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Environmental factors and population at risk of malaria in Nkomazi municipality, South Africa

A. M. Adeola[1], **O. J. Botai**[1], **J. M. Olwoch**[2], **C. J. de W. Rautenbach**[1], **O. M. Adisa**[1], **O. J. Taiwo**[3] **and A. M. Kalumba**[4]

1 *Centre for Geoinformation Science, Department of Geography, Geoinformation and Meteorology, University of Pretoria, Hatfield, South Africa*
2 *Earth Observation Directorate, South African National Space Agency, Pretoria, South Africa*
3 *Department of Geography, University of Ibadan, Ibadan, Nigeria*
4 *Centre for Environmental Study, Department of Geography, Geoinformation and Meteorology, University of Pretoria, Hatfield, South Africa*

Abstract

OBJECTIVE Nkomazi local municipality of South Africa is a high-risk malaria region with an incidence rate of about 500 cases per 100 000. We examined the influence of environmental factors on population (age group) at risk of malaria.

METHODS R software was used to statistically analyse data. Using remote sensing technology, a Landsat 8 image of 4th October 2015 was classified using object-based classification and a 5-m resolution. Spot height data were used to generate a digital elevation model of the area.

RESULTS A total of 60 718 malaria cases were notified across 48 health facilities in Nkomazi municipality between January 1997 and August 2015. Malaria incidence was highly associated with irrigated land ($P = 0.001$), water body ($P = 0.011$) and altitude ≤400 m ($P = 0.001$). The multivariate model showed that with 10% increase in the extent of irrigated areas, malaria risk increased by almost 39% in the entire study area and by almost 44% in the 2-km buffer zone of selected villages. Malaria incidence is more pronounced in the economically active population aged 15–64 and in males. Both incidence and case fatality rate drastically declined over the study period.

CONCLUSION A predictive model based on environmental factors would be useful in the effort towards malaria elimination by fostering appropriate targeting of control measures and allocating of resources.

keywords malaria, environment, Landsat, remote sensing, object-based classification, land use/land cover, elevation

Introduction

Although it is curable, malaria remains a life-threatening disease mainly endemic in tropical and subtropical countries of sub-Saharan Africa, South and Central America, Asia and Oceania [1] that imposes a huge burden on health, economy and social sectors of endemic regions [1]. Malaria in South Africa has been studied extensively [2–5]. One such study is Mapping Malaria Risk in Africa/Atlas du Risque de la Malaria en Afrique (MARA/ARMA), which collected malariometric data in terms of distribution (where), transmission intensity (how much), seasonality (when), environmental determinants (why) and population at risk (who is affected) to create a continental database of the spatial distribution of malaria. Environmentally determined models that define the distribution of malaria, the duration and timing of the transmission seasons [6] also were developed.

In South Africa, malaria is mainly endemic in the low-altitude (below 1200 m) regions of Mpumalanga, Limpopo and KwaZulu-Natal [7]. Since the introduction of dichlorodiphenyltrichloroethane (DDT) for indoor residual spraying (IRS) in 1948, South Africa has seen a drastic decline in the transmission of malaria [4]. However, there was a surge in malaria transmission from 1999 with a major outbreak in 2000 [5]. This was traced to the discontinuation of DDT, which was replaced with synthetic pyrethroid insecticides in 1996, and to other putative factors such as climatic and environmental determinants, agricultural development, biology and behaviour of vector, drug resistance and trans-border population movement (imported vector and parasite) into South Africa from bordering Swaziland and Mozambique [8, 9]. Consequently, there was a return to DDT in 2000 as the main insecticide for IRS and a change from sulphadoxine–pyrimethamine (SP – Fansidar) to artemether/lumefantrine (AL – Coartem) in 2001 as the first-line treatment for malaria [10]. Other malaria control strategies in South Africa are focal larviciding of identified breeding sites, rapid detection, diagnostic testing through rapid diagnostic tests (RDT) and treatment of confirmed malaria cases at healthcare facilities [10, 11].

Through these control strategies the number of reported malaria cases fell from 64 622 cases in 2000 to 7626 in 2010. The number of deaths also fell by 81%, that is from 458 in 2000 to 87 in 2010 [7]. Malaria incidence was high between 1997 and 2001 [7]; the greatest numbers of cases were recorded in 1999 (51 444) and 2000 (64 622). About 4.9 million of the population, that is about 10% living in endemic regions, are still at risk of malaria [7, 12]. Malaria transmission remains particularly high in Nkomazi municipality [13].

Malaria in the region is markedly seasonal with varying intensity of transmission due to altitudinal and climatic factors. Transmission increases during the wet summer months (September–May) and decreases afterwards. Transmission peaks in January/February [14]. *Plasmodium falciparum* is the principal parasite accounting for about 95% of the total malaria infections in South Africa through *Anopheles arabiensis* as the major local vector [15].

Climatic and environmental parameters as determinants of the spatial and temporal distribution of malaria are well documented [3, 16–18]. Major climatic factors for malaria risk are temperature, rainfall and humidity. However, the lack of adequate records of spatial and temporal variability of meteorological and environmental parameters is a major limiting factor. In contrast to conventional ground surveys, earth-observing sensors provide continuous meteorological and environmental data for large areas [19]. Hence, the use of remotely sensed data offers the possibility of identifying mosquito breeding habitats [20–25] and the development of epidemiological forecasting models and early warning systems [19, 25]. Understanding the spatial and temporal distribution of the risk factors and the prevalence of malaria in endemic areas can help predict their abundance, determine their location and quantify the at-risk population [26]. Hence remotely sensed data can significantly enhance strategies for local malaria control. Altitude, vegetation, agricultural practices and the presence of water bodies affect the vector and hence the malaria risk [27–29]. However, studies relating the influence of these factors to malaria incidence have not been performed in the study area.

The goal of WHO is to eradicate malaria [30]. South Africa is scheduled to achieve malaria elimination by 2018 having met the requirement of the pre-elimination phase of (<5 cases per 100 000 population at risk) set out by WHO. As South Africa intensifies its efforts towards elimination of malaria, identifying the spatial distribution of age groups at risk of malaria transmission and its relationship with environmental factors would enhance strategic distribution of scarce resources. Therefore, our aim was to examine the influence of environmental factors on the population (age group) at risk of malaria.

Methods

Ethics

This study used secondary data acquired from the malaria information system (MIS) from the Department of Health that were developed and maintained by the malaria control programme (MCP). Ethical approval for this study was obtained from the Faculty of Natural and Agricultural Sciences Ethical Committee at the University of Pretoria and the Department of Health in Mpumalanga Provincial Government.

Study area

Mpumalanga Province consists of three administrative districts: Gert Sibande, Ehlanzeni and Nkangala. The three districts are subdivided into 24 local municipalities. Within Ehlanzeni district are Nkomazi municipality and four others (Thaba Chweu, Mbombela, Umjindi and Bushbuckridge). Nkomazi is bordered in the east by Mozambique, in the south by Swaziland and in the north by Kruger National Park. Nkomazi has an area of 3255. A total of 67 km^2 with 54 main places mostly concentrated in the southern part of the municipality. The population was 277 864 in 1996; 334 668 in 2001 and 393 030 in 2011 [2]. The climate is subtropical with an average temperature of 28 °C and annual rainfall between 550 and 1000 mm. Nkomazi varies in elevation from 110 to 1320 m above sea level. The western areas are densely vegetated with undulating hills and deeply incised valleys. The area is drained by two major Rivers, the Komati to the east and its main tributary, the Lomati, to the west. Nkomazi is known for its sugarcane, fruit and vegetable production under intensive irrigation.

Data collection

Data on malaria incidence were acquired from the integrated MIS. The data were obtained from patients who presented at health facilities and tested positive for *Plasmodium* (passive case detection) and from patients identified through screening measures, where health workers go into the community to ask for individuals to be tested (active case detection). These include people with non-specific symptoms such as fever, or those residing near or in the same homesteads as recently confirmed cases. The office of the malaria control programme is located in Tonga. The records contain the facility name, date of diagnosis, the number of cases, deaths, age, gender and source of infection and place of residence.

The records span January 1997 to August 2015 for many facilities. For the purpose of this study, five facilities, which account for 56.3% of the total cases within the period under investigation, were used as follows: Tonga hospital, Shongwe hospital, Mangweni CHC, Naas CHC and Komatipoort municipal clinic. Demographic data at main place/village (administrative boundary) were acquired from Statistics SA 2001 and 2011 census. There are 54 villages, mostly concentrated in the southern part of the municipality (Figure 1). The data contained age group and gender population at each village. Accordingly, five villages near selected health facilities were considered.

A geometrically corrected, summer cloud-free Landsat 8 image acquired on 4th October 2015 (Path 168. Row 078) was downloaded from the United States Geological Survey (USGS). Spot height data of approximately 5-m resolution were acquired from the national geospatial information (NGI) of South Africa. Handheld GPS was used to take coordinates of easy-to-identify ground-truth sites during an educational mini field trip to the study area on April 23–24, 2015 (UP CSMC visit on World Malaria Day celebration). A total of 15 points were randomly taken in Tonga village, and another 70 points were taken across the study area using Google Earth images for adequate representation for accuracy assessment.

Data analysis

Although the malaria season lasts from early July to the end of June of the subsequent year [13–15], this study used the calendar year to match the age category of Statistics SA for the national population censuses of 2001 and 2011. Daily diagnosis of malaria cases data was aggregated to monthly and yearly format. Age was categorised into groups of ages 0–14, 15–64 and 65 years and older, with the 0–14 and 65+ age groups indicating the dependent population and the 15–64 age group indicating the economically active population. The data were then geocoded using the coordinates of the recording health facilities and overlaid on the villages to determine the location and proximity of health facilities within the villages. Generally, there is at least 1 health facility in each village or within a 5-km radius of villages that do not have a health facility of their own [31] (Figure 1). Microsoft Excel was used for pre-processing data before importing them into R software.

Landsat 8 data were used to derive the land use/land cover (LULC) types using the object-based classification technique in ENVI 5.0. A false colour composite image using bands 5.4 and 3 (R.G.B) and normalised difference vegetation index (NDVI): ([NIR − RED]/[NIR + RED]) was derived to enhance the identification of available LULC types before the actual classification. Five major broad classes were identified and classified as follows: water body, forest, cultivated/irrigated land, bare land and built-up area. ‘Water body’ is a river, stream, pond or lake; ‘forest’ is an area of dense tree cover with thick closed canopy; ‘cultivated/irrigation’ refers to an area under cultivation and intensive irrigation of crops (sugar cane, orange, banana); ‘bare land’ is non-vegetated, uncultivated farmland and open space; ‘built up’ is an area with asphalt or concrete roads, pavements, buildings or houses.

The rule-based feature extraction method was used. Firstly, image segmentation was performed. Edge algorithm was used for the segment setting with a scale level of 30 and full Lambda-Schedule Algorithm was used for the merge setting with merge level of 98. Texture kernel size of 3 was used. The classes were identified using set rules for the classification using thresholds of mean and or standard deviation of the spectral bands and NDVI. See figure 4a&b showing the false colour composite and the NDVI of the Landsat image. The classification was output to shape file and imported into ARCGIS 10.2.1. On the premise that adult mosquitoes generally remain within 2 km of their breeding habitats [27], a buffer of 2 km was created around the selected five villages, and their respective percentages of LULC classes within the buffer were calculated. An error matrix or confusion matrix was computed to assess the classification accuracy. The matrix relates the sample points collected via field survey and Google Earth (reference data) to those selected from the classified image (classified data). Thus, overall accuracy (86.51%), producer’s (86.74%) and user’s accuracies (86.28%), and Kappa statistic (0.842) were computed (Table 1).

The 5-m resolution spot height was interpolated using the ordinary kriging method to derive the digital elevation model (DEM) in ARCGIS 10.2.1. The elevation was classified into 9 classes using the Jenks natural breaks classification method. The percentages of the each present class within the 2-km buffer were computed. For visual appreciation, Surfer 13 was used to perform a 3D DEM (insert of Figure 1).

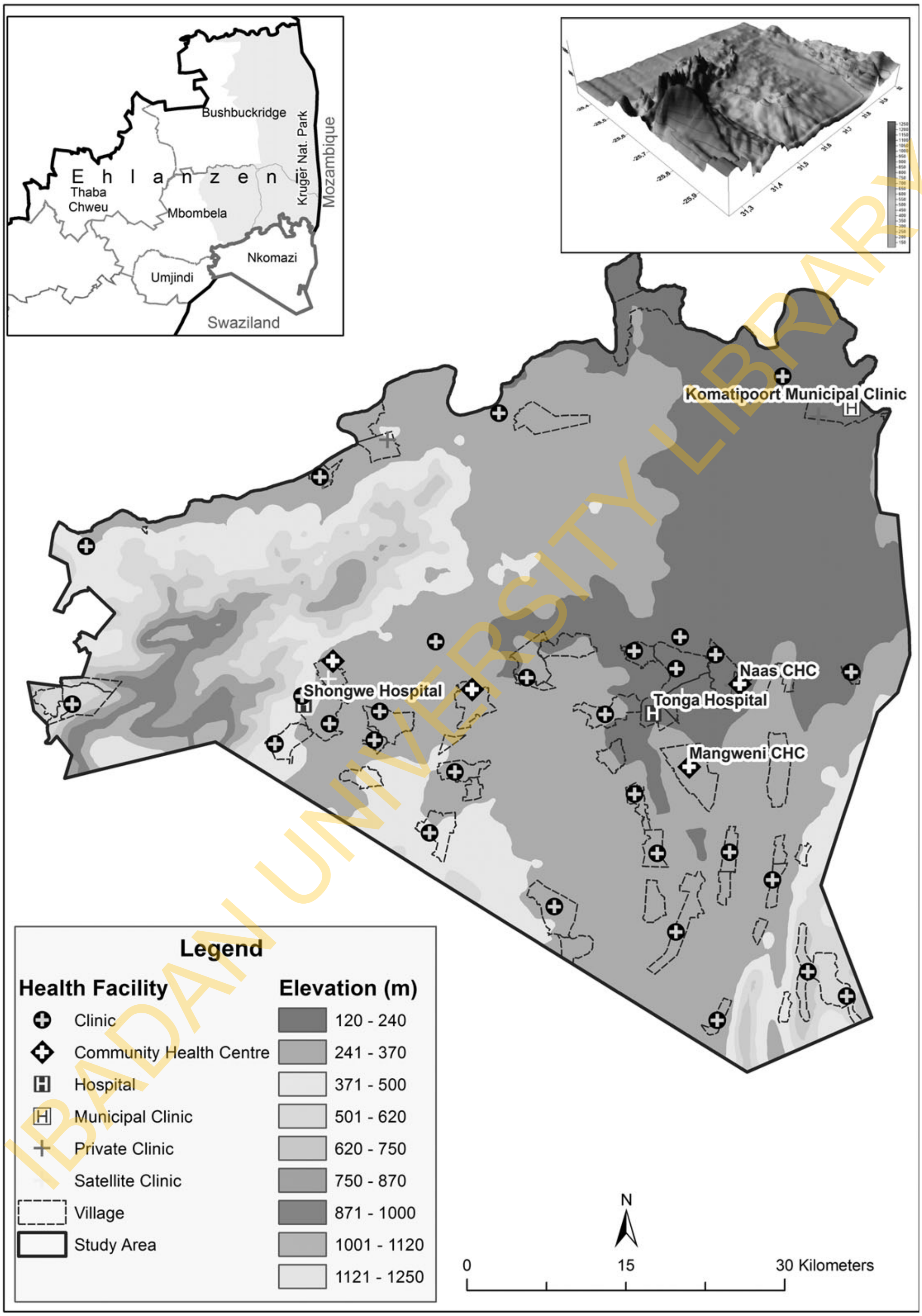

Figure 1 Location of study area showing the 54 villages and 48 health facilities; labelled are the 5 selected villages/health facilities.

Table 1 Accuracy assessment of land use/land cover

Reference data							
Classified data	Water body	Forest	Irrigated land	Bare land	Built up	Total	UA (%)
Water body	14	0	2	0	0	16	87.50
Forest	0	12	1	0	0	13	92.31
Irrigated Land	2	1	16	0	0	19	84.21
Bare land	0	0	0	10	3	13	76.92
Built up	0	0	0	2	19	21	90.48
Total	16	13	19	12	22	80	
PA (%)	87.50	92.31	84.21	83.33	86.36		

Overall accuracy = 86.51%; Kappa statistic = 0.842.

All statistical analyses were performed using the R statistical software. Firstly, malaria data were tested for homogeneity of variance using Levene's test. Secondly, malaria data with variables (age group, sex, death and source of infection) and environmental parameters (water body, forest, cultivated/irrigation land, bare land and built up; and altitude) were subjected to univariate logistic regression to determine their statistical association with malaria incidence through a likelihood ratio test using a liberal *P*-value ($P = 0.20$). Variables with a significant statistical association (significant level $P > 0.05$) with malaria infection were further analysed. Thus, age group, sex, water body, forest, irrigated land, bare land and altitude underwent multivariate regression analysis. The spatial autocorrelation was also determined using a semivariogram to estimate malaria risk and its geographical clustering.

Results

Malaria case notification

The result of the Levene's test indicated that the spatial distribution of malaria incidence in Nkomazi local municipality was heterogeneous, $P = 0.0016$. A total of 60 718 malaria cases were notified across 48 health facilities in Nkomazi municipality between January 1997 and August 2015. Results from Tonga hospital, Shongwe hospital, Mangweni CHC, Naas CHC and Komatipoort municipal clinic indicate the most cases were notified in Komatipoort municipal clinic (10 984); the least in Buffelspruit satellite clinic 3 [3195.68; 95% confidence interval (CI): 2022.53–4368.84]. Both malaria cases and malaria-related deaths declined significantly ($P < 0.001$) albeit with few peaks across the period. As shown in Figure 2, there was a major malaria incidence in the year 2000 (9699) accounting for 15.97% of the total cases within the 18-year period. This is closely followed by the years 2001 (7894) and 1999 (6126), which accounted for 13% and 10.09%, respectively. Although there is a drastic decline in the number of cases after the year 2002, there were a few peaks in 2006, 2011 and 2014.

Malaria affects all ages from infancy (0) to very old age (106); mean age (24), mode (25), and standard deviation (16). As indicated in Table 1, the economically active group of 15–64 is most at risk and accounts for 68.91% (41 842) of all notified cases over the study period. Its share was particularly high in 2005 with 79.67% (1611) of cases. Age 0–14 ranks second, accounting for 29.36% (17 824) of all notified cases [but 41.36% (1675) in 1998]. Age group of 65 and older is less affected by malaria, accounting for only 1.73% (1052) of total notified cases and at most 2.11% in 2011 (41). The malaria incidence rate for age 0–14 was 1894 per 100 000 in 2001 and 259 per 100 000 in 2011; for age 15–64 it was 2798 per 100 000 in 2001 and 649 in 2011; for age 65 and older it was 1045 per 100 000 in 2001 and 255 in 2011 (Table 2). Over the year under study, males were more affected by malaria than females: they accounted for 55.78% (33 869) *vs.* 44.22% (26 849) in females. This trend was consistent throughout the study period ($P < 0.001$).

However, as indicated in Table 3, the picture looks different in Tonga hospital, where females accounted for 51.70% (1977) of the total notified cases *vs.* 48.30% (1847) of males. For males, the malaria incidence rate was 2698 cases per 100 000 in 2001 and 640 in 2011; for females, it was 2056 cases per 100 000 in 2001 and 754 per 100 000 in 2011.

The annual number of malaria-related deaths in Nkomazi greatly declined ($\chi^2 = 27.9$; $P < 0.001$) over the study period. A total of 249 malaria-related deaths were notified. There is no year without malaria-related death. The highest number of 52 was recorded in 1999; in 2000, there were 32 death followed by a steady decline and then a sudden increase to 29 deaths in 2002. As

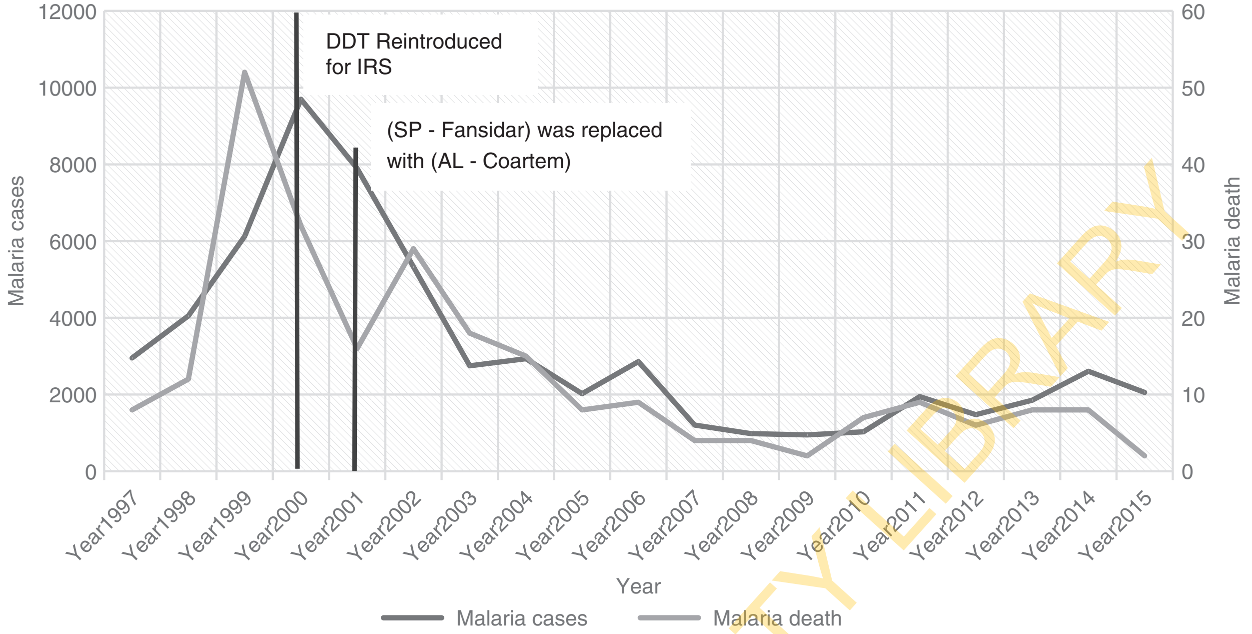

Figure 2 Notified malaria cases and related death in Nkomazi municipality January 1997–August 2015 (blue vertical lines indicate when insecticide and drug policies were introduced).

Table 2 Notified malaria cases and related deaths in Nkomazi municipality Januay 1997–August 2015

Year	Total malaria cases	Age 0–14		Age 15–64		Age 65 above		Male		Female		Death	CFR
		Case	%	Case	%	Case	%	Case	%	Case	%		
1997	2955	1127	38.14	1775	60.07	53	1.79	1524	51.57	1431	48.43	8	0.27
1998	4050	1675	41.36	2291	56.57	84	2.07	2147	53.01	1903	46.99	12	0.30
1999	6126	2198	35.88	3813	62.24	115	1.88	3260	53.22	2866	46.78	52	0.85
2000	9699	3526	36.35	5996	61.82	177	1.82	5175	53.36	4524	46.64	32	0.33
2001	7894	2583	32.72	5169	65.48	142	1.80	4259	53.95	3635	46.05	16	0.20
2002	5330	1407	26.40	3831	71.88	92	1.73	2807	52.66	2523	47.34	29	0.54
2003	2749	640	23.28	2064	75.08	45	1.64	1583	57.58	1166	42.42	18	0.65
2004	2934	576	19.63	2313	78.83	45	1.53	1733	59.07	1201	40.93	15	0.51
2005	2022	383	18.94	1611	79.67	28	1.38	1245	61.57	777	38.43	8	0.40
2006	2859	553	19.34	2256	78.91	50	1.75	1741	60.90	1118	39.10	9	0.31
2007	1204	247	20.51	942	78.24	15	1.25	730	60.63	474	39.37	4	0.33
2008	983	218	22.18	756	76.91	9	0.92	575	58.49	408	41.51	4	0.41
2009	950	262	27.58	676	71.16	12	1.26	599	63.05	351	36.95	2	0.21
2010	1029	232	22.55	780	75.80	17	1.65	626	60.84	403	39.16	7	0.68
2011	1944	360	18.52	1543	79.37	41	2.11	1190	61.21	754	38.79	9	0.46
2012	1474	282	19.13	1164	78.97	28	1.90	893	60.58	581	39.42	6	0.41
2013	1850	459	24.81	1370	74.05	21	1.14	1085	58.65	765	41.35	8	0.43
2014	2609	672	25.76	1891	72.48	46	1.76	1504	57.65	1105	42.35	8	0.31
2015	2057	424	20.61	1601	77.83	32	1.56	1193	58.00	864	42.00	2	0.10

shown in Figure 3 and Table 1, case fatality rates (CFRs) above the national target of 0.5% for malaria in South Africa occurred in 1999 (0.85%); 2010 (0.68%); 2003 (0.65%); and 2002 (0.54%). On average, the CFR was 0.41 in Nkomazi over the period of the year under investigation.

In general, malaria infection source per country indicates that 56.38% (34 230) of malaria infection are loca-

Table 3 Comparison of year 2001 and 2011 notified malaria cases and population in Nkomazi municipality

	Year 2001				Year 2011			
Variables	Malaria case	Population	Case / 100 000	Malaria death	Malaria case	Population	Case / 100 000	Malaria death
Age 0–14	2583	136 355	1894	0	360	139 234	259	0
Age 15–64	5169	184 725	2798	13	1543	237 731	649	9
Age 65 Above	142	13 588	1045	3	41	16 065	255	0
Male	4259	157 855	2698	9	1190	186 017	640	5
Female	3635	176 813	2056	7	754	207 013	364	4
Total	7894	334 668		16	1944	393 030		9
Case per 100 000		2359				495		

lised (South Africa) while the difference is imported malaria cases. Infection from Mozambique accounts for 42.12% (25 573) of the total infection and other countries like Swaziland 1% (610); Somalia 0.2% (119); Zimbabwe 0.07% (40); Ethiopia 0.06% (35); Malawi 0.04% (26) among others make up for the difference. Across the five selected facilities, imported malaria cases from Mozambique are particularly high accounting for 66.1% of the total cases in Komatipoort municipal clinic and 44.8% in Naas CHC (Table 4).

Land use/Land cover and landscape properties

The LULC was derived from cloud-free Landsat 8 using object-based classification technique in ENVI 5.0. Five broad classes were classified, water body (%), forest, cultivated/irrigation land, bare land and built up. The study area predominantly consists of bare land (non-vegetated, uncultivated farmland and open space) covering 61%; irrigated land comprises 18%; built-up areas cover 14% and water bodies the remaining 1% (See Figure 4c). The altitude ranges from 120 to 1250 m with a mean of 395 m above sea level (See Figure 4d). The result from the natural Jenks classification of the altitude into nine classes indicates that about 70% of the total area is 120–400 m above sea level and its significantly associated with malaria incidence ($P = 0.001$).

Discussion

Our aim was to examine the influence of environmental factors on population (age group) at risk of malaria in

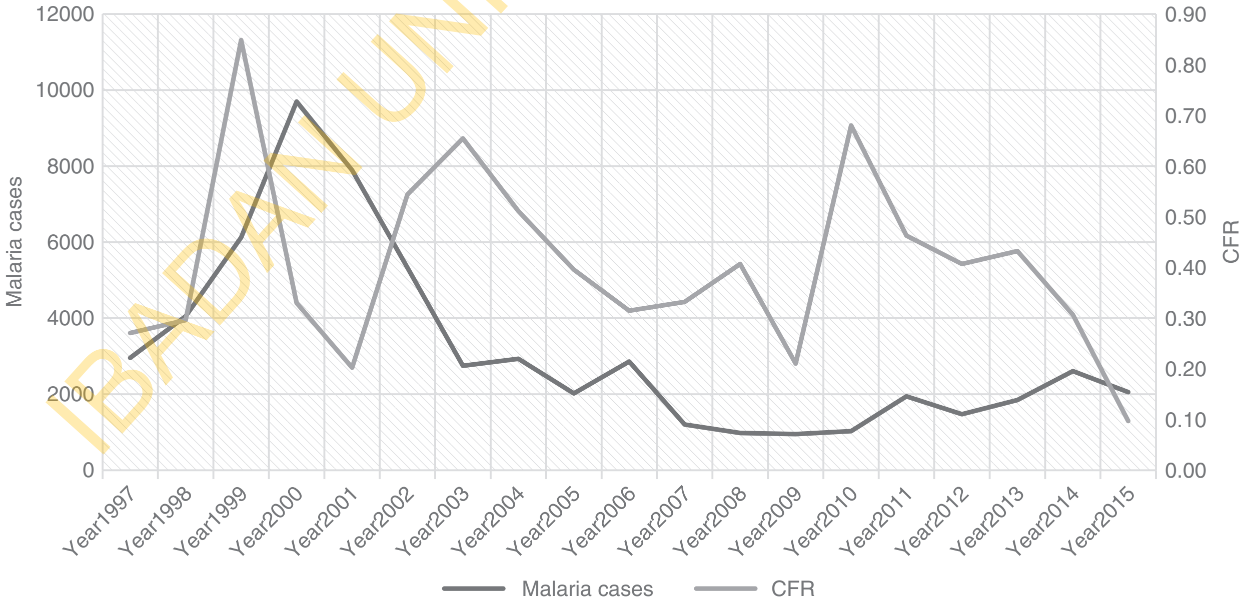

Figure 3 Notified malaria cases and case fatality rate in Nkomazi municipality, January 1997–August 2015.

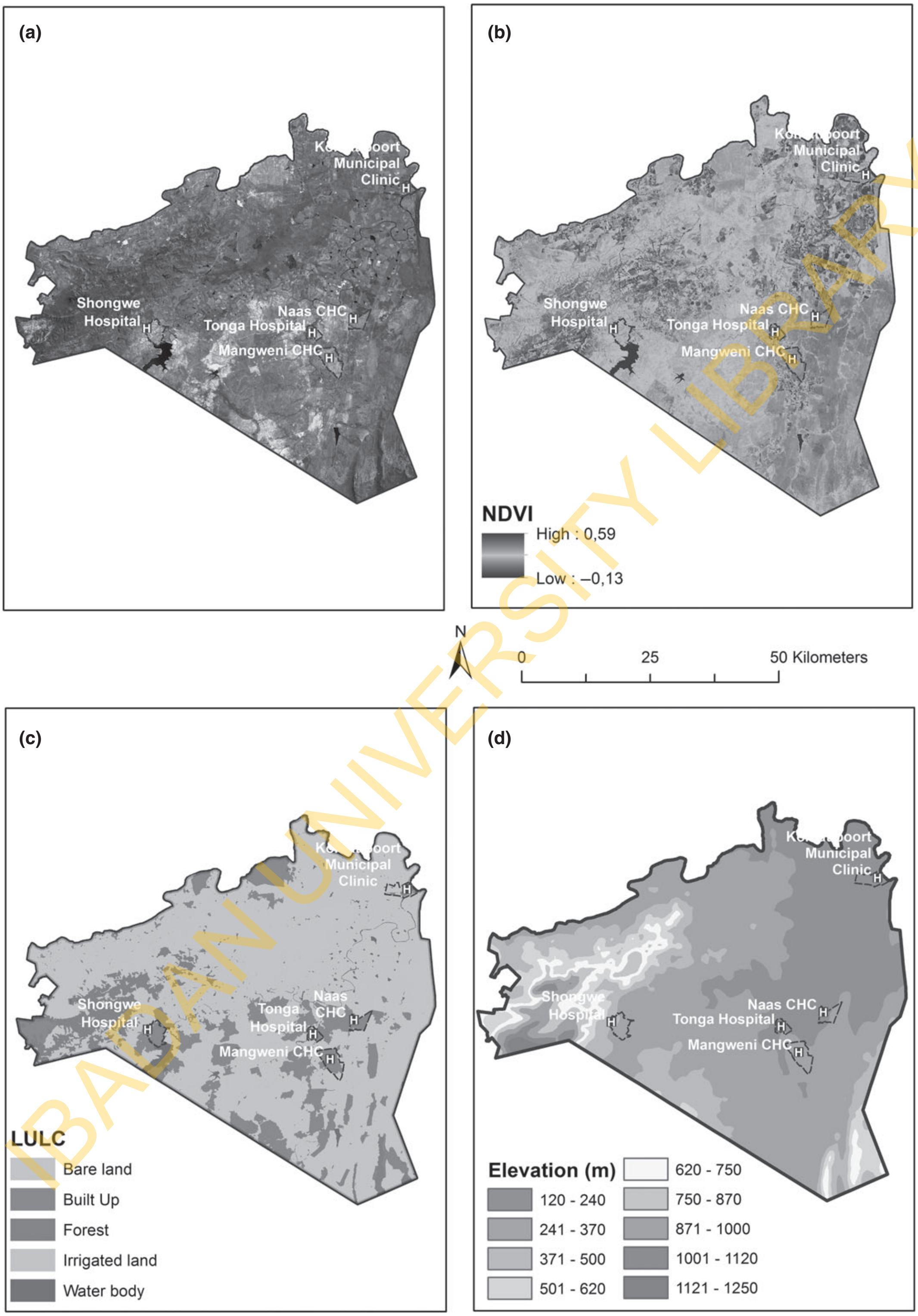

Figure 4 Outputs of environmental factors determining malaria risk in Nkomazi municipality.

Table 4 Notified malaria cases, death and source in the five major health facilities in Nkomazi municipality January 1997–August 2015

		Age 0–14		Age 15–64		Age 65 above		Male		Female				
Health facility	Total malaria cases	Cases	%	Cases	%	Cases	%	Cases	%	Cases	%	Deaths	CFR	Source country
Tonga Hospital	3824 (6.30%)	814	21.29	2923	76.44	87	2.28	1847	48.30	1977	51.70	78	2.04	SA 69.2% Moz. 29.2% Others 1.6%
Shongwe Hospital	5463 (9.00%)	1884	34.49	3452	63.19	127	2.32	2834	51.88	2629	48.12	133	2.43	SA 86.9% Moz. 11.6% Others 1.5%
Mangweni CHC	6012 (9.90%)	1779	29.59	4053	67.42	180	2.99	3401	56.57	2611	43.43	4	0.07	SA 61.1% Moz. 37.9% Others 1.0%
Naas CHC	7878 (12.97%)	2325	29.51	5442	69.08	111	1.41	4397	55.81	3481	44.19	6	0.08	SA 53.9% Moz. 44.8% Others 1.3%
Komatipoort Municipal Clinic	10984 (18.09%)	1896	17.26	9040	82.30	48	0.44	6786	61.78	4198	38.22	5	0.05	Moz. 66.1% SA 33.1% Others 0.8%

the study area to enhance quality targeting for prevention of malaria incidence. This is particularly important because of the high population movement dynamics in the study area (both locally and internationally). Hence, surveillance-response approaches focused on identifying and/or predicting pockets of transmission using remote sensing underpinned this research.

A major limitation of our study is the use of object-based classification on a medium rather than a high-resolution Landsat image for the LULC classification, which might have resulted in better-simplified classes and higher accuracy. Although the use of object-based classification on Landsat images yields a better result than pixel-based classification, a high-resolution image like QuickBird would have given a better result and helped to remove mixed classification of LULC for a localised, small-scale study as this.

Actively and passively detected malaria cases as well as environmental parameters derived from remotely sensed data were used to establish the population risk factors. The results showed that malaria incidence and mortality in Nkomazi municipality have been on the decline in the last 18 years. However, malaria incidence remains high in the study area compared to other endemic regions [15]. This declining trend is also seen in Limpopo [32] and KwaZulu-Natal [33]. The drastic decline of about 71% of notified malaria incidences after the peak years of 2000, 2001 and 2002 (from 9699 in year 2000 to 2749 in 2003) is not unconnected to the reintroduction of DDT in year 2000 after it was discontinued in 1996 because of both environmental concerns and social conflict [8–10]. The decline could also be traced to the change in the drug policy from sulphadoxine–pyrimethamine to artemether/lumefantrine as the first-line treatment as a result of the resistance developed by the parasite to sulphadoxine–pyrimethamine [8–10]; and the transborder initiatives among South Africa and neighbouring countries.

Although malaria risk is generally elevated in the 15–64 age group, it is particularly high in the intensely irrigated areas of Komatipoort and Kamaqhekeza (Naas CHC). Across all recording health facilities, there was a statistically significant difference ($P < 0.001$) in malaria incidence between males and females except in Tonga hospital, which has to do with irrigated farming there. Agriculture ranks second to government and community services in terms of labour and source of income [34]. Komatipoort, which borders Mozambique, accounts for the 66.1% of imported cases from young Mozambicans who are mostly farm workers.

In terms of the malaria case fatality rates, the pattern is similar to that of malaria incidence. There were high peaks of CFR (above the national target of 0.50%) in

1999, 2010, 2003 and 2004 in order of their magnitude. However, the CFR has fallen significantly the study period to a total average of 0.41%, which is less than the 0.5% of the national target. In a complete deviation from the findings in other African countries, where infants, children and pregnant women account for the highest proportions of malaria-related deaths, here the economically active population aged 15–64 accounted for most malaria-related deaths, perhaps due to self-management of illness leading to late presentation at the nearest health facilities [35]. The general reduction in the death rate could be related to the change in first-line treatment and to continuous awareness through health promotion and educational projects organised by the Malaria Control Programme and the Centre for Sustainable Malaria Control, University of Pretoria.

The univariate logistic regression model indicated that only the covariates age group, sex, water body, forest, irrigated land and altitude were significantly associated with malaria infection. A further step of multivariate analysis revealed that people of all age groups, particularly 15–64 years, living at lower altitude (<400 m above sea level) are at greater risk of malaria infection than people at higher altitude ($P = 0.001$). Hence, malaria infection increases with decreasing altitude. People living in close proximity to irrigated sites are at significantly higher risk of getting infected than people in areas without irrigation or cultivation. Malaria risk also increased with the presence of a water body. However, these covariates varied when conducting the analysis within the buffered 2 km of the selected villages. For instance, the forest near Kamataso village/Shongwe hospital accounts for 1% of the LULC within the 2-km buffer.

Malaria risk increases with decreasing distance to irrigated areas, which are suitable mosquito breeding habitats and hence can be used as an internal tool to validate analyses [36, 37]. Our model showed that a 10% increase in the extent of irrigated areas increased malaria risk by almost 39% in the entire study area and by almost 44% within the 2-km buffer of the selected villages. This seems to underpin the high rate of malaria incidence in Komatipoort (Komatipoort hospital) and Kamaqhekeza (Naas CHC), where irrigated land within their 2-km buffers accounts for 82% and 19% of the total LULC. Furthermore, a proportion of bare land within the 2-km buffer was associated with a slightly increased risk of malaria. This could be because a large proportion of the classified bare land contained uncultivated farmland with some within the irrigated areas, which are suitable habitat for mosquitoes to breed. In our model, the forested area – on at 900 to 1250 m above sea level – seems not to be significantly associated with increased malaria incidence ($P = 0.166$). Hence, the proximity of forest may not account for increased malaria incidence, although we propose a more detail study for adequate reporting on this. Our model showed a likely association between malaria incidence and an increase in the proportion of built-up areas, although this scenario changed after adjustment of the most strongly correlated variables irrigated land and water body. Hence, the scenario could partly be explained by the presence of a few pockets of seemingly irrigated land, which are a mix of irrigated land and green/open areas classified as part of the bare land.

Conclusions

Nkomazi local municipality in South Africa is a high-risk malaria region with an incidence rate of about 500 cases per 100 000. Studies relating malaria incidence and environmental factors using remote sensing has not been done in the malaria endemic regions of South Africa [38]. Malaria incidence is associated with irrigated land, water bodies and altitude, and more pronounced in the economically active population of age group 15–64 and in males. Although still high, malaria incidence and case fatality rates have drastically declined between 1997 and 2015. Our findings offer current information on hot spots for malaria infections that is fundamental in developing a local warning and surveillance response and for strengthening trans-border control measures. Further studies identifying the crops in the irrigated/cultivated areas and determining the peak growing season could establish the relationships of certain crops with malaria.

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Corresponding Author A. M. Adeola, Centre for Geoinformation Science, Department of Geography, Geoinformation and Meteorology, University of Pretoria, Hatfield, South Africa. E-mail: amadeola@yahoo.com