs and irrigated area boundary.



DISCUSSION

The Advantages of Using GIS for This Study

Spatial Visualization

The GIS allowed for computerized input, storing, analyzing, and display of geographically referenced data. However, it was most useful, when attempts were made to explain the spatial distribution of the variable. In other database management systems (DBMS), it is impossible to visualize the spatial variations and, therefore, impossible to perform the visual comparisons. Of course, visual analysis was not sufficient on its own but it was an important preliminary stage of the analysis, and it was useful to guide the following steps. A comparison can be made with a classical statistical approach. Although one can easily perform a regression analysis to any set of data without a preliminary visual analysis, it is still normal procedure to first plot data as two-dimensional graphs. This gives an impression of possible nonlinear relationship of the data in relation to dispersion, possible correlation, outliers, etc. The visual abilities of the GIS can play an important role for spatial data, by pointing at spatial relationships between dependent and independent factors.

Overlay Process

The overlay process was useful in combining several water-related indicators to produce a vulnerability map. From the disease control point of view it is important, for instance, to deal with scenarios such as identifying high-risk areas and risk factors. With conventional database systems the only thing that could be identified is those high-risk areas numerically and then referring to a map according to the information obtained from the DBMS. In the GIS, both tasks can be carried out simultaneously.

Spatial Interpolation

The other main advantage of GIS was the ability to spatially interpolate the available data. Idrisi, the GIS software used in this study, was efficient in performing this type of interpolation as in the case of rainfall, were the inverse distance weighting process was used (see Renault 1996 for more information).

Defining Representative Areas around PPHC

Because of limited background information a simple technique was chosen on purpose to define the catchment for every PPHC: the Thiessen polygon technique. However, GIS offers several possibilities to define a catchment or a representative area around the PPHC. Among them are:

- *Buffers related to each PPHC.* In this way a circle (buffer) is created around each PPHC, assuming that the information within the circle is representative of the environment of the PPHC catchment with the possibility of changing the size of the circle and allowing for circles to overlap.

- *Distance weighted process.* In this approach it is assumed that any point of the area contributes to the environment with an influence decreasing with distance.

- *Smart composite approach.* This would require additional information on the treatment-seeking behavior of the population and the layout of the infrastructure of the study area. The catchment would still be based on distance but it would include a rough assessment of the most favorable travel routes of the population and their preferences in health services.

Aggregation of Data at Proper Scale

With the help of the GIS it was possible to aggregate environmental information at the level of a PPHC catchment area to generate an average value as an input into further analysis.

Limitations of Data

The information used in this study drew mainly on secondary sources of routinely collected information and is unlikely to be of the same quality as could be expected from data collected for a specific research project. The most significant weakness with the data used relates to the quality of the API values. The API values presented here are likely to represent only a fraction of the real number of malaria cases since not all patients will make use of a government treatment center but may prefer private doctors, indigenous medicine, over-the-counter drugs from a pharmacy or to practice only self-treatment at home. Since no information is available from the study area regarding the treatment-seeking behavior of the population it is not possible to assess to what extent the API information is an underestimation of the real malaria situation. Also, the treatment-seeking behavior is unlikely to be the same for the whole study area depending on, for example, the degree of urbanization or the services provided by the nearby PPHC. This difference in treatment-seeking behavior in diagnostic and reporting practices between the centers and the degree of underreporting may disguise the real difference in API between the various parts of the Kheda District. The spatial interpolation technique available in Idrisi was used to obtain the spatial variation of the rainfall over the whole command area, based on the data recorded at the seven rain gauges. But in the case of API, there was no method to model the spatial distribution. Another weakness of the API information for the greater Mahi Kadana study area was that only annual figures were available. Therefore, the seasonality of rainfall, distinction between irrigated months and nonirrigated months, seasonality of irrigation index, and rice intensity were not incorporated in the analysis.

CONCLUSIONS

Results of the statistical analysis show that, in 1981, the main factor explaining the variation of API in the whole command area was rainfall. However, for 1982, rainfall did not explain the variation of API. For both 1981 and 1982, rice intensity, depth to groundwater, and irrigation density did not explain the variation of API maybe owing to the interaction between variables. These interactions could be controlled by using more detailed data-collection methods. Analysis based on seasonal data from the Nadiad thaluka showed that the main explanatory factors of SPI were rainfall and rice intensity. These two factors explained most of the seasonal variation for the PPHC in the irrigated area of the Nadiad thaluka. Also, the comparison of SPI between irrigated and nonirrigated areas in the Nadiad thaluka indicated that the median SPI value in an irrigated area was marginally higher than that in a nonirrigated area.

In brief, this study has not been able to identify a good variable to explain the variation in the API. Although rainfall, in some years, explains variation, the inconsistency in the findings makes this parameter less-conclusive. It was only for the Nadiad thaluka that factors under irrigation management control were found to be of importance in explaining the variation in API.

The usefulness of GIS and the accuracy of spatial analysis depend on the quality of data. In this study, the quality of API data was low. Therefore, it was difficult to show the correct spatial distribution of API by using GIS. To perform accurate analysis, it is important to be able to define the PPHC catchment areas more precisely rather than using techniques such as the Thiessen polygons. However, this would require more information related to infrastructure in the study area and treatment-seeking behavior of the community. In this study, GIS was important in performing visual preliminary comparison and to provide inputs to the statistical analysis.

References

Bradly, D. J. 1988. The epidemiology of ricefield-associated diseases. In *Vector-borne disease control in humans through rice agroecosystems management. Proceedings of the workshop on research and training needs in the field of integrated vector-borne disease control in riceland agroecosystems of developing countries.* The Philippines: International Rice Research Institute.

Brêtes, G. 1994. Geographical information systems for the study and control of malaria. In *Proceedings of an international workshop held in Colombo, Sri Lanka* on *GIS for health and the environment*, ed. Don de Savigny and Pandu Wijeyaratne. Ottawa, Canada: International Development Research Centre.

Connor, S. J., M. C. Thomson, S. Flasse, and J. B. Williams. 1994. The use of low-cost remote sensing and GIS in identifying and monitoring the environmental factors associated with vector-borne disease transmission. In *Proceedings of an international workshop held in Colombo, Sri Lanka on GIS for health and the environment,* ed. Don de Savigny and Pandu Wijeyaratne. Ottawa, Canada: International Development Research Centre.

Donnelly, M. J., M. H. Birley, and F. Konradsen. 1997. *An investigation of the relationship between depth to groundwater and malaria prevalence, Punjab, Pakistan.* Working Paper No. 41. Colombo, Sri Lanka: International Irrigation Management Institute.

Gill, C. A. 1930. The relationship of canal irrigation and malaria. *Records of Malar. Surv. India* 1(3): 417-422.

Jayaraman. T. K. 1982. Malarial impact of surface irrigation projects: A case study from Gujarat, India. *Agriculture and Environment* 7: 23-34.

Rajnikant, S. D., S. D. Pandy, and R. C. Sharma. 1992. Seasonal prevalence and succession of rice field breeding mosquitoes of central Gujarat. *J. Com.Dis*, 23(3): 164-172.

Renault, D. 1996. GIS manual 1: *First step to geographic information system.* Colombo, Sri Lanka: International Irrigation Management Institute.

Russel, P. F., M. K. Menon, and T. Ramachandra Rao. 1938. Epidemiology of malaria in Pattukkottai thaluka, Tanjore District, Madras Presidency. *India.Jour.Malar.Inst.India.* 1(3): 285-326.

Yadav, R. S., R. C. Sharma, R. M. Bhatt, and V. P. Sharma. 1989. Study on the Anopheline fauna of Kheda District and species specific breeding habitats. *Indian Journal of Malariology,* 26: 65-74.