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

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Abstract

Background: Nkomazi local municipality of South Africa is a high risk malaria region having an incidence rate of about 500 cases per 100,000. The aim of this study was to examine the influence of environmental factors on population (age group) at risk of malaria in the study area to enhance quality targeting for prevention of malaria incidence. Hence, the study contributes to the country's aim of eliminating malaria by the year 2018. **Methods:** R software was used to statistically analyse the data. Using remote sensing technology; a Landsat 8 image of 4th October 2015 was classified using object-based classification technique and a 5 m resolution spot height data was used to generate digital elevation model of the area. **Results:** A total of 60,718 malaria cases were notified across 48 health facilities in Nkomazi municipality within the 18 year period of investigation (January 1997 to August 2015). The study found that malaria incidence is 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 amount of irrigated areas, malaria risk increased by almost 39% in the entire study area and by almost 44% within the 2 km buffer of the selected villages. Malaria incidence in the study area is more pronounced within the economically active population of age group 15-64 and the male gender are at higher risk of malaria. The result also indicated that though malaria incidence in the study area is high, the incidence and its case fatality rate have drastically declined over the study period. **Conclusion:** Hence, a predictive model, based on environmental factors would be useful in the effort towards the elimination of the disease by fostering proper malaria control targeting and resource allocation.

Keywords: Malaria, environment, Landsat, remote sensing, object-based classification, LULC, elevation

Background

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]. Exacting a huge burden on health, economy and social sectors of the endemic regions [1]. Malaria in South Africa has been studied extensively by various foremost researchers [2-5]. A major example of such studies is Mapping Malaria Risk in Africa/Atlas du Risque de la Malaria en Afrique (MARA/ARMA).The project aimed at the collection of malariometric data in the form of distribution (where), transmission intensity (how much), seasonality (when), environmental determinants (why) and population at risk (who is affected) in order to create a continental database of the spatial distribution of malaria. In addition, the project focused on developing environmentally determined models that define the distribution of malaria, the duration and timing of the transmission seasons [6].

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Malaria is mainly endemic in the low altitude (below 1200 m) regions of Mpumalanga. Limpopo and KwaZulu-Natal located in the north-eastern part of the country [7]. Since the introduction of dichlorodiphenyltrichloroethane (DDT) for indoor residual spraying (IRS) in 1948, South Africa have 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 among other speculated factors like 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 countries of 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 include; focal larviciding of identified breeding sites, rapid detection, diagnostic testing through rapid diagnostic tests (RDT) and treatment of confirmed malaria cases at health care facilities [10,11].

These control strategies saw the number of reported malaria cases reduced from 64,622 cases in 2000 to 7,626 in 2010. On the other hand, the number of deaths also reduced by 81% i.e. from 458 deaths in 2000 to 87 deaths in 2010 [7]. Malaria cases were high during the 1997-2001 periods [7]. During this period, two main consecutive years 1999 and 2000 had the highest number of reported cases amounting to 51,444 and 64,622 respectively. Despite this effort, about 4.9 million of her population, translating to about 10% of the population are still prone to malaria living in the endemic region [7,12]. In particular malaria transmission remains high in Nkomazi municipality in relation to other regions [13].

Malaria in the region is markedly seasonal with varying intensity of transmission due to altitudinal and climatic factors. The transmission increases from the wet summer months (September to May) and decreases afterward. The peak transmission occurs 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 parameter as major determinants for the spatial and temporal distribution of malaria is well documented [3,16-18]. Major climatic factors for malaria risk are temperature, rainfall and humidity. However, the lack of adequate spatial and temporal variability of these major meteorological and environmental parameters is a major limiting factor. Data from earth-observing sensors provides continuous meteorological and environmental information over large areas in contrast to conventional ground surveys [19]. Hence, the use of remotely sensed data offers the possibility of identifying mosquitoes breeding habitats [21-25] and the development of epidemiological forecasting models and early warning systems [19,25]. The understanding of the spatial and temporal distribution of the risk factors and the prevalence of malaria in endemic areas can help in predicting the abundance, determine the location and quantify the at-risk population [26]. Hence, can significantly enhance strategies for local malaria control. An in-depth understanding of the role of landscape/environmental factors in the spatial distribution of malaria is vital so that suitable localised efforts towards elimination can be established. Environmental factors such as altitude, vegetation, agricultural practices, and the presence of water bodies affect the vector and hence the quantity of malaria risk [27-29]. However, studies relating the influence of these factors to malaria incidence have not been done over the study area.

The ultimate goal of the 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 the WHO. Hence, as the country intensify effort towards the elimination of malaria, the identification of the spatial distribution of age group at risk of malaria transmission and its relationship with environmental factors would enhance strategic intervention by public health decision makers in the study area for proper distribution of scarce resources. Therefore, the aim of this study is to examine the influence of environmental factors on population (age group) at risk of malaria in the study area to enhance quality targeting for prevention of malaria incidence and subsequent elimination.

Methods

Ethics statement

This study uses secondary data acquired from the malaria information system (MIS) from the department of health; 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 (EC140721-065) and the Department of Health in Mpumalanga Provincial Government (MP_2014RP39_978).

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 is located Nkomazi municipality with other four municipalities (Thaba Chweu. Mbombela. Umjindi, and Bushbuckridge). Nkomazi is bordered in the east by Mozambique, in the south by Swaziland and the Kruger national park is situated to the north. Nkomazi has a total area of 3255. 67 km^2 with 54 main places mostly concentrated in the southern part of the municipality. The municipality has a total population of 277,864 in 1996; 334,668 in 2001 and in 2011 the municipality has grown to 393,030 in population [2]. It enjoys a sub-tropical weather condition with an average temperature of 28 °C and annual rainfall between 550 and 1000 mm. Nkomazi varies in elevation from about 110 to about 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. The municipality is known for its richness in sugarcane, fruits 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 themselves at health facility and were tested positive to *Plasmodium* across (passive case detection) and those collected through screening measures in which 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 with recently confirmed cases. The office of the malaria control programme is located in Tonga (31.783 E. -25.706 S). The records from the facilities contain information such as facility name, date of diagnosis, the number of cases, deaths, age, gender and source of infection and place of residence.

The record spans from January 1997 to August 2015 for many of the facilities. For the purpose of this study, 5 facilities (Tonga hospital, Shongwe hospital, Mangweni CHC, Naas CHC and Komatipoort municipal clinic) accounting for 56.3% of the total cases within the period under investigation was used. The demographic data at main place/village (administrative boundary) was acquired from statistics SA for 2001 and 2011 census. There are 54 villages mostly concentrated in the southern part of the municipality, see figure 1. The data contained age group and gender population at each village. Accordingly, 5 villages in the location of selected health facilities were considered.

Geometrically corrected, summer cloud-free Landsat 8 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 was acquired from the national geospatial information (NGI) of South Africa. Handheld GPS was used to take coordinates of easy to identify ground-truth site during an

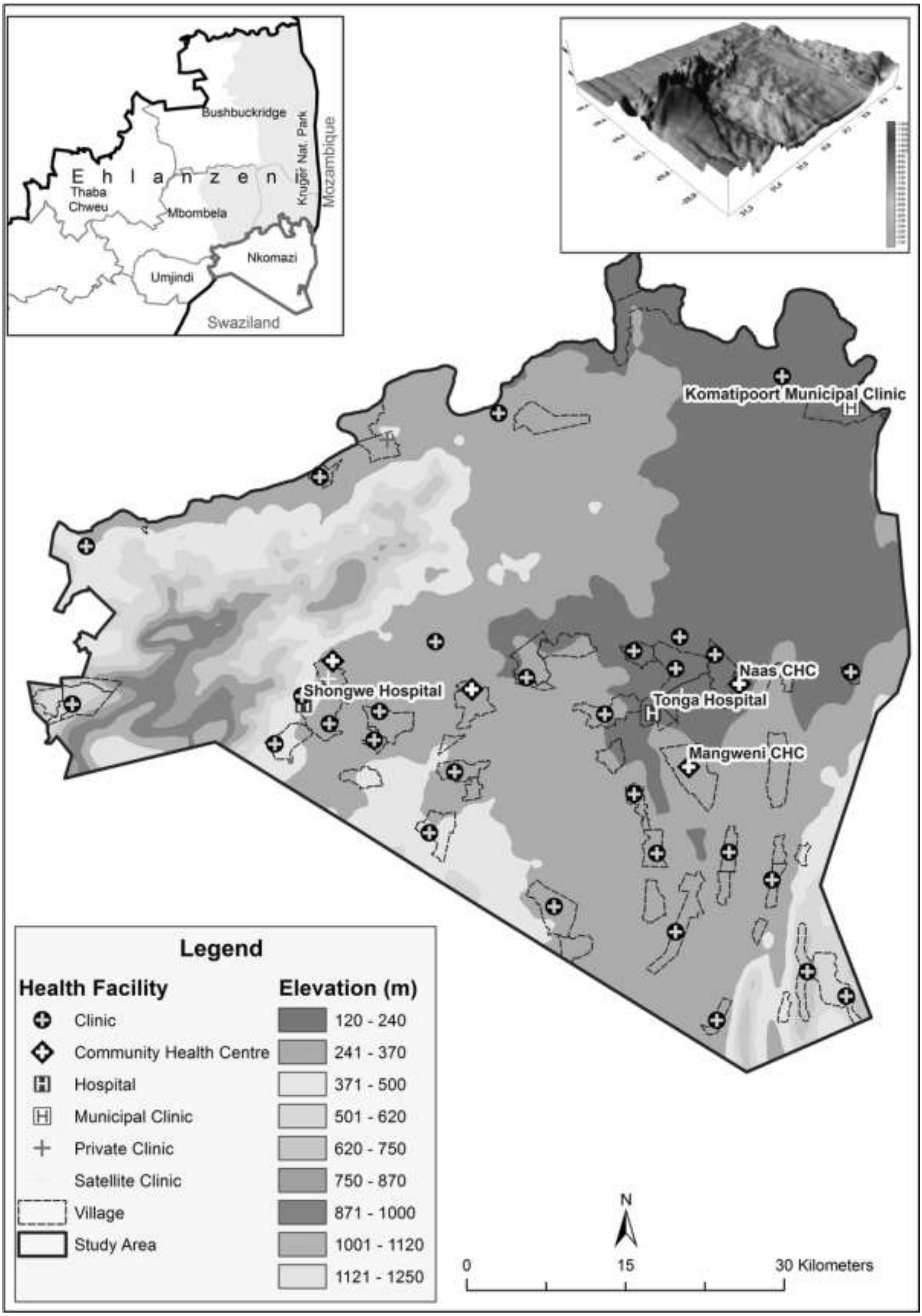

Figure 1: Location of study area: Showing the 54 villages and 48 health facilities; labelled are the 5 selected villages/health facilities

educational/mini field trip to the study area on April 23-24. 2015 (UP CSMC visit on world malaria day celebration). 15 points were randomly taken within Tonga village and additional 70 points were taken across the study area using Google Earth images for adequate representation for accuracy assessment.

Data analysis

Malaria case notification

Although as reported in [13-15] that malaria season starts at the start of July to the end of June the subsequent year, this study used calendar year in order to match the age category of Statistics SA for the population census of 2001 and 2011 national census. The daily diagnosis of malaria cases data was aggregated to monthly and yearly format. The age was categorised into groups of ages 0-14. 15-64 and 65 and above. The 0-14 and 65 above indicating the dependent population and 15-64 indicating the economically active population. The data was there after geo-coded using the coordinates of the recording health facilities. This then overlay on the main place to determine the location and proximity of the health facilities within the villages (main place). Generally, there is at least 1 health facility within each village or within 5 km radius in proximity to villages where not a specific health facility is located [31]. See figure 1. Microsoft Excel was used for the pre-processing before it was imported into R software.

Environmental parameters characterisation

Landsat 8 data was used to derive the land use/land cover (LULC) types using 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 such (water body, forest, cultivated/irrigated land, bare land and built up). 'Water body' is characterised by river, stream, ponds and lakes; 'forest' is characterised by areas of dense tree cover with thick-closed canopy; 'cultivated/irrigation' refers to as area under cultivation and intensive irrigation of crops (sugar cane, orange, banana); 'bare land' are non-vegetated, uncultivated farmland and open space while 'built up' is characterised by asphaltic/concreted road, pavement, building/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. The classification was outputted to shape file and was imported into ArcGIS 10.2.1. Using the premise that adult mosquitoes generally remain up to 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 was 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 that selected from the classified image (classified data). Hence, overall accuracy (86.51%), producer's (86.74%) and user's accuracies (86.28%), and Kappa statistic (0.842) were computed see table 1.

Table 1: Accuracy assessment of LULC

	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.							

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, see insert of figure 1.

All statistical analyses were performed using the R statistical software. Firstly, malaria data was 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 the significant statistical association (significant level $p > 0.05$) with malaria infection were further analysed. Hence, age group, sex, water body, forest, irrigated land, bare land and altitude were subjected to a multivariate regression analysis. The spatial autocorrelation was also determined using semivariogram to estimate malaria risk and its geographical clustering.

Results

Malaria case notification

The result of the Levene's test indicates that the spatial distribution of malaria incidence in Nkomazi local municipality is 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 the 5 health facilities; Tonga hospital, Shongwe hospital, Mangweni CHC, Naas CHC and Komatipoort municipal clinic, indicate the highest cases were notified in Komatipoort municipal clinic 10,984; the lowest in Buffelspruit satellite clinic 3; mean 3195.68; 95% confidence interval (CI): 2,022.53 – 4,368.84. For the period under investigation, malaria cases, as well as malaria-related death in the study area, has been significantly declining ($p < 0.001$) although with few peaks across the period. As shown in figure 2, there was a major malaria incidence in the year 2000 (9,699) accounting for 15.97% of the total cases within the 18-year period. This is closely followed by the year 2001 (7,894) and year 1999 (6,126) both accounting for 13% and 10.09% of the 18-year period respectively. Although there is a drastic decline in the number of cases after the year 2002, there are few peaks in years 2006. 2011 and 2014.

The notified malaria cases indicates that malaria affects all ages from infancy (0) to old aged (106) as the maximum, mean age (24), mode (25), Standard deviation (16). As indicated in table 1, age group 15-64; the economically active group is mostly at risk of malaria. The age group accounts for 68.91% (41,842) of the total notified cases over the study period and particularly high in the year 2005 with 79.67% (1,611) of the cases in that year. Age 0-14 ranks second accounting for 29.36% (17,824) of the total notified cases although account for 41.36% (1,675) in the year 1998. Age 65 and above is less affected by malaria accounting for only 1.73% (1,052) of the total notified cases and it highest contribution in the year 2011 with 2.11% (41). Malaria incidence rate for age 0-14 was 1,894 per 100,000 in 2001 and significantly fell to 259 per 100,000 in 2011; for group 15-64 incidence rate was

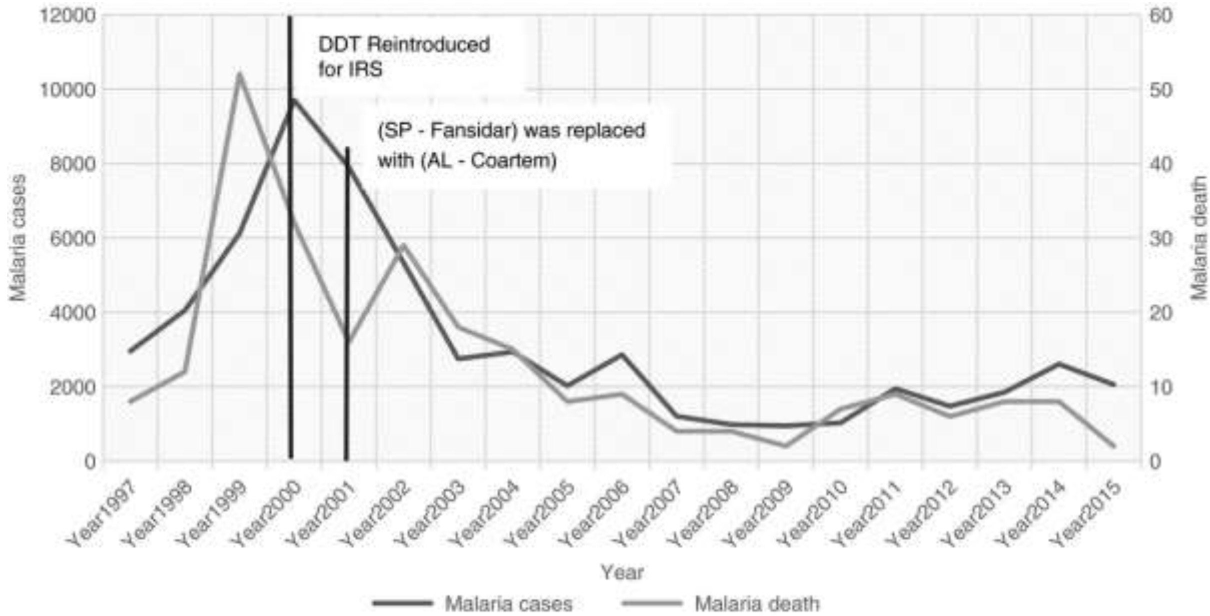

Figure 2: Notified malaria cases and related death in Nkomazi municipality Jan. 1997 - Aug. 2015 (The blue coloured vertical lines indicate when insecticide and drug policies were introduced)

2,798 per 100,000 in 2001 and 649 in 2011; for age group 65 and above incidence rate was 1,045 and 255 per 100,000 in 2001 and 2011 respectively, see table 2.

Table 2: Notified malaria cases and related death in Nkomazi municipality Jan. 1997 - Aug. 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

Over the year under study, the male gender is more affected by malaria than the female counterpart. The male accounts for 55.78% (33,869) as against the 44.22% (26,849) of the female. This trend is

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

Variables	Year 2001				Year 2011			
	Malaria case	**Population**	**Case /100,000**	**Malaria Death**	**Malaria case**	**Population**	**Case /100,000**	**Malaria Death**
Age 0-14	2583	136355	1894	0	360	139234	259	0
Age 15-64	5169	184725	2798	13	1543	237731	649	9
Age 65 Above	142	13588	1045	3	41	16065	255	0
Male	4259	157855	2698	9	1190	186017	640	5
Female	3635	176813	2056	7	754	207013	364	4
TOTAL	7894	334668		16	1944	393030		9
Case per 100,000	2359				495			

consistent throughout the study period with statistically significant ($p < 0.001$). However, as indicated in table 3, the picture looks different within the recording health facility in Tonga hospital were female accounts for 51.70% (1,977) of the total notified cases as against male's 48.30% (1,847). Malaria incidence rate was 2,698 and 640 cases per 100,000 for males in 2001 and 2011 respectively while incidence rate in females is 2,056 cases per 100,000 in 2001 and 754 cases per 100,000 in 2011.

On the other hand, there is a significant decline in the annual total number of malaria-related deaths in Nkomazi ($x^2 = 27.9$; $p < 0.001$) within the study period. A total of 249 malaria-related deaths were notified. There is no year without malaria-related death. The highest death was recorded in the year 1999 (52) while the year 2000 had (32) and subsequently a steady decline but for a sudden increase in 2002 (29). As shown in figure 3 and table 1, case fatality rate (CFR) above the national target of 0.5% for malaria in South Africa occurred in years 1999 (0.85%); 2010 (0.68%); 2003 (0.65%); and 2002 (0.54%). On the average, there is CFR of 0.41 in the Nkomazi over the period of the year under investigation.

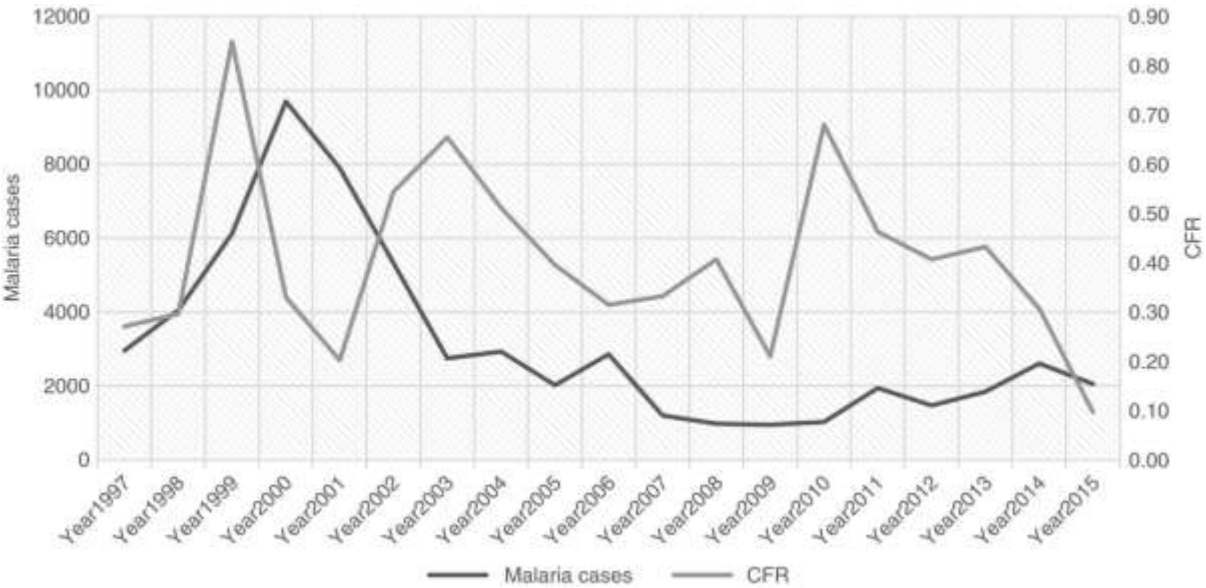

Figure 3: Notified malaria cases and Case fatality rate in Nkomazi municipality, Jan. 1997 - Aug. 2015

In general, malaria infection source per country indicates that 56.38% (34,230) of malaria infection are localised (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 5 selected facilities, imported malaria cases from Mozambique is particularly high accounting for 66.1% of the total cases in Komatipoort municipal clinic and 44.8% in Naas CHC, see table 4.

Table 4: Notified malaria cases, death and Source in the 5 major health facilities in Nkomazi municipality Jan. 1997 - Aug. 2015

Health Facility	Total Malaria case	Age 0-14		Age 15-64		Age 65 Above		Male		Female		Death	CFR	Source Country
		Case	**%**	**Case**	**%**	**Case**	**%**	**Case**	**%**	**Case**	**%**			
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%

Land use/Land cover and landscape characterisation

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 result indicates that the study area is dominantly covered by bare land (non-vegetated, uncultivated farmland and open space) covering a total area of 1,964.59 km^2 (61%), the irrigated land ranked second with a total area of 592.38 km^2 (18%), this is closely followed by built up with total area of 447.45 km^2 (14%) and water body contributing the remaining 1%.

The altitude ranges from a minimum of 120 m to maximum of 1250 m with a mean of 395 m above sea level. The result from the natural Jenks classification of the altitude into 9 classes indicates that about 70% of the total area is between 120-400 m above sea level and its significantly associated with malaria incidence (p = 0,001).

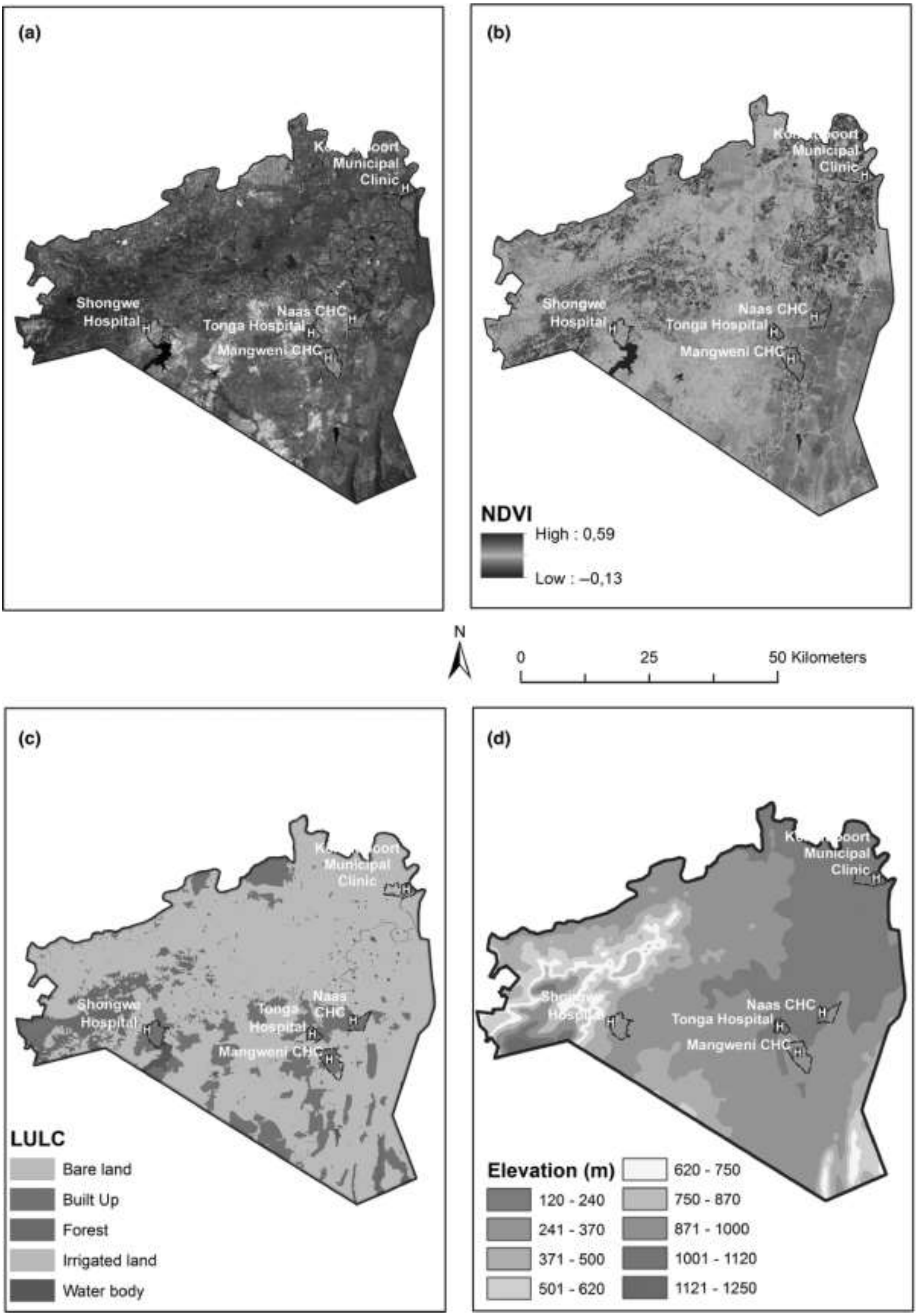

Figure 4: Outputs of Environmental factors determining malaria risk in Nkomazi municipality

Discussion

The aim of this paper was to examine the influence of environmental factors on population (age group) at risk of malaria in the study area to enhance quality targeting for prevention of malaria incidence. This is particularly because of the population movement dynamics which are high in the study area both locally and internationally, therefore, contribution to malaria elimination efforts through 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 technique on medium ranged resolution image Landsat for the LULC classification rather than a high-resolution image which might have given the opportunity of a better-simplified classes and hence a better accuracy. Although, the use of object-based classification technique on Landsat image has been shown to yield a better result than the pixel-based classifications techniques, a high-resolution image like Quick Bird would have given a better result and help to remove mixed classification of LULC for such 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 has been on the decline in the last 18 years. However, malaria incidence remains high in the study area when compared to other endemic region [15]. This declining trend is at pal with earlier published studies by scholars from in other malaria endemic region of South Africa; 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 9,699 in year 2000 to 2,749 in 2003) is not unconnected to the re-introduction 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 trans-border initiatives among South Africa and neighbouring countries.

Although malaria risk is generally high within the 15-64 age group (economically active) in the study area, it’s particularly high in Komatipoort and Kamaqhekeza (Naas CHC) where there is high irrigation practice. Across all the recording health facilities there is a statistical significant difference of ($p < 0.001$) in malaria incidence between the male and the female gender except in Tonga hospital. This is not unconnected with the high farming activities (irrigation) within the area. Agriculture ranks second to government and community services in term of the labour-absorbing sector and source of income for the people [34]. In addition, Komatipoort as a border town with Mozambique explains the 66.1% of imported cases from the youthful population of Mozambique who are mostly farm workers.

In term of the malaria case fatality rates, the pattern is similar to the pattern exhibited by malaria incidence. Over the period of study, there were high peaks of CFR (above the national target of 0.50%) in years 1999, 2010, 2003 and 2004 in order of their magnitude. However, CFR has reduced significantly within the study period with 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 infant, child and pregnant women are reported to account for higher degree of malaria-related death, the age group 15-64 representing the economically active population are seen to account for more malaria-related death in the study area. This could be associated with self-management of illness leading to a late report of illness to the nearest health facilities as found by [35]. The general reduction in the death rate could be related to the change in first-line treatment and continuous awareness through various health promotion and educational projects organised by the malaria control programme and with other collaborative efforts from academic institutions like 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. In the further step of analysis using the multivariate model, the model shows that all age groups, particularly age 15-64 living in lower altitude (< 400 m above sea level) are at more risk of malaria infection than others in higher altitude (p = 0.001). Hence, malaria infection increases with decreasing altitude. The population living in close proximity to the irrigated sites were significantly at higher risk of getting infected compared to the area without irrigation or cultivated land. Additionally, malaria risk also increased with the presence of water body. However, these covariates varied when conducting the analysis within the buffered 2 km of the selected villages. For instance, in Kamataso village/Shongwe hospital, there is the presence of forest which accounts for 1% of the total LULC within the 2 km buffer.

Studies have shown that malaria risk increases with decreasing distance to irrigated area which are suitable mosquito breeding habitats and hence, can be used as an internal tool to validate the analyses [36,37]. Our model showed that with 10% increase in the amount of irrigated areas, malaria risk increased by almost 39% in the entire study area and by almost 44% within the 2 km buffer of the selected villages. This, therefore, tends to underpin the high rate of malaria incidence in Komatipoort (Komatipoort hospital) and Kamaqhekeza (Naas CHC) where irrigated land within their 2 km buffer accounts for 82% and 19% of the total LULC. Furthermore, a proportion of bare land within the 2 km buffer were associated with a slightly increased risk of malaria. This could be largely traced to the fact that 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; also on a high altitude ranging from 900 to 1,250 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 proposed a more detail study for adequate reporting on this. In addition, our model showed a likelihood of an association between malaria incidence and an increase in the proportion of built-up areas. Although, this scenario changed after adjustment of the mostly correlated variables (irrigated land and water body). Hence, the scenario could partly be explained by the presence of few pockets of seemly irrigated land which are mixed classes between the irrigated land and green/open areas classified as part of the bare land.

Conclusions

Nkomazi local municipality of South Africa is a high risk malaria region having an incidence rate of about 500 cases per 100,000. Studies have shown that the understanding of the spatial and temporal distribution of the risk factors and the prevalence of malaria in endemic areas can help in predicting the abundance, determine the location and quantify the at-risk population. Hence, can significantly enhance existing control strategies and influence the establishment of localised system towards elimination of malaria. Studies using remotely sensed images in the study of vector-borne diseases have been done in other malaria endemic countries in sub-Saharan Africa areas [20,23,38-41]. However, studies of the relationship between malaria and environmental factors, particularly using object-based classification technique on remotely sensed image to quantify LULC has not been done in the malaria endemic regions of South Africa [42]. The study found that malaria incidence is highly associated with irrigated land, water body and altitude. There is high rate of population movement locally and internationally Malaria incidence in the study area is more pronounced within the economically active population of age group 15-64 and the male gender are at higher risk of malaria. The result also indicated that though malaria incidence in the study area is high, the incidence and its CFR have drastically declined over the period of study. Hence, a predictive model, based on environmental factors would be useful in the effort towards the elimination of the disease by fostering proper malaria control targeting and resource allocation. In general, these findings offer current information about the target group and the hot spots for malaria infections which is fundamental in fostering the development of a local based warning/specific surveillance response system and the strengthening of trans-border control measure.

This study recommends that further studies, such as a detailed identification of the crop types within the irrigated/cultivated area should be conducted as well as the determination of peak growing season to establish the relationship of certain crop type with malaria.

List of abbreviations

AL: Artemether/Lumefantrine

CFR: Case Fatality Rate

CHC: Community Health Centre

CI: Confidence Interval

DDT: Dichlorodiphenyltrichloroethane

GIS: Geographic Information Systems

GPS: Global Positioning System

IRS: Indoor Residual Spraying

LSDI: Lubombo Spatial Development Initiative

LULC: Land use/Land cover

MIS: Malaria Information System

MRC: Medical Research Council

MRP: Malaria Research Programme

NDoH: National Department of Health. South Africa

NDVI: Normalised Difference Vegetation Index

NGI: National Geospatial Information

RDT: Rapid Diagnostic Tests

RS: Remote Sensing

SA: South Africa

USGS: United States Geological Survey

WHO: World Health Organisation

Competing interests

The authors declare that they have no competing interests.

Authors Contribution

AAM, BOJ and OJM conceived the research idea and also participated in the writing of the manuscript. RCJ, AOM, KAM and TOJ were primarily responsible for the revision of the manuscript. AAM conducted the field work and was responsible for the overall writing up of the entire manuscript and preparing the figures and tables. The final manuscript was read and approved by all authors.

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References

1. World Health Organization: The Africa Malaria Report, 2013. Geneva: World Health Organization.
2. Sharp BL, Craig M, Mnzava A, Curtis B, Maharaj R, Kleinschmidt I: Review of malaria in South Africa. *Tech. rep., Health Systems Trust*, 2001.
3. Kleinschmidt I, Sharp BL, Clarke GP, et al. Use of generalized linear mixed models in the spatial analysis of small-area malaria incidence rates in KwaZulu Natal, South Africa. *Am. J. Epidemiol.* 2001;153:1213–21.
4. Kleinschmidt I, Sharp BL, Mueller I, et al. Rise in malaria incidence rates in South Africa: a small-area spatial analysis of variation in time trends. *Am. J. Epidemiol*. 2002;155(3):257–64.
5. Sharp BL, Kleinschmidt I, Streat E, Maharaj R, Barnes KI, et al.: Seven years of regional malaria control collaboration - Mozambique. South Africa and Swaziland. *Am J of Trop Med Hyg* 2007. 76: 42–47.
6. MARA/AMRA, Towards an atlas of malaria risk in Africa. First Technical Report of the MARA/ARMA Collaboration. Durban; 1998.
7. South Africa National Department of Health: Progress and impact series; focus on South Africa: Country report. South Africa National Department of Health. NDoH 2013. Available: http://apps.who.int/iris/bitstream/10665/89363/1/9789241506144_eng.pdf
8. Sharp BL, le Sueur D: Malaria in South Africa–the past, the present and selected implications for the future. *S Afr Med J* 1996, 86:83–9.
9. Craig MH, Kleinschmidt I, Nawn JB, Le Sueur D & Sharp BL: Exploring 30 years of malaria case data in KwaZulu- Natal, South Africa: Part I. The impact of climatic factors. *Trop Med and Int Health* 2004, 9: 1247–1257.
10. Blumberg L, Frean J: Malaria control in South Africa - challenges and successes. *S Afr Med J* 2007, 97:1193-1197.
11. Coetzee M, Kruger P, Hunt RH, Durrheim DN, Urbach J, Hansford CF: Malaria in South Africa: 110 years of learning to control the disease. *S Afr Med J* 2013. Vol 103, No 10.
12. Statistics South Africa: Statistical release Mid-year population estimates. Technical Report July 2011. Statistics South Africa. Available: http://www.statssa. gov.za/publications/P0302/P03022011.pdf.
13. Silal SP, Little Francesca , Barnes Karen I, White LJ: Towards malaria elimination in Mpumalanga, South Africa: a population-level mathematical modelling approach. *Malar J* 2014, 13:297
14. Silal SP, Barnes KI, Kok G, Mabuza A. Little F: Exploring the seasonality of reported treated malaria cases in Mpumalanga. South Africa. *PLoS One* 2013, 8(10): e76640
15. Ngomane L, de Jager C: Changes in malaria morbidity and mortality in Mpumalanga Province. South Africa (2001- 2009): a retrospective study. *Malar J* 2012. 11:19.
16. Govere JM, Durheim DN, Coetzee M, Hunt RH, La Grange JJ: Captures of mosquitoes of the Anopheles gambiae complex (Diptera: Culicidae) in the Lowveld Region of Mpumalanga Province. South Africa. *Afr Ent* 2000. 8:91-99.
17. Dlamini SN, Franke J, Vounatsou P: Assessing the relationship between environmental factors and malaria vector breeding sites in Swaziland using multi-scale remotely sensed data. *Geospatial Health 2015, 10:88-98*

18. Teklehaimanot HD, Lipsitch M, Teklehaimanot A, Schwartz J: Weather-based prediction of Plasmodium falciparum malaria in epidemic-prone regions of Ethiopia I. Patterns of lagged weather effects reflect biological mechanisms. *Malar J* 2004. 3:41
19. Adimi F, Soebiyanto RP, Safi N, Kiang R: Towards malaria risk prediction in Afghanistan using remote sensing. *Malar J* 2010. 9:125.
20. Bogh C, Lindsay SW, Clarke SE, Dean A, Jawara M, Pinder M, Thomas CJ: High spatial resolution mapping of malaria transmission risk in The Gambia, West Africa, using Landsat TM satellite imagery. *Am J Trop Med Hyg* 2007, 76. 875- 881.
21. Adeola AM, Olwoch JM, Botai OJ, Rautenbach CJ de W, Kalumba AM, et al: Landsat satellite derived environmental metric for mapping mosquitoes breeding habitats in the Nkomazi municipality, Mpumalanga Province, *South Africa. South Africa Geographical Journal*, 2015. http://dx.doi.org/10.1080/03736245.2015.1117012
22. McFeeters SK: Using the Normalized Difference Water Index (NDWI) within a Geographic Information System to Detect Swimming Pools for Mosquito Abatement: A Practical Approach. *Remote Sen* 2013, *5*, 3544-3561.
23. Machault V, Vignolles C, Borchi F, Vounatsou P, Pages F, Briolant S, Lacaux J, Rogier C: The use of remotely sensed environmental data in the study of malaria. *Geospat Health* 2011, 5. 151-168.
24. Clennon J, Kamanga A, Musapa M, Shiff C, Glass GE: Identifying malaria vector breeding habitats with remote sensing data and terrain-based landscape indices in Zambia. *Int J Health Geogr*. 2010 Nov 5;9:58
25. Midekisa A, Senay G, Henebry GM, Semuniguse P, Wimberly MC: Remote sensing-based time series models for malaria early warning in the highlands of Ethiopia. *Malaria J* 2012. 11:165.
26. Kleinschmidt I, Sharp BL: Patterns in age-specific malaria incidence in a population exposed to low levels of malaria transmission intensity. *Trop Med Int Health* 2001, 6: 986–991.
27. Thomas CJ, Cross DE, Bogh C: Landscape Movements of Anopheles gambiae Malaria Vector Mosquitoes in Rural Gambia. *PLoS One* 2013. 10:1371
28. Haque U, Sunahara T, Hashizume M, Shields T, Yamamoto T, Haque R, Glass GE: Malaria prevalence. risk factors and spatial distribution in a hilly forest area of Bangladesh. *PLoS One* 2011. 6:e18908.
29. Lindsay SW, Wilkins HA, Zieler HA, Daly RJ, Petrarca V, Byass P: Ability of Anopheles gambiae mosquitoes to transmit malaria during the dry and wet seasons in an area of irrigated rice cultivation in The Gambia. *J Trop Med Hyg* 1991. 94:313-324.
30. WHO: World malaria report 2010 World Health Organization. Geneva.
31. CSIR guidelines for the provision of social facilities in South African settlements. first edition: August 2012.
32. Gerritsen AA, Kruger P, van der Loeff MF, Grobusch MP: Malaria incidence in Limpopo Province, South Africa 1998-2007. *Malar J* 2008, 7:162.
33. Barnes KI, Durrheim DN, Little F, Jackson A, Mehta U, Allen E, Dlamini SS, Tsoka J, Bredenkamp B, Mthembu DJ, White NJ, Sharp BL: Effect of Artemether-Lumefantrine Policy and Improved Vector Control on Malaria Burden in KwaZulu-Natal, South Africa. *PLoS Med* 2005, 2:e330.
34. Integrated development plan; Nkomazi local municipality 2006/07, Nkomazi municipality, Mpumalanga 2007
35. Durrheim DN, Fieremans S, Kruger P, Mabuza A, de Bruyn JC: Confidential inquiry into malaria deaths. *Bull World Health Organ* 1999, 77:263-265.
36. Ijumba JN, Lindsay SW: Impact of irrigation on malaria in Africa: paddies paradox. *Medical and Veterinary Entomology* 2001, 15, 1-11
37. Kibret S, Wilson GG, Tekie H, Petros B: Increased malaria transmission around irrigation schemes in Ethiopia and the potential of canal water management for malaria vector control. *Malaria J* 2014, 13:360

38. Mushinzimana E, Munga S, Minakawa N, Li L, Feng CC, et al.: Landscape determinants and remote sensing of anopheline mosquito larval habitats in the western Kenya highlands. *Malar J* 2006, 5: 13.
39. Kulkarni MA, Desrochers RE, Kerr JT: High Resolution Models of Malaria Vectors in Northern Tanzania: A New Capacity to Predict Malaria Risk? *PLoS One* 2010, 5(2): e9396.
40. Edillo FE, Toure YT, Lanzaro GC, Dolo G, Taylor CE: Spatial and habitat distribution of Anopheles gambiae and Anopheles arabiensis (Diptera: Culicidae) in Banambani village, Mali. *J Med Entomol* 2002, 39: 70–77.
41. Krefis AC, Schwarz NG, Nkrumah B, Acquah S, Loag W, et al.: Spatial Analysis of Land Cover Determinants of Malaria Incidence in the Ashanti Region, Ghana. *PLoS One* 2011, 6(3): e17905
42. Adeola AM, Botai OJ, Olwoch JM, Rautenbach CJ de W, Kalumba AM, et al.: Application of geographical information system and remote sensing in malaria research and control in South Africa: a review. *South Afr J Infect Dis* 2015, 1(1):1-9. http://dx.doi.org/10.1080/23120053.2015.1106765