

UNITED  
NATIONS/ZAMBIA/ESA REGIONAL  
WORKSHOP ON

THE APPLICATIONS OF GLOBAL  
NAVIGATION SATELLITE SYSTEMS  
TECHNOLOGIES IN

SUB-SAHARAN AFRICA

*Mr. F. D. Ohemeng*

# **MODELLING THE SPATIAL DISTRIBUTION OF THE ANOPHELES MOSQUITO**

## **FOR MALARIA RISK ZONING USING RS/GIS**

### **A CASE STUDY IN ZIMBABWE**

# INTRODUCTION

- ✚ In Zimbabwe malaria is one of the most important communicable diseases contributing to about 20-30% of out-patient attendance of the age group above 5 years (MOH&CH, 1993) and known to cause high mortality and mobility resulting in low productivity.
- ✚ In Zimbabwe **malaria risk zones** are stratified as **permanent or endemic** (in the low altitude zones less than 900 m asl), **seasonal** (900-1200 m asl.), and very little or absent (above 1200m), MOH&CH,1993.
- ✚ Malaria is referred to as “seasonal” when potential transmission occurs 1 to 7 months during the course of one year and “perennial” if 8 to 12 months a year (Martin et al., 1995).
- ✚ The disease is hyper endemic and fairly stable in parts of the Zambesi Basin especially the low lying areas.

# INTRODUCTION cont.d

- ✚ Malaria epidemic is observed to occur especially in the seasonal zones among unprotected, non-immune populations. As high as 400 cases per 100,000 people had been reported in the area during the transmission season between December and April (MOH&CW, 1993).
- ✚ Malaria control planning in Zimbabwe had used the above stratification but Samusosa (pers. com., 1996) has revealed that areas that were previously malaria free now encounters periodic epidemics due to either misclassification or expansion of existing zones.
- ✚ At a Malaria Conference held at Victoria Falls in September 1996 the need to re-stratify malaria zones for future control planning was muted.

# INTRODUCTION cont.d

- ✚ Application of Remote Sensing and Geographic Information System is increasingly being used in recent years for studying disease epidemiology.
- ✚ These techniques allow the use of spatial analysis of environmental factors that contribute to the spread of vector-borne diseases, by identifying hot spots, monitoring disease patterns, and defining areas (locations) that need attention in disease control planning.
- ✚ Data collected by satellites and validated by fieldwork are extensively used for monitoring changes in disease patterns and delineating risk areas.
- ✚ How these data products, when incorporated in a geographic database, could be used to develop a spatial model for malaria risk zoning for effective malaria control planning in Zimbabwe was the subject of this study.

# OBJECTIVES OF STUDY

- IDENTIFY ENVIRONMENTAL FACTORS OTHER THAN TEMPERATURE THAT COULD BE USED TO RE-STRATIFY MALARIA ZONES IN ZIMBABWE

- DEVELOP A MODEL FOR RE-STRATIFYING MALARIA ZONES

# MODEL CONCEPTS

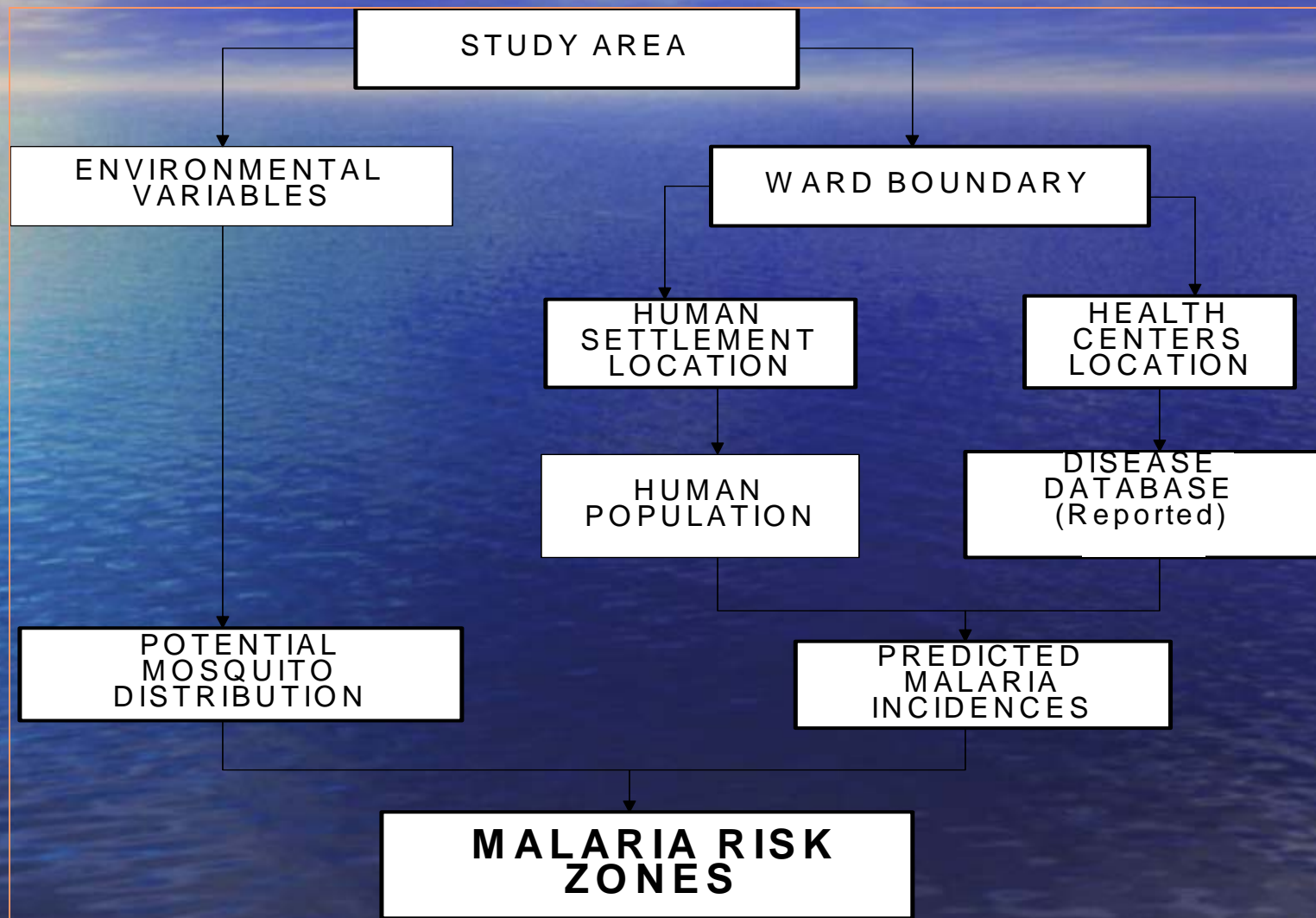
- ✚ Malaria control could be achieved by controlling the vector and its **habitat**.
- ✚ The vector's habitat is determined by the **environment** e.g., elevation, slope, soil texture, hydrology and vegetation cover.
- ✚ A **habitat** is defined as an area (spatial) with the combination of resources and environmental conditions that promote the existence of the malaria vector

# CONCEPTS CONT,D

- ✚ Environmental variables that create favourable conditions for the breeding and survival of the anopheles mosquito have certain optimum ranges outside which their survival is impaired
- ✚ By setting up thresholds conditions, one could predict the suitability of an area as a potential (favourable) habitat for the Anopheles mosquito
- ✚ Environmental variables have spatial variability which when analysed geostatistically could be used to determine the potential distribution of the vector and malaria risk areas



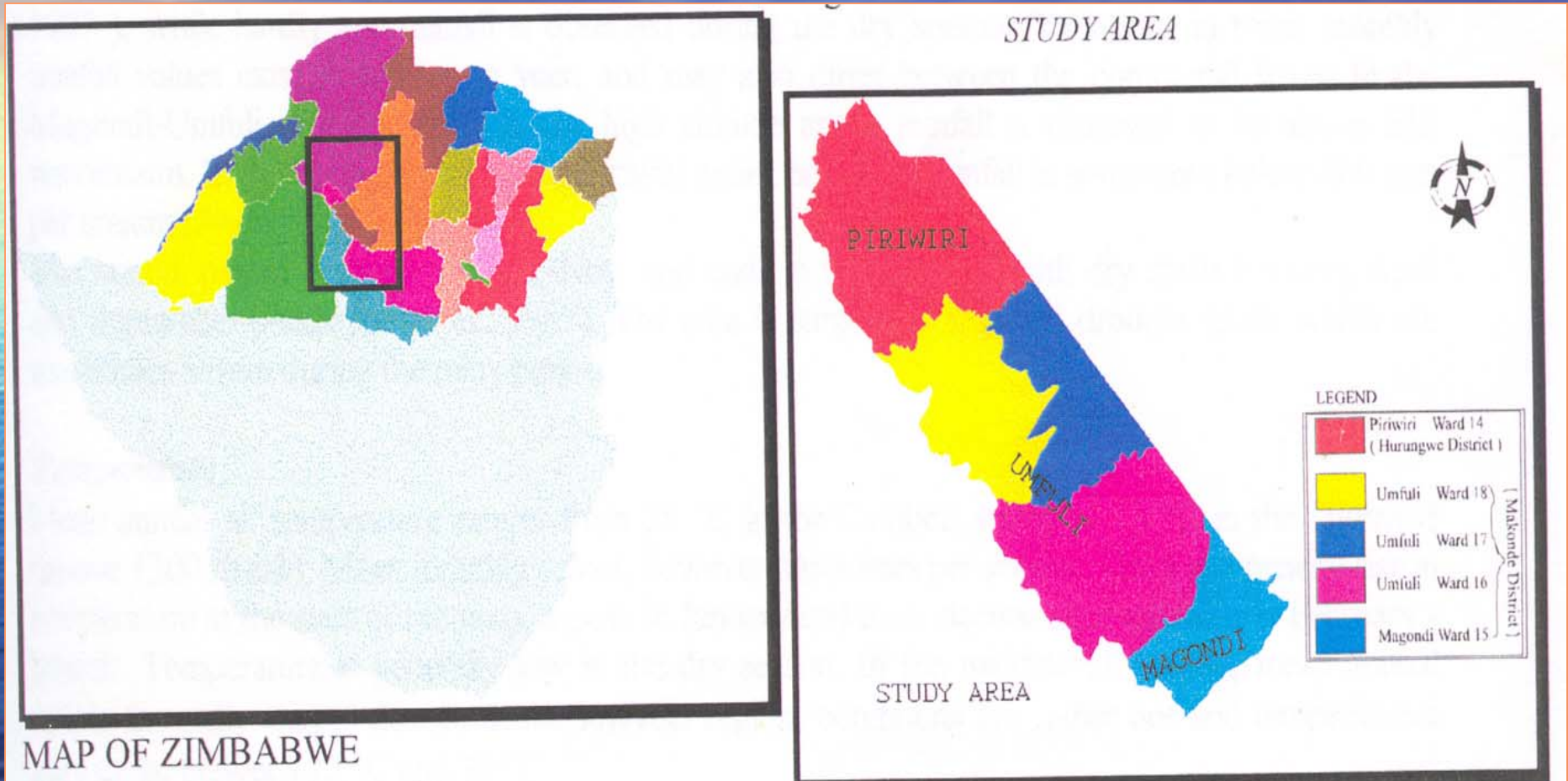
# Figure 1. General Structure of the Malaria Risk Zoning Model



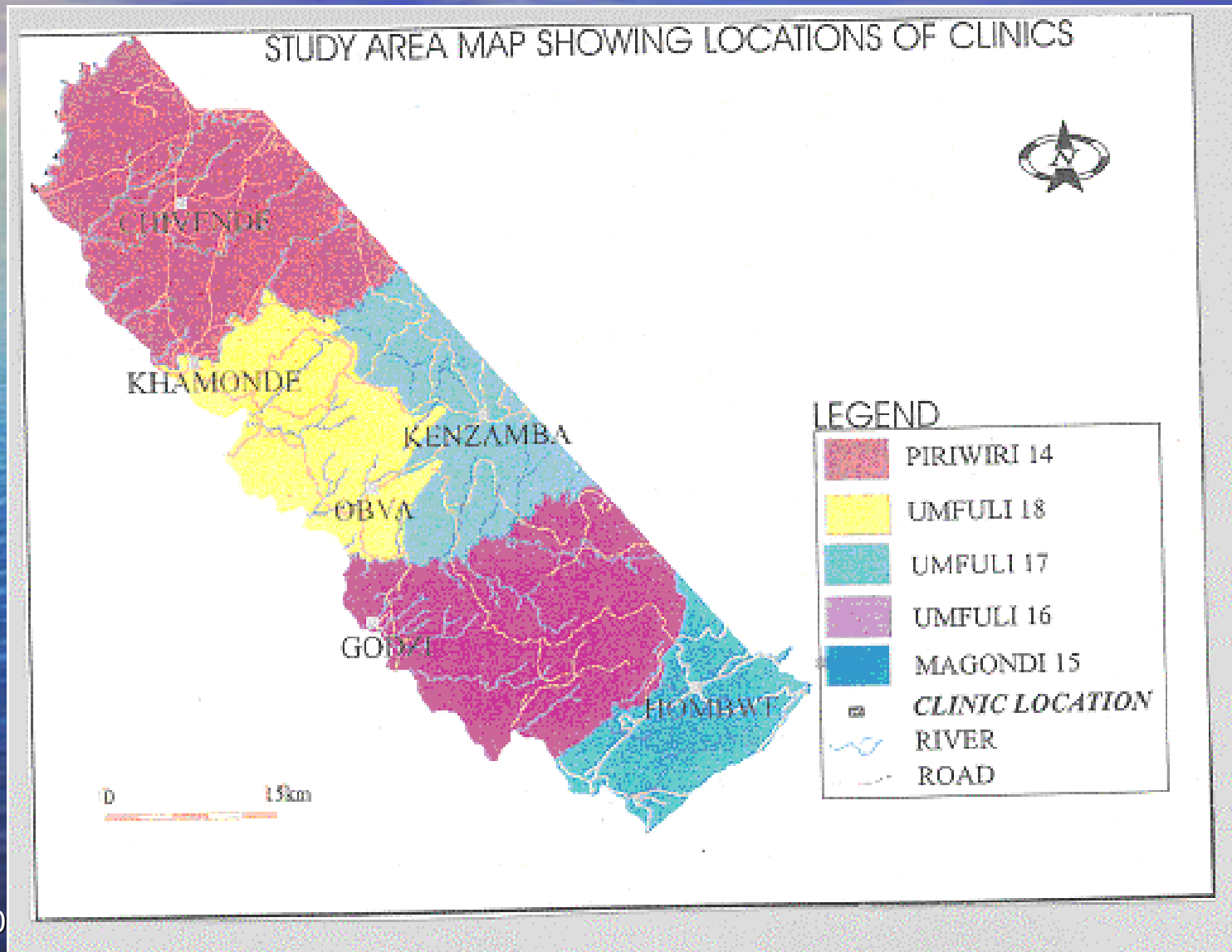
# STUDY LOCATION

- ✚ The study took place in 1997 in the Piriwiri, Umfuli and Magondi communal lands which are located in the Hurungwe and Makonde Administrative districts of the Mashonaland Province of Zimbabwe, and which form part of the Zambesi Basin

# Fig. 2A THE STUDY AREA



# Fig 2B. STUDY LOCATION








# CHARACTERISTICS OF THE AREA

- + Moderate rainfall (650-800 mm per annum) occurring between October and March.
- + Temperature normally exceeds 20 °C and arid.
- + It has a moderately dissected plateau that shelves gradually from the Sanyati river.
- + The southern portion is very hilly and rolling.
- + Important rivers and streams are Sanyati , Mupfure, Tengwe, Susuji and Washanje
- + A few dams are distributed within the project area. They serve as sources of water for both human and livestock consumption.
- + Agriculture (crops and livestock) is the main economic activity in the area.
- + Small scale mining also takes place in the dry river beds especially during the dry season.
- + The area has few hospitals and health posts/clinics which are linked by a few dilapidated unpaved rugged roads.

# Materials and Methods


## MATERIALS

-  A topographic map (1981) of scale 1:50000 served as a base map for digitizing rivers, clinic locations and roads
-  Landsat Thematic Mapper (TM) of 18th December 1994 FCC 471 IMAGE was used for design of a sample scheme and the preparation of a landcover map, including settlements of the area
-  All image processing and GIS actions were carried out using Integrated Land and Water Information System (ILWIS) and GEOEAS softwares.
-  Co-ordinates of sample point were measured with Garmin 45 GPS (precision less than 10 m accuracy).
-  Percent slope of each sample point was recorded with a Slope Metre

# MATERIALS AND METHODS

## METHODS ADOPTED FOR THE STUDY ARE:

-  PREPARATION OF QUESTIONNAIRES AND SAMPLE SHEETS

-  FIELD WORK TO COLLECT BOTH SECONDARY AND PRIMARY DATA

  - Biophysical (environmental) factors

  - Present land use

  - Population characteristics (i.e., age, occupation, ethnicity).

  - Malaria cases per clinic

  - Other information on the vector


  - crop and livestock types,

  - number and type of houses,

  - period when mosquitoes are abundant and

  - general activities carried out by the dwellers during the evening and night hours.

-  SAMPLE ANALYSIS (Limited to only vegetation and soil)

-  DATA ANALYSIS (followed the general structure of the malaria risk model indicated in the figure 1)

## A. POTENTIAL MALARIA VECTOR DISTRIBUTION ANALYSIS

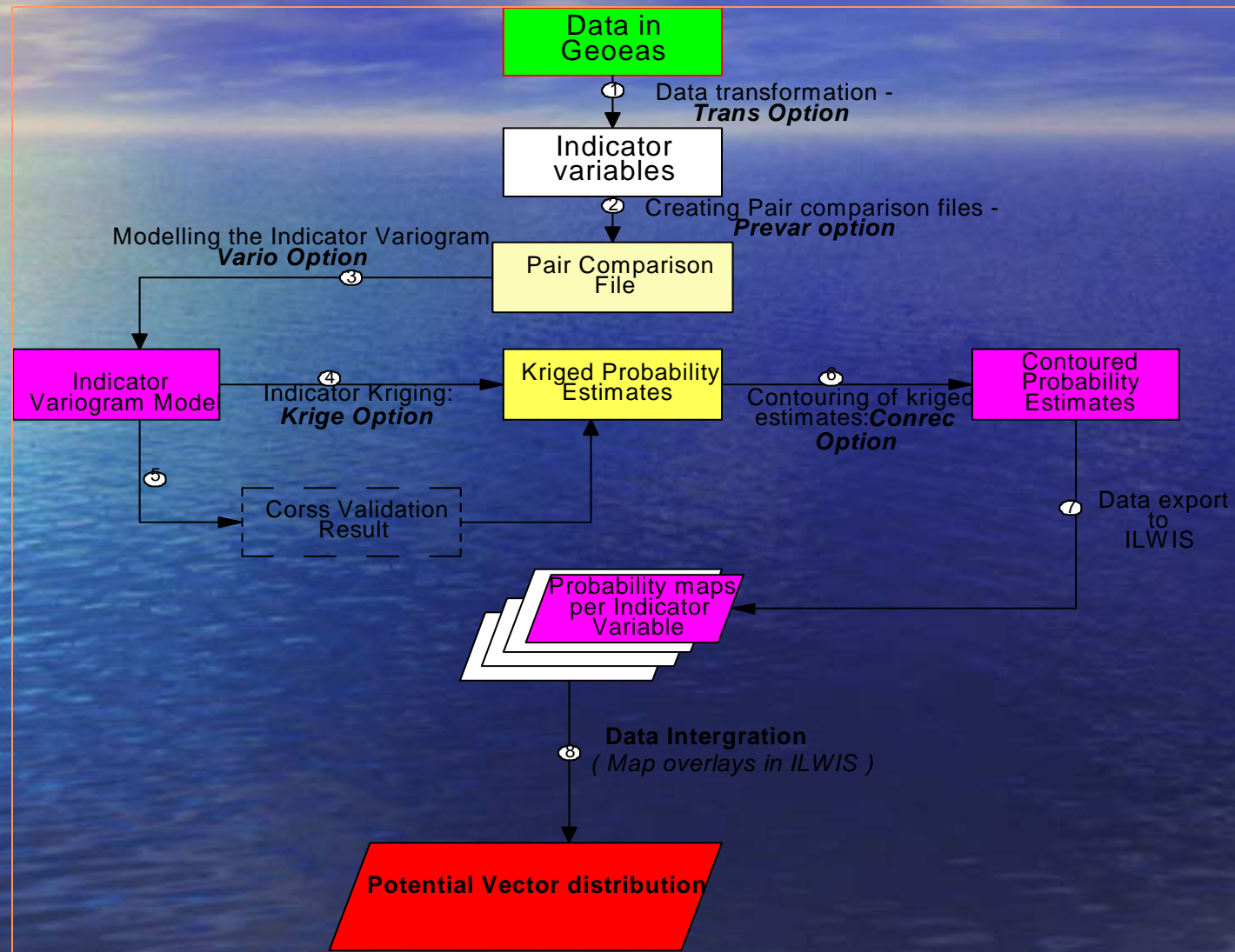
- ✚ A **Potential malaria vector distribution** analysis was done to describe areas that were spatially risky for the malaria vector by estimating the probabilities of occurrence of specific limiting environmental conditions .
- ✚ These probabilities were predicted spatially using the **INDICATOR KRIGING ALGORITHM** by setting threshold conditions based on expert knowledge.
- ✚ These thresholds were used to transform normal environmental data into indicator values, that is into 1 if the condition is less than the threshold and into 0 if otherwise (Isaaks et al., 1987; and Cressie, 1993).
- ✚ One (1) means favourable environmental condition for the vector, and 0 not favourable. These values are described as non-parametric. The environmental indicators included in the analysis are shown in the table below.



# ENVIRONMENTAL INDICATORS USED IN THE ANALYSIS

VARIABLE	THRESHOLD VALUE	INDICATOR VALUE
<i>Elevation</i>	< 900 m	1
	> 900 m	0
<i>Slope</i>	< 2 %	1
	> 2 %	0
<i>Soil texture</i>	Medium & fine sandy clay, Silty clay, clay, clay loam	1
	Coarse sandy clay, medium & fine sandy loam, loam	0
<i>Soil Salinity</i>	< 5 %	1
	> 5 %	0
<i>Vegetation type</i>	Shrub land, Sparse vegetation, Herb land, field	1
	Dense forest , open forest, woodland	0
<i>Cattle</i>	presence	1
	absence	0

# FIG. 3 POTENTIAL MALARIA VECTOR DISTRIBUTION ANALYSIS



# POTENTIAL MALARIA VECTOR DISTRIBUTION ANALYSIS

- ✚ In Figure 3 a stepwise overview is given for implementing the probability kriging approach towards the malaria vector distribution mapping
- ✚ The selected continuous variables (transformed 0 and 1 data) were used to model indicator variograms that served as input for the indicator kriging process
- ✚ Indicator isotropic models were produced that took the general form:

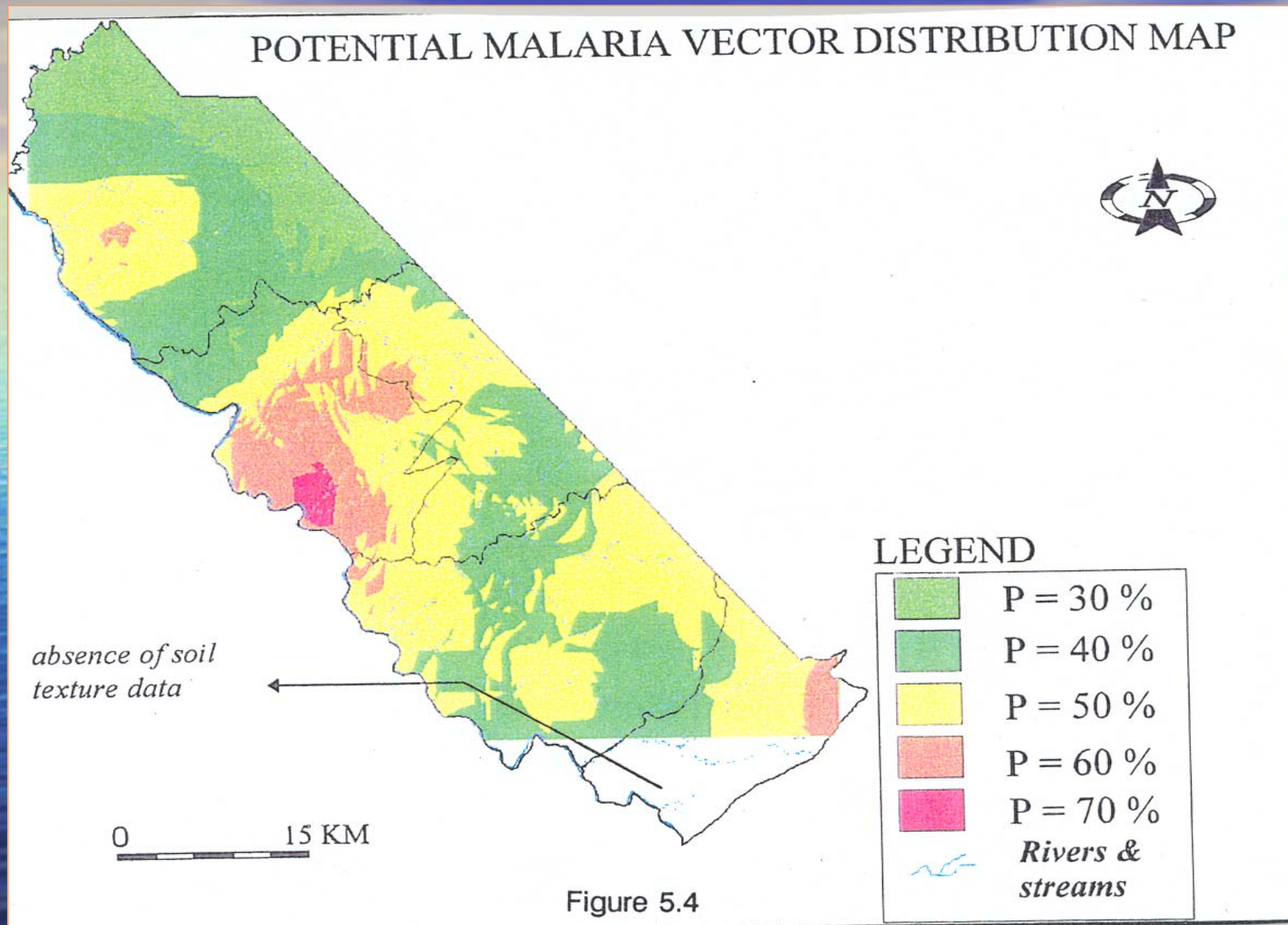
- ✚ 
$$\gamma(h) = a + b(fn)R(h)$$

- ✚ where,

- ✚ **a** is nugget; **b** is sill; **fn** is a specific function (model e.g. spherical, gaussian, linear ect.; **R** is the range and **h** is distance between pairs of sample points.

- ✚ Probability map of each indicator variable was produced and aggregated into a potential vector distribution map by map overlay procedure. The resulting map was then reclassified into potential vector distribution zones as shown in figure 4

Figure 4.



## RESULTS OF POTENTIAL VECTOR DISTRIBUTION ANALYSIS

- ✚ The potential vector distribution (figure 4) indicates less favourable to favourable areas in the study area. The figure shows that none of the study area is highly favourable for the vector.
- ✚ The favourable areas were observed in Umfuli 18 and the south-eastern corner of Magondi 15. The western part of Piriwiri 14 registered a few areas in this zone.
- ✚ The moderately favourable areas were fairly uniformly distributed within the study area. Most areas in Piriwiri 14, Umfuli 17 and 16, and Magondi 15 fell in this class.
- ✚ From the figure, most of the less favourable areas were found in Piriwiri 14 (33 % ) and only a few areas in Umfuli 18 (1 %) of ward area.

## POTENTIAL MALARIA VECTOR DISTRIBUTION ANALYSIS contd LIMITATIONS

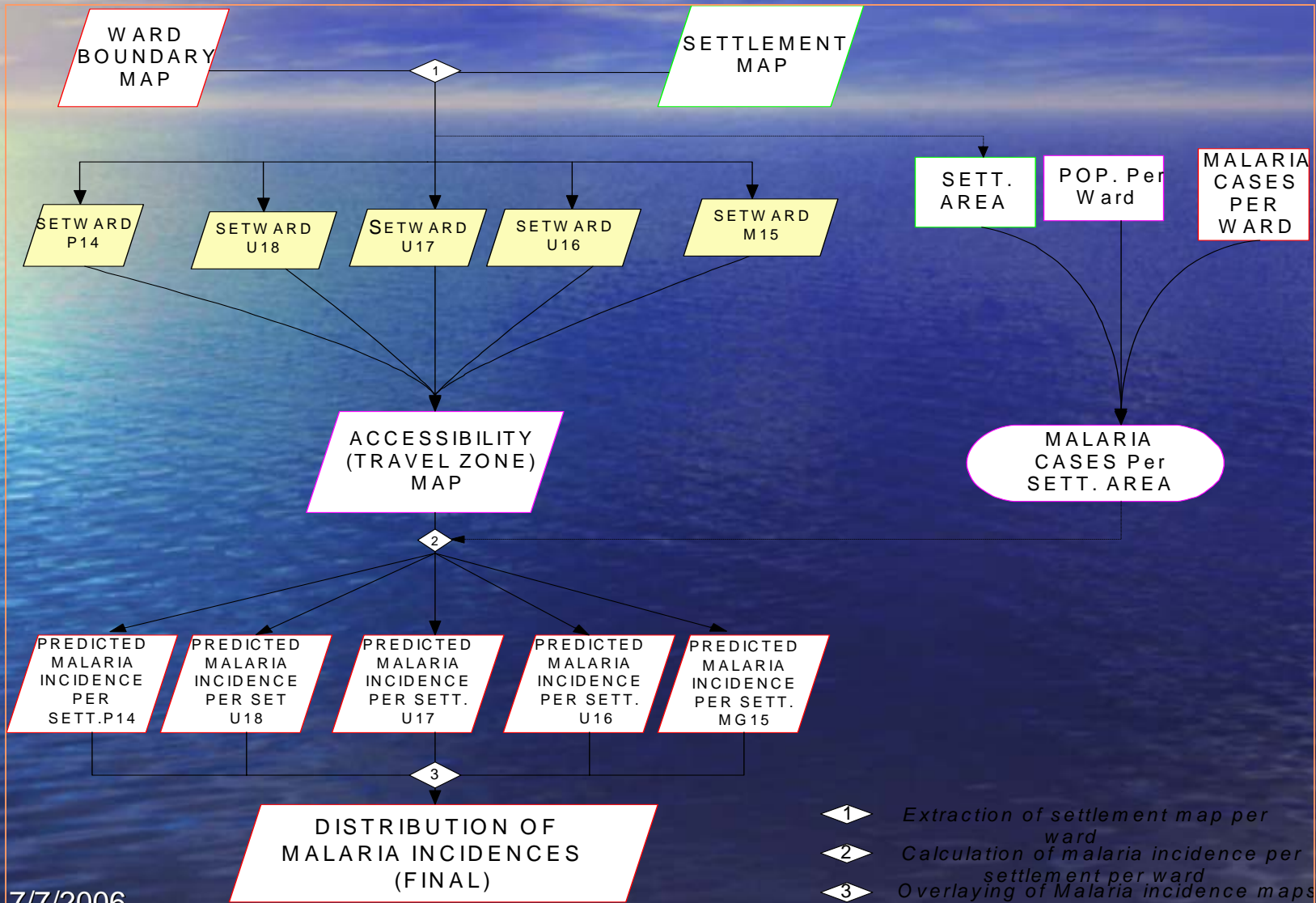
- ✚ Sample locations (observation points) were stratified randomly, according to mapping units. This may influence the output of the sample indicator variogram model. For such an approach, a uniform grid for sample observation points would be better.
- ✚ If time and logistics available, the number of observations points (76) should be increased to about 120 in order to improve the results of the indicator variogram analysis.
- ✚ Environmental thresholds were set based on expert knowledge. A more plausible approach would be to carry out an environmental response analysis of the vector. This will involve carrying out a survey on the vector **itself**.
- ✚ Other environmental data e.g. climatic data such as rainfall, humidity and wind should be included in the analysis if available. In this case, a space-time kriging could be employed.
- ✚ The final vector probability distribution map could have been better produced if a multivariate and or principal component analysis were carried out. This was not possible because of absence of hard point data on the vector itself.
- ✚ Contouring of kriged data in ILWIS might introduce a smoothing effect of the kriged estimates.

# Malaria Incidence Analysis

- ✚ Malaria Incidence was calculated and compared with the potential vector distribution using malaria data obtained from the health centres/clinics and the population census data per ward. The analysis process is shown in figure 5 below.
- ✚ Clinical malaria incidence was calculated per ward using the clinical data of 1994 obtained for the different health clinics. Clinical incidence (CI) was calculated thus:

✚  $C.I = \text{reported malaria cases} \div \text{ward population} * 1000$

# FIG 5. Malaria Incidence Analysis

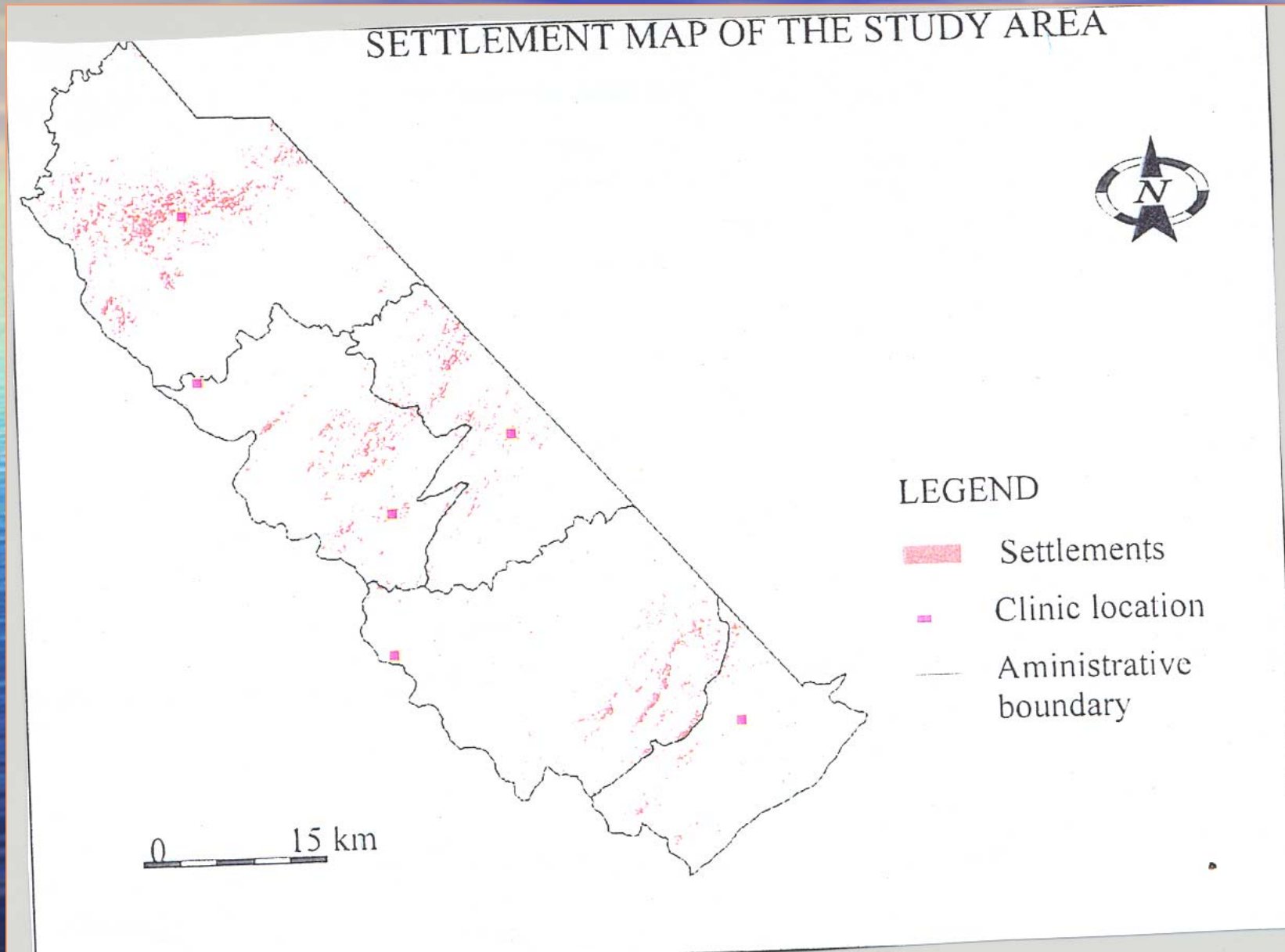




# 1. CALCULATION OF SETTLEMENT MAP OF THE AREA

- ✚ A **settlement map** (Fig. 6) was calculated from the TM FCC471 image by extracting all pixels with reflectance value that represented settlements.
- ✚ **Settlement areas** were obtained by calculating the histogram of the settlements per ward
- ✚ **Settlement density** was calculated as fraction of settlement pixels per total ward pixels.
- ✚ The effect of **settlement density on malaria incidence between wards** was analysed.
- ✚ Effect of **population density on malaria incidence** was also analysed for the wards by constructing **Population pyramids** using the population data of the area

FIGURE 6



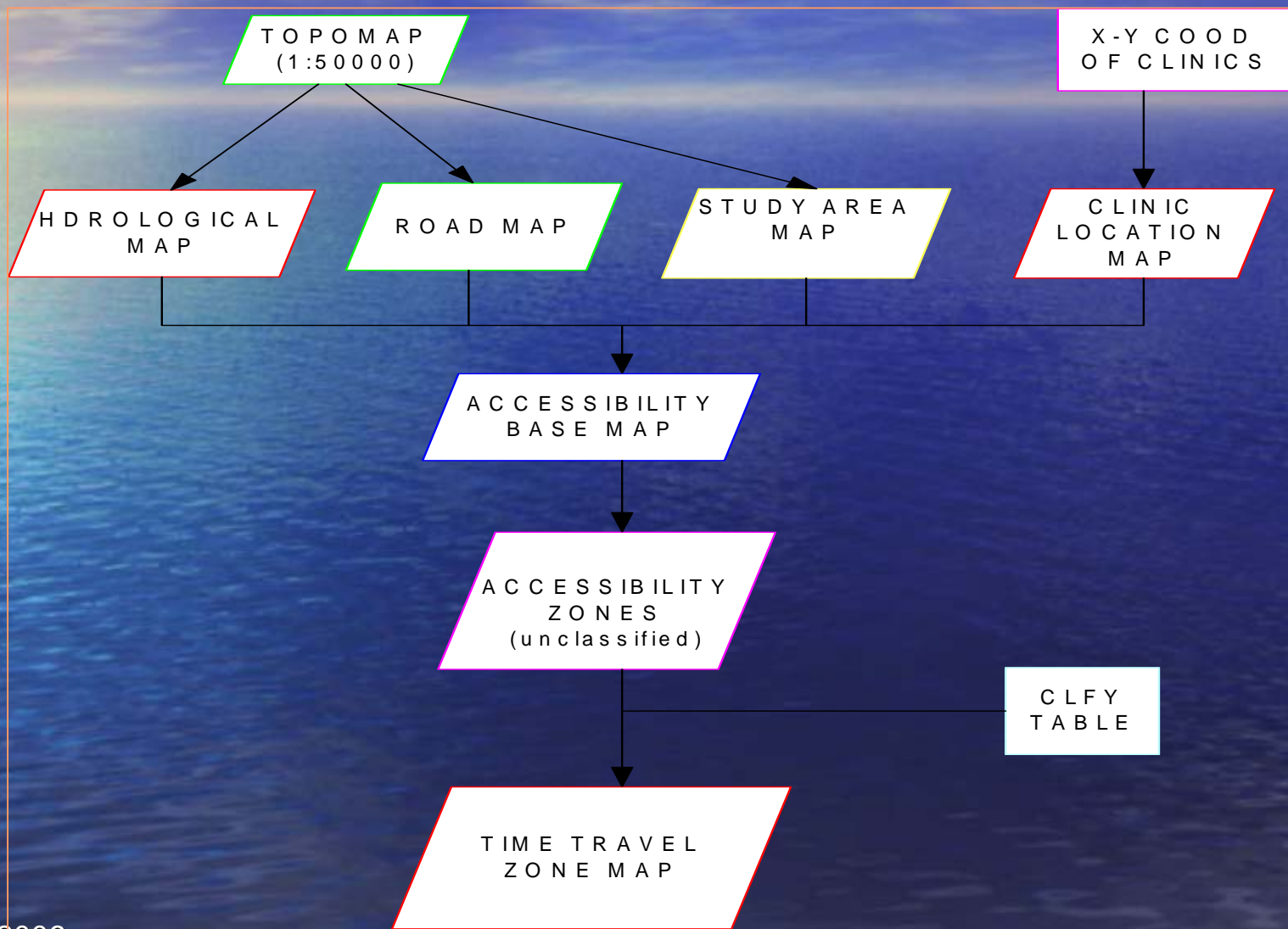
# REPORTED MALARIA CASES OF DIFFERENT HEALTH CLINICS

WARD	CLINIC	< 4 YRS	4 - 15 YRS	> 15 YRS
14 ( Piriwiri )	CHIVENDE	64	367	100
18 ( Umfuli )	KAMHONDE	15	74	29
	OBVA	284	407	313
17 ( Umfuli )	KENZAMBA.	101	322	88
16 ( Umfuli )	GODZI	37	57	202
15 ( Magondi)	HOMBWE	76	189	94

## 2. Calculation of Accessibility (Time Travel) map

- ✚ The accessibility map was calculated by employing the procedure indicated in the flow chart below (Figure 7). Accessibility to clinics served as indication of possible locations of reported malaria cases because, there was lack of empirical data that gave reference on locations of the reported cases. In this study reporting to a clinic was assumed to depend on how far a patient lives from a particular clinic.
- ✚ Assumptions:
  - ✚ a patient will visit a particular clinic if he lives near a road plied by the local transport bus
  - ✚ A maximum speed of 30 km per hour (due to the terrain and road conditions) was set for the local transport buses. This estimation was based on my personal observation during field work.
  - ✚ a patient will travel without bus (i.e. walking) at a speed of 3 km per hour to the clinic if the clinic is not far away to be reached within a walking time of one hour.
  - ✚ Rivers that have no bridges would serve as barriers to cross by bus or persons.

# Figure 7. Procedure for calculating Accessibility (Time Travel) map



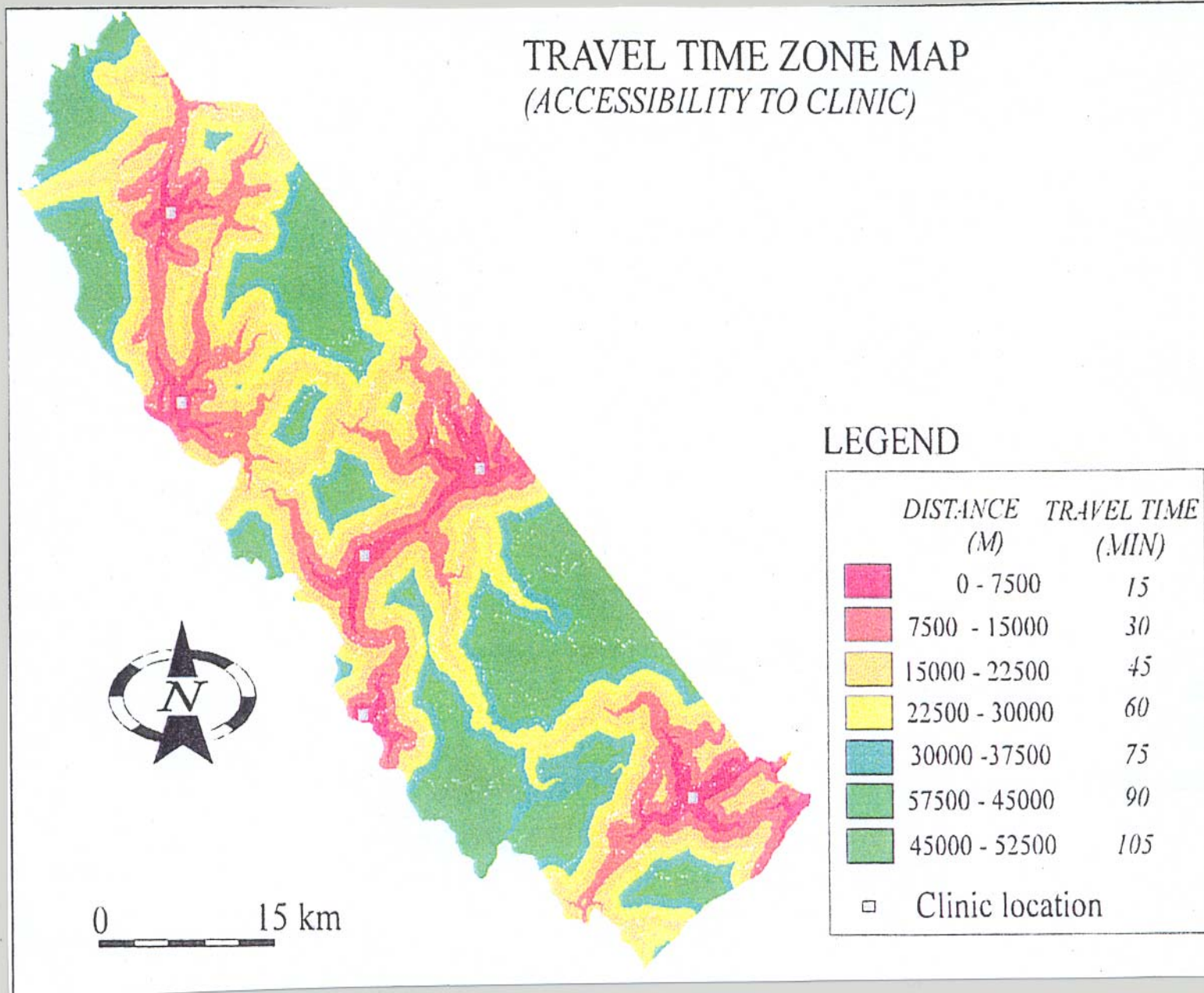
## Time Travel map

- ✚ A time travel map (Fig. 8) was calculated based on a bus travel speed of 30 km/hr (or 3 km/hr by walking).
- ✚ Accessibility zones were re-classified into a time travel zone map (based on a travel time travel interval of 15 minutes) by map calculation using table 3.

# TABLE 3. Travel Time Classify Table and Weights



DISTANCE FROM CLINIC (M)	TRAVEL TIME (MIN)	DISTANCE CLASS	WEIGHT
7500	15	1	0.4
15000	30	2	0.3
22500	45	3	0.1
30000	60	4	0.08
37500	75	5	0.06
45000	90	6	0.04
52500	105	7	0.02

# FIGURE 8





# COMPARISON OF RESULTS OF TIME TRAVEL ANALYSIS AND REPORTED MALARIA CASES

-  A significant direct relationship was found between the reported malaria cases and accessibility to clinics.
-  People will likely visit a clinic if it is easily accessible.

# Calculation of Malaria incidence map

- ✚ Malaria incidence was expressed as a function of accessibility to clinics, percent of reported malaria cases of total ward population and the size of the settlements. Malaria incidence was calculated per settlement per ward thus:

- ✚ 
$$\varphi = \sum [ \lambda_i * \{ (I_\tau \div P_\tau) / hp \} * Hmp ] * 1000 / 10$$



- ✚ *where,*



- $\lambda_i$  = time travel zone map (weighted)*



- $I_\tau$  = total reported malaria cases per ward*



- $P_\tau$  = total ward population*

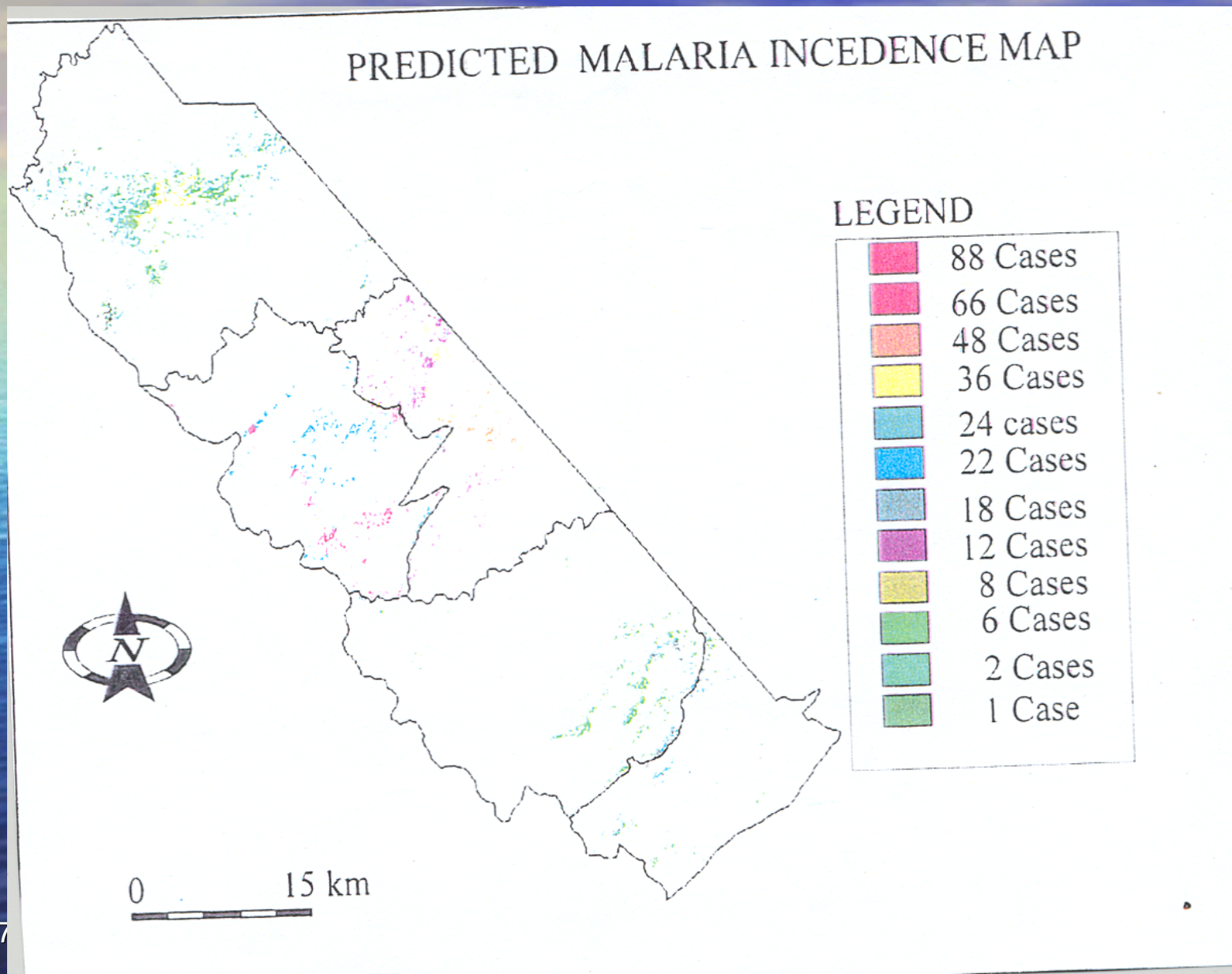


- $hp$  = total number of settlement (house) pixels*



- $Hmp$  = settlement map*

# FIGURE 9



# RESULTS OF MALARIA INCEDENCE ANALYSIS

- ✚ In figure 13, the highest malaria incidence rates (66 and 88 cases per 1000 persons) were found in Umfuli ward 18, corresponding to the higher probability zones 6 and 7
- ✚ In Umfuli ward 17 malaria incidence rates of 36 and 48 are found which corresponds with vector distribution zones 5 and 6 respectively.
- ✚ Malaria incidences in Umfuli ward 16 and Magondi ward 15 were lower than 25 cases per 1000 persons corresponded with probability zones 4 and 5
- ✚ The lowest malaria incidence rate below 10% occurred in Piriwiri ward 14 and corresponds with probability zones 1-3

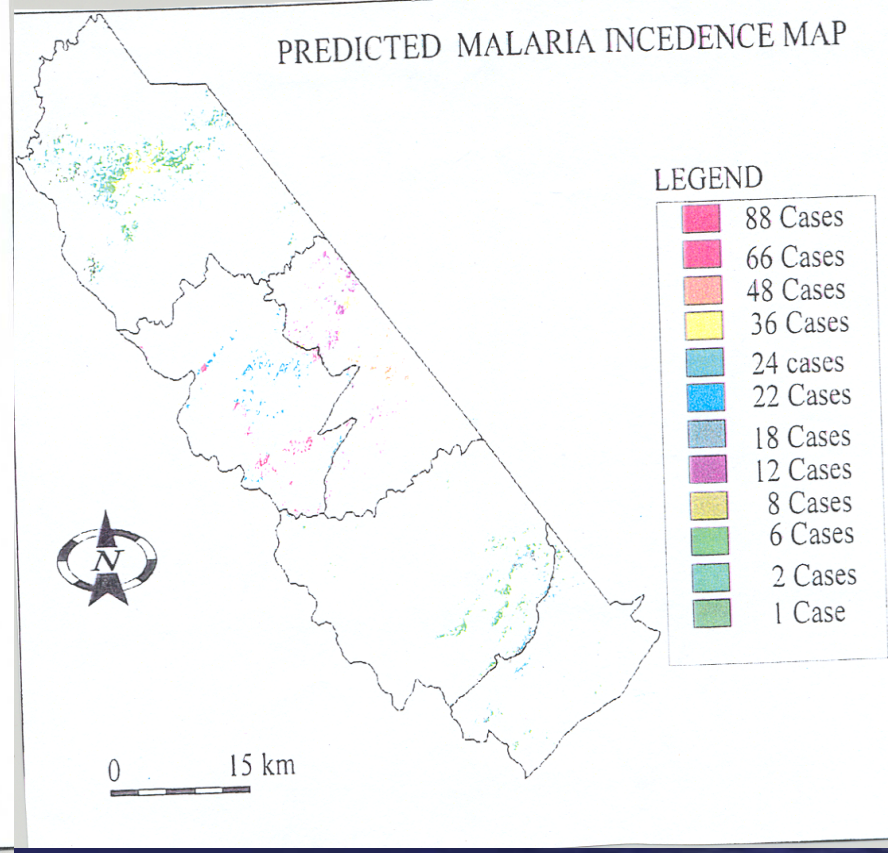
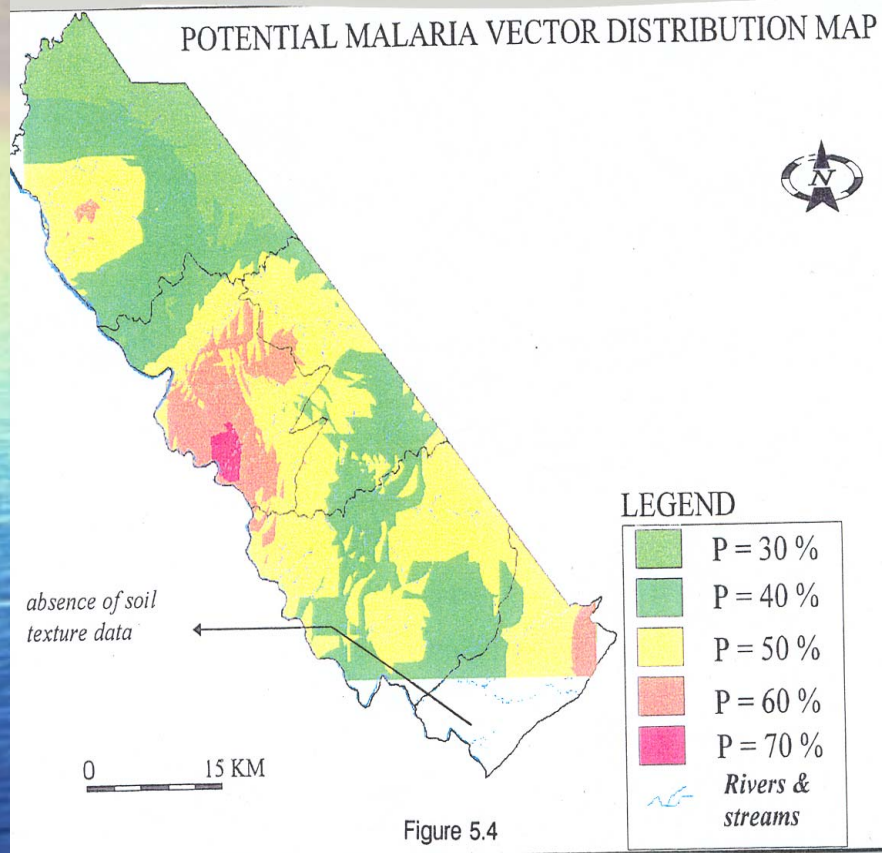
# Limitations:

- ✚ Lack of hard data on malaria cases.
- ✚ Not all people having malaria report to the clinics. This of course might influence the calculation of the malaria incidences.
- ✚ Clinical diagnosis may be less useful for the analysis since there may be differences in diagnostic criteria applied by different medical practitioners. Confirmed malaria cases through blood examination will give more plausible results

# Potential vector distribution and predicted malaria incidences compared

	MALARIA INCIDENCES ( <i>cases per 1000 pop</i> )													
	1	2	6	8	12	18	22	24	36	48	66	88	Total	
POTENTIAL VECTOR DIST. ZONES	2	0.0	63.0	3.0			1.0						67	
	3	45.0	185.0	54.0			0.0	0.0	0.0			0.0	284	
	4	103.0	437.0	<b>1141.0</b>	109.0	121.0	257.0	3.0	72.	80.0 0	157.0	8.0	1.0	2489
	5	279.0	406.0	<b>850.0</b>	190.0	431.0	139.0	313.0	20.	321.0 0	110.0	91.0	75.0	3225
	6	6.0	26.0	9.0		40.0	1.0	<b>451.0</b>		27.0		137.0	46.0	713
	7							30.0				49.0	22.0	101

# FIGURE 10



# CONCLUSION

- ✚ Remote sensing and GIS in combination with geostatistics is a promising approach to define areas with high risk of malaria in Zimbabwe.
- ✚ Application of indicator kriging is useful for predicting spatial variations in environmental biophysical factors that are associated with the distribution of the anopheles mosquito. This made possible the determination of areas at risk of malaria infection
- ✚ Further research is needed to validate the relationships within the malaria transmission system, especially on the vector and the human environment aspects