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Application of geographical information system and remote sensing in malaria research and control in South Africa: a review

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This paper presents a review of numerous items of published literature on the use of spatial technology for malaria epidemiology in South Africa between 1930 and 2013. In particular, focus is on the use of statistical and mathematical models as well as geographic information science (GIS) and remote sensing (RS) technology for malaria research. First, the review takes cognisance of the use of predictive models to determine the association between climatic factors and malaria epidemics only in KwaZulu-Natal province. Similar studies in other endemic regions such as Limpopo and Mpumalanga provinces have not been reported in the literature. While the integration of GIS with remote sensing has the potential of identifying, characterising, and monitoring breeding habitats and mapping malaria risk areas in South Africa, studies on the application of spatial technology in malaria research and control in South Africa are inexhaustive and have not been reported in the literature. As a result, a critical robust malaria warning system, which uses GIS and RS in South Africa, is yet to be realised. It is recommended that the wide range of datasets available from different sources including RS and global positioning systems (GPS) ought to be integrated into a GIS system, which is a core spatial technology vital for understanding the epidemiological processes of malaria and hence support in decision-making in malaria control.

Keywords: early warning system, environment, GIS, malaria, modelling, remote sensing

Introduction

Malaria is classified as one of the major health problems globally, causing about one million deaths annually of which approximately 90% of cases occur in sub-Saharan Africa.\textsuperscript{1} The causal agent of malaria is a parasite belonging to the \textit{Plasmodium} species, which is often transmitted between humans through the bites of female \textit{Anopheles} mosquitoes. In sub-Saharan Africa, the environmental conditions, which include the physical (temperature, rainfall and humidity), social (migration patterns), economic (quality of housing stock and poverty) and political (regional collaboration), largely account for the prevalence of the parasites.\textsuperscript{2}

Although malaria cases were first reported in Durban in 1902, the South African government notice number 2081 formally acknowledged its existence in 1956.\textsuperscript{3} About 4.9 million of South Africa’s (SA’s) population, representing 10% of the total population, live in malaria endemic areas.\textsuperscript{4} \textit{Anopheles arabiensis} is the major local vector causing malaria in SA.\textsuperscript{5} In SA malaria is prevalent in three provinces, namely Limpopo, Mpumalanga and Kwa-Zulu-Natal (Figure 1). However, some occurrences are reported in the Northern Cape and North West provinces along the Orange and Molopo rivers as a result of suitable breeding habitats for mosquitoes to survive.\textsuperscript{5}

The prevention of local transmission plus prompt and effective management of malaria cases have been the major control strategies adopted by the National Department of Health in malaria-endemic provinces. As a result, the burden of malaria in the endemic provinces has greatly decreased, by 88%.\textsuperscript{6} For example, the adopted control strategies saw the number of reported malaria cases reduced from 64,622 cases in 2000 to 7,626 in 2010 (Figure 2). Additionally, the number of deaths decreased by 81%, i.e. from 458 deaths in 2000 to 87 deaths in 2010. Malaria cases increased during the 1997–2001 periods and 2010–2011, with 64,622 cases and 626 respectively.\textsuperscript{7}

Malaria is one of the oldest diseases to have been widely studied across various disciplines based on varying analysis methods. These methods, accompanied by the collection, integration and analysis of relevant datasets, are vital in providing insight into the different phases of the disease and the widespread patterns. Consequently, it is conceived that the collective use of modelling procedures, geographic information systems (GIS) and remote sensing (RS), as well as the associated datasets, presents a more effective strategy for analysing the widespread outbreak and spatio-temporal patterns of malaria disease. Such a strategy could potentially aid efforts to control and eradicate the disease.\textsuperscript{8}

The aim of this paper is to review methods that have been used for malaria study in SA. However, a key focus has been placed on three major (spatial and quantitative) methods that encompass statistical or mechanistic models, GIS and RS technology. The use of GIS technology has been proposed; however, this paper further assesses the importance of integrating GIS, RS and proxies for malaria epidemics in SA and recommends an integrated malaria monitoring system as a ‘now and future’ paradigm for malaria research in southern Africa and the African continent. Overall, the recommended system would support the development of a malaria early warning system for the country.
Materials and methods

The archives of the National Centre for Biotechnology Information (NCBI) through PubMed (http://www.ncbi.nlm.nih.gov/pubmed), a US government-funded national library for medicine and South African Medical Journal (SAMJ) (http://www.samj.org.za/index.php/samj/issue/archive) were used to search for literature related to malaria research. The NCBI was selected because it has access to many public databases and other references. Additionally, the SAMJ was chosen for being a local journal and it was therefore assumed to have a South African scope and content. The terms used for searching include ‘Malaria in South Africa’, ‘Articles from South Africa on Malaria’, and ‘Malaria + South Africa’. This was further streamlined by using definite words such as ‘Models’ ‘Geographic Information Systems’ and ‘remote sensing’ combined with ‘malaria and South Africa’. Short communications, letters and updates on general malaria control were excluded from the search. The search was limited to peer-reviewed papers published from 1997 to 2012 in South Africa.

Figure 1: Official malaria risk map for South Africa, 2013 (MRC).

Source: SA National Department of Health.

Figure 2: Multi-annual reported malaria cases and deaths spanning the period 1997–2012 in South Africa.

In summary, the use of models — whether statistical, mathematical or a combination — has been minimal in SA. This is in comparison with the proportion of the number of publications related to malaria research in other sub-Saharan African countries where malaria is endemic. For instance, works using models for malaria research have been published for southern Africa. Results of the search revealed that SAMJ articles were also included in the PubMed database and this made the search more comprehensive. In all, five articles were found relating directly to the use of models, five articles relating to GIS and almost none were found on the use RS for malaria study in SA except for the Malarea project.

Models and malaria study in South Africa

Results from models can offer valuable information that can enhance decision-making on subjects such as determining the potential effectiveness of combining control strategies; selecting areas for prompt interventions (hot spots); forestalling the effects of introducing new interventions; predicting malaria resurgence; and informing on how malaria can be monitored to enhance its control. The use of models has long been applied to malaria control. For example, Sir Ronald Ross is the particular pioneer of malaria modelling. He developed the classical ‘Ross model’ to study the transmission of malaria between mosquitoes and humans. In past years, several efforts have been undertaken by various researchers to modify the Ross model in order to cater for the different compartments of malaria ranging from its transmission to its environmental and socio-economic factors. In particular, the transmission of malaria has been modelled, while the socio-economic factors such as human and mosquito population dynamics have been incorporated and the environmental factors have been modelled.

Table 1 summarises publications on the use of models for malaria study in SA. The generalised linear mixed model was used to spatially analyse malaria incidence rates in the population of the northernmost districts of Kwa-Zulu Natal during the period 1994 and 1995. The results of the model indicated that there was a significant positive linear relationship between malaria incidence and higher winter rainfall; and a negative relationship between high average maximum temperature and increasing distance from water bodies. In 2002, the Bayesian statistical model was used to examine the spatial and temporal variations in malaria incidence rates for two districts in northern Kwa-Zulu Natal between 1986 and 1999. The results suggested an uneven increase in the spatial distribution of malaria incidence. Additionally, a model was developed to determine the cost implication of exchanging chloroquine for sulfadoxine-pyrimethamine as first-line treatment in Mpumalanga.

This model suggested that sulfadoxine-pyrimethamine was found to be 4.8 times more cost-effective than chloroquine in the study area. In 2009, the SaTScan method was employed to detect local malaria clusters for guiding malaria control programmes in Mpumalanga. The results of the model indicated that there is a strong relationship between the identified local clustering of cases and reported malaria outbreaks in certain areas of Mpumalanga. Furthermore, the simple linear regression model was developed to analyse seasonal malaria case totals and seasonal changes against climatic factors acquired from three weather stations in Kwa-Zulu Natal. While the study discovered inter-annual variability in malaria incidence across the study area, the link between malaria cases and climatic data was not evident.

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Malawi,22−26, for Botswana,27−29 and for Mali.30,31 Also, the existing models do not integrate other important malaria transmission factors such as environmental, social and economic factors as they are principally based on modelling the rate of malaria transmission. As has been reported,18 a single model might not be capable of integrating all the factors, but a combination of more than one factor will be more functional. Even though the models have shortcomings, their results can be useful in providing information for policy-makers and academic researchers towards an effective framework for malaria control and its eradication. Therefore, there is a need for the development of more robust (perhaps coupled) models that could be used for effective control and elimination of malaria in SA.

**Geographic information systems and malaria study in South Africa**

The spatio-temporal dynamics of malaria and other environmental related diseases can be quantitatively analysed using GIS. A GIS is a tool that allows for the superimposition, analysis, manipulation, storage, retrieval and display of datasets from various sources. The spatial modelling tool embedded in GIS can be used in understanding the spatial variability of the disease, the interaction of the disease causal organisms and the environment as well as other contributing factors.32 Timely information on the epidemiology of the disease and other causal factors is essential to the public health practitioners. This could potentially enhance prompt and effective disease control measures, which can be provided for through the use of GIS and potentially enhance prompt and effective disease control.

The use of GIS for malaria studies in Africa has been acknowledged in the literature. For example, GIS was used for malaria study in Africa in a collaborative project called Mapping Malaria Risk in Africa/Atlas du Risque de la Malaria en Afrique (MARA/ARMA).19 The MARA/ARMA project involved the collection of malarialometric 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. Furthermore, the project focused on developing environmentally determined models that define the distribution of malaria and the duration and timing of the transmission seasons. As proved through a model, the transmission of malaria in Africa is assumed to be primarily driven by climatic factors.14 The model used a fuzzy-logic concept against rigid Boolean limits to analyse mean monthly temperature and rainfall data for a period of 60 years (i.e. 1920–1980) derived from interpolated weather station data at a spatial resolution of about 5 × 5 km. The results show degrees of climate suitability for the distribution of endemic malaria, in which a fuzzy value of one predicts endemic malaria and a fuzzy value of zero predicts highly unstable or no transmission. Other studies in Africa include the use of GIS to develop models of malaria transmission and intensity,15 the mapping of the spatial distribution of mosquito species, habitat and density,36,37 and the use of GIS as a decision support system in the control of malaria.38

The use of GIS technology for malaria control studies in SA dates back to 1990 when a GIS was created in two Northern magisterial districts of Kwa-Zulu-Natal province (Ingwavuma and Ubombo) by the Malaria Research Programme (MRP). The project primarily created a relational database, which incorporated population data, malaria cases, tribal affiliation, clinics, schools, shops, nature camps, churches, etc. through the use of a global positioning system (GPS). Distribution maps of malaria incidence at sub-district and village level were generated from the database. The MARA/ARMA project in 1998 was substantially implemented by malaria researchers from SA. This represented an era of the foremost use of GIS for malaria studies in SA and served as a model for other African countries.38 The use of GIS in South Africa was taken a step further in 1999 when MRP established a Health
GIS Centre in the South African Medical Research Council (MRC). The overall aim of introducing GIS application was to formalise the facility and to extend its support to other research areas of the MRC and to encourage the use of GIS within the health sector in the southern African region.43

Results of the literature search conducted in this study showed that the first cited paper on the use of GIS for malaria studies in SA is traced to the work by Le Sueur et al.44 The study presented a malaria information system (MIS) that integrates the use of GPS and GIS technology for the KwaZulu-Natal province based on the infrastructure provided by the MRP. With the use of the MIS, breeding habitats were mapped against human population distribution data. This informed a prompt intervention programme (distribution of bed nets and indoor residual spraying, IRS). In addition, the MIS was used to assess the proximity of the population at risk to health facilities such as clinics and hospitals. In 1997, a GIS-based information system was developed to evaluate the spatial heterogeneity of malaria transmission and its implications for control strategies and research.45 The study, which was an extension of the work of Le Sueur et al.,46 is a system that houses a spatial rural database derived from existing health service activities, and demographic and health information. In a follow-up to previous work,47 at a conference on multilateral initiatives on malaria in Durban in 1999, a paper was presented titled ‘Computer assisted health information system for malaria control’. The paper recapitulated the advantages of using GIS for malaria control in South Africa. As published in the bulletin of the WHO in 2000, Booman et al.48 demonstrated the extended MIS from Le Sueur et al.44 in Mpumalanga province of South Africa. Malaria cases and other related information were gathered using a simplified notification form. The authors implemented GIS for Mpumalanga by using Microsoft Access to create a relational database in which malaria cases, demographic data and other spatial datasets with their attributes were captured. MapInfo software (MapInfo Corporation, New York, USA) was used as the GIS platform. The system was able to display malaria cases at town or village level thereby allowing the stratification of malaria risk within the districts of Barberton and Nkomazi. The overall result indicates that GIS is a reliable tool for more efficient malaria control within the study area. In Martin et al.49 the novel development and application of a GIS-based malaria information system for research and control of malaria in SA is discussed. The system, which is a collaborative effort between a malaria research programme and a malaria control programme, was developed to capture, store, analyse, retrieve and display malaria data for proper quantification, monitoring and control. Furthermore, Booman et al.50 developed a GIS-based computerised management system for Maputo province in Mozambique. This is an extension of Martin et al.49 as a result of the successful implementation of the GIS-based computerised system in Mpumalanga and Kwa-Zulu Natal provinces of SA. The system was designed to help in effective insecticide spraying coverage over the study area. Table 2 gives a summary of some of the characteristics of the papers in peer-reviewed publications that discuss the application of GIS in malaria research.

In summary, since the recommendation for the use of GIS as the future direction towards malaria control in SA in 1996,4 an increased number of studies have been done employing the use of GIS for malaria studies compared with other sub-Saharan African countries where malaria is endemic.51−53 This could, however, be due to some shortcomings of GIS applications in disease studies for instance, scarcity of skilled or trained GIS personnel, the high costs involved in implementing a GIS project and acquiring proprietary software, as well as hardware among others. However, GIS provides a handful of advantages despite its criticism.54 The capability of GIS to integrate datasets from various sources and the ability to analyse a large volume of data makes it a useful tool. In addition, the manipulative and modelling techniques embedded in the application and other add-ins/toolboxes are of advantage particularly in Africa where there is lack of reliable statistics for diseases. GIS can be used to fill gaps for missing data and, as a result, GIS technology provides a good platform to enhance the control and elimination of malaria. More importantly, it can in addition be used to implement an early warning system.

Remote sensing and malaria study in South Africa

RS is defined as the acquisition of information on an object or phenomenon without direct or physical contact with it.55 For instance, electromagnetic radiation reflected or emitted by the Earth's surface can be recorded by sensors on board satellites. Since the launch of Landsat-1 41 years ago and other satellite sensors such as Terra (ASTER and MODIS) in 1999, NOAA-M (AVHRR) in 2002, Radarsat-1 (SAR) in 1995 and Meteosat-7 (VISSR) in 1997, the use of remotely sensed data to map and monitor the Earth's surface features has been on the increase.56

In the past 30 years, a number of studies using RS data for disease surveillance, monitoring and mapping have increased in general and in particular in terms of malaria studies.57−59 These studies have contributed towards a better understanding of malaria vector ecology. The rapid increase in the use of RS data can partly be attributed to the declaration of free usage of Landsat data in 2008. In particular, RS can be used for epidemiological studies due to the link many diseases have with certain environmental features.57,60 Environmental factors such as land use and land cover, land surface temperature (LST), rainfall, vegetation and elevation can affect the spread of diseases associated with environmental conditions.51 Some factors, such as the transmission parameters, can be extracted indirectly from RS data.52 For example, RS derived environmental variables, such as the normalised difference vegetation index (NDVI), the enhanced vegetation index (EVI), and LST, have been used to monitor and develop a risk map for vector-borne disease.53 Additionally, precipitation, LST and vegetation indices derived from RS have been shown to be beneficial for the early detection and prediction of malaria and are thus vital for malaria control.64,65 The RS data offer advantages such as large area coverage simultaneously, and also allow for spatially complete and almost continuous characterisation of the Earth's surface.66

However, in spite of the 30 years of research and the advantages offered by the use of RS in malaria control as demonstrated in various studies in countries where malaria is endemic in sub-Saharan Africa, the use of RS technology is greatly lacking in SA. According to the search results from both the PubMed and SAMJ databases based on a string of keywords such as ‘Remote Sensing and Malaria in South Africa,’ ‘Malaria and Remote Sensing in South Africa’ and ‘Remote Sensing in South Africa’, no record of studies was found directly linking the use of RS for malaria study in South Africa. Although RS has been applied to other fields of study like land degradation,67 vegetation analysis68 and early warnings of fire,69,70 the use of RS in general appeared to be low in SA compared with other countries.

Downloaded by [University of Pretoria] at 01:02 11 November 2015
The closest malaria research done using RS in South Africa is the Malareo: Earth Observation (EO) in the Malaria Vector Control and Management project. The project was a collaboration effort by EUROSENSE Belfotop nv (Belgium), the South African Medical Research Council (South Africa), the Ministry of Health (Swaziland), Remote Sensing Solutions GmbH (Germany), the University of Kwa-Zulu-Natal (South Africa) and the Swiss Tropic and Public Health Institute (Switzerland). The overall objective of the project was through the use of RS data from Geo-Eye (2010), RapidEye (2011), MODIS and NOAA-CPC to build GIS, RS and spatial statistics capacities and implement the use of EO products within the malaria vector control and management programmes in southern Africa. The project set out to map and identify mosquito breeding habitats from the selected satellite images and perform spatial analysis towards the control of malaria within the focus area.

In summary, this finding coincided with the review of research literature carried out by Mabaso and Ndlovu, although was not directly focused on the use of models, GIS or RS but on climate-driven malaria epidemics in sub-Saharan Africa. As shown in Figure 3, the authors discovered that Kenya had the highest number of publications, closely followed by Ethiopia and Uganda, while SA had a relatively low publication rate and Sahel had none.

The paper concluded that the high number of publications from East Africa can be credited to the reappearance of highland malaria epidemics, which drew the attention of the political sector and stirred research interest. On the other hand, the lower number of publications in SA and other Southern regions can be attributed to challenges related to technical and practical ability. These may include gaps in policies, institutional practices, research interest and capacity among others.

### Future research direction on malaria: Malaria Early Warning System (MEWS)

This is a system that allows the integration of datasets like historical case data, environmental and meteorological data in a modelling form for early detection, prediction and forecasting of malaria. The World Health Organization (WHO) Roll Back Malaria campaign had proposed the development of operational MEWS for prompt detection, prevention and control of malaria epidemics. This is a sequel to the outcome of the Abuja Declaration, which requires that 60% of epidemics should be detected within two weeks of inception and contained within two weeks of detection. To attain these goals, health professionals and programme managers need reliable information on where (location), when (time) and how (magnitudes) epidemics are likely to occur. An effective MEWS can help provide public health decision-makers with warnings of an epidemic several months in advance by helping to prioritise limited resources to the most vulnerable areas and inform a prompt response. As stated and proven in the literature, the distribution of mosquitoes and subsequent transmission of malaria in sub-Saharan Africa is climate-driven. A major approach to develop a MEWS is to use mathematical or statistical models with historical malaria cases and environmental risk indicators. This will help to establish the links between meteorological and environmental variables, malaria cases and possibly the behaviour of mosquitoes. The advantage of a wide spatial range and consistent temporal data from Earth-observing sensors provides a source of environmental data that can be used as surrogate data for the development of epidemiological forecasting models. Many attempts have been made to develop and implement functional climate-driven MEWS across Africa, for instance in Kenya, and Ethiopia among other malaria-endemic countries. The attempt has been minimal in SA where there is no functional MEWS. Although, in 2011, an operational malaria outbreak identification and response system was

### Table 2: Summary of publications on the use of GIS for malaria study in South Africa

<table>
<thead>
<tr>
<th>Authors</th>
<th>Malaria data</th>
<th>Other data</th>
<th>Methods</th>
<th>Main findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Le Sueur et al.</td>
<td>On-site cases</td>
<td>Clinic, water body, school</td>
<td>GPS, spatial analysis</td>
<td>Spatial distribution of malaria cases coincided with water body. Also there is an association between agricultural development such as irrigation and malaria cases at the micro-level of the study. GIS can be used to produce risk maps at different spatial scales for effective malaria control</td>
</tr>
<tr>
<td>Le Sueur et al.</td>
<td>Cases from archive</td>
<td>Human population, road, water body, school</td>
<td>GPS, spatial analysis</td>
<td>Risk maps of malaria prevalence were generated. MIS is reliable to inform proper planning for effective control of malaria</td>
</tr>
<tr>
<td>Sharp et al.</td>
<td>Cases from archive</td>
<td>Human population</td>
<td>Spatial analysis</td>
<td>The uses of a computer with relevant tools like GIS are reliable for effective malaria incidence reporting for malaria control</td>
</tr>
<tr>
<td>Booman et al.</td>
<td>Cases from archive</td>
<td>Notification form</td>
<td>GPS and spatial analysis</td>
<td>Displayed data on malaria cases at village and town level help in stratifying malaria risk. GIS helps to provide opportunity for more efficient malaria control in the study area</td>
</tr>
<tr>
<td>Martin et al.</td>
<td>Cases from archive and notification forms</td>
<td>Road, school, clinics, homestead</td>
<td>GPS, spatial analysis</td>
<td>The generated maps assist in formulating malaria insecticide and drug policies, providing appropriate information for tourists, evaluating changes in malaria transmission over time. It also helps health officials in allocating resources and informs prompt response for effective malaria control</td>
</tr>
</tbody>
</table>

**Figure 3:** Distribution of research publications on climate-driven malaria epidemics by country in sub-Saharan Africa from 1994 to 2009 as studied by [61].
developed in Mpumalanga Province, SA. The system is aimed at early detection of a malaria outbreak for a prompt response, but the system was devoid of environmental indicators. However, this can provide a framework for developing a more robust MEWS in SA.

Discussion
The review shows that there has been a moderate increase in studies related to malaria since 1902. Published literature on malaria epidemics in SA includes letters, research updates, commentaries, communiqués and reviews, with little primary research. From the output of the literature search, a total of 287 articles relevant to the current study were gathered of which 246 were found in the PubMed and the remaining 41 in the SAMJ. More than 96% (categorised as 'others') were review papers, letters, communiqués and papers on control measures such as indoor spraying, mosquito repellents, bed nets and use of drugs and study of drugs resistance (e.g. DDT, sulfadoxine-pyrimethamine, artemether-lumefantrine, and chloroquine among others). Although in the current review these control measures were not considered except for Wilkins et al.\textsuperscript{19} who used a model to estimate recurrent direct costs between chloroquine and sulfadoxine-pyrimethamine. The remaining percentages as shown in Figure 4 are distributed as follows: 0.3% RS, 1.7% models and 1.7% GIS.

The literature revealed that most studies on modelling were conducted about a decade ago, the first being developed in 2001,\textsuperscript{17} others in 2002,\textsuperscript{18,19} another in 2004\textsuperscript{21} and only one\textsuperscript{20} in 2009 (see Figure 5). This implies that efforts towards implementing effective models and their validation have been minimal. Similarly, the use of GIS for the study of malaria in SA was initiated only in 1990 through the effort of the MRC. The use of both GIS and RS tools as the future direction for malaria research in SA was echoed in 1996.\textsuperscript{5} However, minimal outputs have resulted since then considering the results from the literature search (see Table 2).\textsuperscript{41-44} Also worthy of note is that most of the reviewed articles have been authored by researchers within the medical research institutes and only a few have come from the purely academic institutes, indicating a gap between the medical researchers and their academic counterparts. Malaria information ranging from historical clinically reported malaria cases to results from laboratory analysis on mosquitoes done by medical researchers can be an added advantage to academic researchers to further improve the fight against malaria in SA.

Lastly, one limitation of this review is that by restricting the search to the literature published between 1930 and 2013, articles published prior to this date or after this date might have been omitted. Also the use of only PubMed and the SAMJ database might not give a full picture of available articles because it is possible that one or more relevant journal databases are not synchronised with PubMed. In addition, there is a possibility that initiatives, projects and research that have utilised both technologies may exist but are not in publication and as a result not captured in this review. However, the reliability of the PubMed database has been demonstrated by Mabaso and Ndlouv\textsuperscript{61} in addition to a local journal. Therefore, it is held that this work has given a good picture of what exists in SA in terms of methods used for malaria research and control.

Conclusion
The outcome from the literature review revealed that the development of a functional MEWS remains a challenge in SA. This could be partly due to the low research output on the collective use of modern technologies (i.e. GIS and RS) in malaria studies as well as minimal collaborative efforts among academic and medical research institutes. On the other hand, predictive models have been implemented to determine the association between climatic factors and malaria epidemics in Kwa-Zulu Natal; however, more research is encouraged in other endemic provinces such as Limpopo and Mpumalanga. In addition, multi-sensor satellite data that are typical of high spatial, spectral and temporal resolutions could offer valuable information for use in a GIS or RS tool. Various vegetation indices for instance, NDVI and other environmental data like LST and elevation can be extracted from satellite images and used as surrogate data to forecast an epidemic locally. The extracted data can be integrated with socio-economic factors such as migration patterns either locally or internationally. Finally, existing MEWS can potentially be considered as a framework to guide the implementation of a functional MEWS in SA.

List of abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>GIS</td>
<td>Geographic Information Systems</td>
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<td>RS</td>
<td>Remote Sensing</td>
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<td>SA</td>
<td>South Africa</td>
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<tr>
<td>NCBI</td>
<td>National Centre for Biotechnology Information</td>
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<tr>
<td>SAMJ</td>
<td>South African Medical Journal</td>
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<tr>
<td>MRP</td>
<td>Malaria Research Programme</td>
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<tr>
<td>MRC</td>
<td>Medical Research Council</td>
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<tr>
<td>GPS</td>
<td>Global Positioning System</td>
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<tr>
<td>MARA</td>
<td>Mapping Malaria Risk in Africa</td>
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<tr>
<td>LSDI</td>
<td>Lubombo Spatial Development Initiative</td>
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<tr>
<td>MIS</td>
<td>Malaria Information System</td>
</tr>
</tbody>
</table>

Figure 4: Literature search distribution of articles in South Africa (1930–2013).

Figure 5: Epochal distribution of malaria research methods in South Africa.
LST  Land Surface Temperature
NDVI  Normalised Difference Vegetation Index
EVI  Enhanced Vegetation Index
MEWS  Malaria Early Warning System

Authors Contribution
AAM, BOJ and OJM conceived the research idea and also participated in the revision of the manuscript, RCJ, NFW and MP were primarily responsible for the revision of the manuscript. KAM, TLP, AOM and SAA were involved in data collection, analysis and interpretation and revised the manuscript. AAM 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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