Investigating the resurgence of malaria prevalence in South Africa between 2015 and 2018: A scoping review

Gbenga J. Abiodun (abiodun234@gmail.com)
Southern Methodist University https://orcid.org/0000-0002-6805-2128
Babatope Adebiyi
University of Cape Town Chancellor Oppenheimer Library
Rita O. Abiodun
University of the Western Cape
Olanrewaju Oladimeji
University of Namibia
Kelechi Oladimeji
Fort Hare University
Abiodun M. Adeola
South African Weather Service
Olusola S. Makinde
Federal University of Technology Akure
Kazeem O. Okosun
Vaal University of Technology
Ramsès Djidjou-Demasse
MIVEGEC, IRD, CNRS, University Montpellier
Vyes J. Semegni
North West University
Kevin Y. Njabo
University of California Los Angeles
Peter J. Witbooi
University of the Western Cape
Alejandro Aceves
Southern Methodist University

Research article

Keywords: malaria resurgence; climate change; South Africa;

Posted Date: October 14th, 2019

DOI: https://doi.org/10.21203/rs.2.16007/v1

Abstract

Background Malaria remains a serious concern in most African countries, causing nearly one million deaths globally every year. The review aims to examine the extent and nature of the resurgence of malaria prevalence in South Africa.Method Using the Arksey and O'Malley framework, this scoping review included articles published between the year 2015 and 2018 on the resurgence of malaria prevalence in South Africa. Articles were searched from October 2018 to January 2019 using these electronic databases: CINAHL, Pubmed, Science Direct and SCOPUS. Grey literature from Google Scholar was also hand searched. Key search terms and subject headings such as climate variables; climate changes; climatic factors; malaria resurgence; malaria reoccurrence, and malaria increase over epidemic regions in South Africa were used to identify relevant articles. Articles for selection and characterization were performed by three independent reviewers. Data collected were synthesized qualitatively.Results A total number of 748 studies were identified. Among these, 24 studies met the inclusion criteria. The results were grouped by factors (four main themes) that influenced the malaria resurgence: Climatic, Epidemiological, Socio-economic, and Environmental factors. Climatic factors were found to be the major factor responsible for the resurgence of malaria, as more than 55% of the selected articles were climate focused. This was followed by epidemiological, socio-economic and environmental factors, in that order. Grey literature from Google Scholar yielded no results.Conclusion This study shows that malaria transmission in South Africa is more associated with climate. Climate-based malaria models could be used as early warning systems of malaria over the epidemic regions in South Africa. Since epidemiological factors also play significant roles in the transmission, regular and unrelaxed use of indoor residual spraying (IRS) should be encouraged in these regions. While some studies have indicated that vectors have developed resistance to insecticides, continuous research on developing new insecticides that could alter the resistance are ongoing. Individuals should also be educated on the importance and the usefulness of these deliveries. Furthermore, all efforts to eradicate malaria in South Africa must also target the epidemic neighbouring countries.

Background

Malaria continues to be a major threat in most African countries, claiming a significant number of lives every year [1]. Although, its burden has declined recently in sub-Saharan countries due to improvement in prevention, diagnosis, and treatment [1, 2], the region still carries the largest share of the global malaria burden[1]. In South Africa, malaria is mainly found in three epidemic provinces, namely; Limpopo, Mpumalanga and KwaZulu-Natal [3, 4]. The vector mainly responsible for malaria transmission in South Africa is the female *Anopheles* mosquito species (*An. arabiensis* and *An. funestus*), caused by *Plasmodium falciparum* [3, 4]. Malaria transmission over the region is seasonal, with the greatest risk between September and May, and peaks in January and April [3]. As part of the Malaria Elimination Strategic Plan (MESP), South Africa, together with a few African countries have been working towards eradication of malaria since the major outbreak in 2000 across all the epidemic provinces [3, 4]. Several control activities and interventions have been put in place across the endemic provinces. For instance, efforts are currently ongoing to increase the coverage of indoor residual spraying (IRS) to over 85%, to successful control of vectors (*An. funestus* near zero and low density of *An. arabiensis*), annually train spray teams, and so on [3, 4]. Although, these activities significantly reduced malaria transmission in 2004 through 2014. The nation recently experienced a noticeable resurgence between 2015 and 2018 across the three epidemic provinces [5-8].

The recent resurgence initiated several studies to investigate the possible factors influencing malaria transmission over the nation. It has been established that malaria parasites being transmitted by mosquitoes are very sensitive to climatic conditions [9-12]. Consequently, the resulting epidemics is strongly dependent on climate variability. Also, since mosquitoes thrive better in a warm moist environments, there is a big concern that the projected global warming may make malaria parasites spread over more regions across the nation, thereby exposing more people to the deadly disease. [9-12]. *Anopheles arabiensis*, which is one of the main vectors of malaria in South Africa are more aggressive in summer and do not lay eggs in winter period [13, 14]. Due to climate or other factors, new malaria-transmitting mosquito species are likely to be found. For example, a new mosquito species carrying malaria parasite was recently found in South Africa in the provinces Mpumalanga and KwaZulu-Natal [15].

Other studies have linked malaria transmission in South Africa to factors other than climate. For instance, the transmission has been associated with malaria-drug resistance [16], mosquito resistance to insecticides [17] and socio-economic factors [18]. The current study aims to establish the major factor responsible for the recent malaria resurgence in South Africa between 2015 and 2018.

Methods

In this study, the Arksey and O'Malley (2005) framework for conducting scoping reviews was adopted [2]. This framework was considered appropriate for the aim of our study, and has been used in other studies [19, 20].

Identifying relevant studies

The search was conducted by three (3) reviewers and using four (4) databases: CINAHL, PubMed, Science Direct, SCOPUS while grey literatures was searched from Google Scholar. Terms that described climate variables combined using the Boolean operator (e.g. climate variable and climate factors) with terms that described malaria resurgence (e.g. malaria reoccurrence) were used. An initial search using all identified keywords and index terms were undertaken across all included databases. The text words contained in the title and abstract, and of the index and medical subject heading (MeSH) terms were used to ensure that all relevant materials were captured. Secondly, the reference list of all identified articles was searched for additional studies to identify studies that could not be located through this search strategy.

After key concepts were identified and databases selected, search terms were combined with Bloom operators and searches were run in selected databases. The articles were imported to Endnote reference manager where titles and abstracts were screened and full-text articles were reviewed for eligibility based on the inclusion criteria (PICO). Grey literature search using Google Scholar with key words and search terms was also conducted. We used the "sort by relevance ranking" within Google Scholar to bring the most relevant results to the top of the list, we further set the page numbers to be screened to first ten pages of each search's results. This strategy ensures that the most relevant results are captured and also that a reasonable amount be screened. The results were further screened using the inclusion criteria for the review.

Selection of studies included

The inclusion criteria included;

- Articles focused on malaria epidemic regions in South Africa between 2015-2018.
- Phenomenon of interest/Outcome: This review focused on malaria resurgence, malaria re-occurrence or malaria increase.
- Type of study: This review considered empirical studies, but not limited to designs such as non-experimental observational study, descriptive studies and case study conducted in South Africa,
- The search included published articles from 2015-2018 in South Africa on malaria resurgence during this period.
- The search was restricted to English language papers and studies conducted in South Africa.

Extraction & charting of data from included studies

We reviewed articles for inclusion, manually extracted data from the selected articles using Microsoft Excel and summarized in a tabular form. Extracted data included: authors, article title, year of publication, study location, study population, aims of the study, methodology/instruments, outcome measure, importance of the result (see supplementary table). The table enabled identification of differences, similarities and common themes in the studies. The extracted data were synthesized and summarized and presented in a narrative summary.

Results And Discussion

The initial 534 records and 4 from other sources are highlighted (Fig. 1). After duplicates were removed 449 records were left. A further 363 records (irrelevant) were excluded based on the inclusion criteria discussed above. A total of 86 abstracts were accessed based on the PICO, of which a further 62 were excluded after full reading. A total of 24 papers were left for review and further citation search yielded no new articles.

Climatic factors

With various approaches, malaria transmission in South Africa has been linked to climatic conditions. For instance, 14 studies (58.3%) out of 24 presented in supplementary table highlighted the significant roles that climate plays on the resurgence. Although some of the 14 studies also mentioned other factors, emphasis was more on climate. Furthermore, it is noted in line with Adeola et al (2017) that climatic factors affecting malaria transmission in South Africa cannot be generalized across the epidemic regions [5]. For instance, temperature seems to be the major factor in KwaZulu-Natal province as highlighted in 4 of the 14 studies [21-24]. However, two of the four studies [21, 23] also acknowledge the importance of rainfall on malaria transmission over the province. Rainfall seems more significant on malaria resurgence in Limpopo than temperature as indicated by four other studies [5, 6, 25, 26]. Also, two of the four likewise pointed to the significance of temperature. [5, 26] In addition, Behera et al (2018) attributed malaria resurgence over the province to El Niño/La Niña and sea surface temperature (SST) from the south-western Indian Ocean [26]. We found only three studies [5, 8, 27] linking the resurgence to climate in Mpumalanga province over the study period. Kapwata and Gebreselassie (2016) and Adeola et al (2017) believe that transmission over the province is associated with surface land temperature and other non-climatic factors [5, 27], while Abiodun et al (2018c) found that rainfall and relative humidity are more significant [8].

Similar findings were established over some South African neighbouring countries such as Zimbabwe [28, 29], Mozambique [30, 31], Botswana [32] and East African highlands [33-35].

Epidemiological factors

Half of the 24 papers highlight the importance of mosquito abundance on malaria resurgence across the epidemic regions in South Africa [5, 8, 15, 21, 22-24, 36-40]. For example, using climate-based mathematical models, the impact of mosquito (mainly *An. arabiensis*) population dynamics on malaria transmission was investigated over KwaZulu-Natal [21, 22, 24, 36, 39]. Limpopo[24] and Mpumalanga provinces [8]. With statistical approach, other studies confirm mosquitos' impact on the resurgence [5, 38, 40]. More importantly, the resurgence has been traced to arrival of new mosquito species across the epidemic regions [15].

Similarly, the importance of mosquito abundance on malaria transmission has been investigated in Zimbabwe [41, 42], Mozambique [43, 44] and Namibia [45].

Soci-economic factors

Six (25%) out of the 24 selected studies have connected malaria resurgence in South Africa with socio-economy factors [6, 37, 46-49]. For instance, it has been established that migration from neighbouring countries were found to be the cause of malaria over Limpopo [6] and KwaZulu-Natal provinces [37]. Most researchers and stakeholders working on malaria in South Africa believe that South Africa's 2018 malaria elimination target was not realistic due to lack of new tools, resources and the capacity to fight malaria; coupled with poor cross-border collaborations; overreliance on partners to implement; poor community involvement; and poor surveillance [46, 47]. Inadequate communication channels on malaria control, such as Sterile Insect Technique (SIT) also play significant roles on malaria transmission [49]. Practicing animal husbandry, residing in household structures that had not been sprayed were greatly found to be associated with malaria infection over KwaZulu-Natal province [37]. It has also been established that the odds of malaria infection are lower in modern, improved housing compared to traditional housing in sub-Sahara Africa [48].

The impacts of socio-economic factors on malaria transmission have also been highlighted in Malawi [50] Gambia [51] and Ghana [52].

Environmental factors

Four studies (16.7%) linked the resurgence to environmental factors. The resurgence in Mpumalanga province has been associated with normalized difference vegetation index (NDVI) [5, 53] normalized difference water index (NDWI), altitude, water body and irrigated land [5, 54]. Malahlela et al (2018) concluded that the resurgence in Limpopo province is traceable to vegetation moisture and vegetation greenness. We found no study in this regard over KwaZulu-Natal within the study period [38].

Environmental factors such as vegetation index, water body, among others have been similarly linked to malaria incidence in Kenya [55], Zimbabwe [56, 57], Botswana [12] and Eritrea [58].

In general, climate variables play major roles in malaria transmission across all the epidemic provinces. For instance, four of the papers suggested that both temperature and rainfall are equally responsible for the transmission in KwaZulu-Natal, while two suggested similar findings over Limpopo. However, three additional papers concluded that the impact of temperature on the transmission is more significant than that of rainfall on KwaZulu-Natal and Mpumalanga provinces. This implies that effect of temperature is more pronounced over the two provinces. Rainfall is seen to be more significant than temperature over Limpopo province.

Conclusions And Recommendations

The inclusion criteria above show that climate variables (mainly, rainfall, temperature and relative humidity) are mostly mentioned but not solely responsible for the malaria resurgence in all the epidemic regions in South Africa. Environmental and socio-economic factors are also mentioned as vital elements to be considered in order to understand the dynamics of malaria transmission. Consequently, some preventive measures and interventions are suggested to minimize and gradually eradicate malaria from these regions.

Therefore, malaria models that integrate all variables could be used to monitor the progression of malaria and assist in intervention and prevention efforts with respect to malaria. These models could be implemented for developing methodology necessary to detect malaria pathogen, vector and habitat preference. More importantly, climate-based malaria models should be used as a framework for strengthening the institutional capacity of malaria surveillance by providing a malaria-risk management based on climate information and early warning system.

Regular and unrelaxed use of indoor residual spraying (IRS) should be encouraged in these epidemic regions. Sufficient insecticides-impregnated bed nets should also be supplied to the communities in these regions, and more importantly, individuals should be educated on the importance and the usefulness of these deliveries.

Furthermore, since it has been established that most malaria cases found in South Africa are imported from neighbouring countries [6], it is important to strengthen cross-border control of malaria to minimize its spread. All goals to eliminate malaria in South Africa must also target the epidemic neighbouring countries.

Declarations

Acknowledgements. We would like to thank the Expert Advisory Panel and Systematic Review Team for their guidance and assistance in the completion of this systematic review.

Contributors. All authors made substantial contributions to study design, including development of systematic review procedures. GJA, BA and ROA conducted the literature search and data extraction and independently assessed the methodological quality of included studies and conducted analysis. OO, KO, AMA and VJS adjudicated in any disagreements in methodological quality assessments and contributed to analysis. GJA, BA, ROA, OSM and RDD drafted the original manuscript while KOO, KYN, PJW and AA critically reviewed the manuscript for important intellectual content. All authors have given approval of this final version to be published and agree to be accountable for all aspects of the work.

Competing interests. None declared.

References

1. WHO, 2018. World Malaria Report: World Health Organization https://www.who.int/malaria/publications/world-malaria-report-2018/en/
2. O'Meara, W.P., Mangeni, J.N., Steketee, R. and Greenwood, B., 2010. Changes in the burden of malaria in sub-Saharan Africa. *The Lancet infectious diseases*, *10*(8), pp.545-555.
3. South African Malaria Elimination Strategic Plan (SAMESP, 2012) http://www.ccoat.uct.ac.za/sites/default/files/image_tool/images/229/SA%20Malaria%20Elimination%20Strategic%20Plan%20%202012.pdf
4. National Department of Health (NDoH) - Annual Report 2018.http://www.health.gov.za/index.php/2014-08-15-12-56-31?download=2924:annual-report-2018
5. Adeola, A.M., Olwoch, J.M., Botai, J.O., Rautenbach, C.D., Kalumba, A.M., Tsela, P.L., Adisa, O.M. and Nsubuga, F.W.N. (2017) 'Landsat satellite derived environmental metric for mapping mosquitoes breeding habitats in the Nkomazi municipality, Mpumalanga Province, South Africa', *South African Geographical Journal*, *99*(1), pp.14-28.
6. Ikeda, T., Behera, S.K., Morioka, Y., Minakawa, N., Hashizume, M., Tsuzuki, A., Maharaj, R. and Kruger, P. (2017) 'Seasonally lagged effects of climatic factors on malaria incidence in South Africa', *Scientific reports*, *7*(1), pp.2458.
7. National Institute for Communicable Diseases (NICD), Update, 2017, http://www.nicd.ac.za/wp-content/uploads/ 2017/05/Malaria-update.pdf
8. Abiodun, G.J., Njabo, K.Y., Witbooi, P.J., Adeola, A.M., Fuller, T.L., Okosun, K.O., Makinde, O.S. and Botai, J.O. (2018c) 'Exploring the Influence of Daily Climate Variables on Malaria Transmission and Abundance of Anopheles arabiensis over Nkomazi Local Municipality, Mpumalanga Province, South Africa. *Journal of environmental and public health*', Article ID 3143950.
9. Craig, M.H., Snow, R.W. and le Sueur, D., 1999. A climate-based distribution model of malaria transmission in sub-Saharan Africa. *Parasitology today*, *15*(3), pp.105-111.
10. Coetzee, M., Craig, M. and Le Sueur, D., 2000. Distribution of African malaria mosquitoes belonging to the Anopheles gambiae complex. *Parasitology today*, *16*(2), pp.74-77.
11. Tanser, F.C., Sharp, B. and Le Sueur, D., 2003. Potential effect of climate change on malaria transmission in Africa. *The Lancet*, *362*(9398), pp.1792-1798.
12. Craig, M.H., Sharp, B.L., Mabaso, M.L. and Kleinschmidt, I., 2007. Developing a spatial-statistical model and map of historical malaria prevalence in Botswana using a staged variable selection procedure. *International Journal of Health Geographics*, *6*(1), p.44.
13. le Sueur D, Sharp BL. The breeding requirements of three members of the Anopheles gambiae Giles complex (Diptera: Culicidae) in the endemic malaria area of Natal South Africa. Bull Entomol Res. 1999;78:549–60.
14. Maharaj R. Life table characteristics of Anopheles arabiensis (Diptera: Culicidae) under simulated seasonal conditions. J Med Entomol. 2003;40:737–42.
15. Burke, A., Dandalo, L., Munhenga, G., Dahan-Moss, Y., Mbokazi, F., Ngxongo, S., Coetzee, M., Koekemoer, L. and Brooke, B. (2017) 'A new malaria vector mosquito in South Africa', *Scientific Reports*, *7*, p.43779.
16. Barnes, K.I., Durrheim, D.N., Little, F., Jackson, A., Mehta, U., Allen, E., Dlamini, S.S., Tsoka, J., Bredenkamp, B., Mthembu, D.J. and White, N.J., 2005. Effect of artemether-lumefantrine policy and improved vector control on malaria burden in KwaZulu–Natal, South Africa. *PLoS medicine*, *2*(11), p.e330.
17. Hargreaves, K., Koekemoer, L.L., Brooke, B.D., Hunt, R.H., Mthembu, J. and Coetzee, M., 2000. Anopheles funestus resistant to pyrethroid insecticides in South Africa. *Medical and veterinary entomology*, *14*(2), pp.181-189.
18. Govere, J., Durrheim, D., la Grange, K., Mabuza, A. and Booman, M., 2000. Community knowledge and perceptions about malaria and practices influencing malaria control in Mpumalanga Province, South Africa. *South African medical journal*, *90*(6), pp.611-618.
19. Puts, M.T.E., Toubasi, S., Andrew, M.K., Ashe, M.C., Ploeg, J., Atkinson, E., Ayala, A.P., Roy, A., Rodríguez Monforte, M., Bergman, H. and McGilton, K., 2017. Interventions to prevent or reduce the level of frailty in community-dwelling older adults: a scoping review of the literature and international policies. *Age and ageing*, *46*(3), pp.383-392.
20. Adebiyi, B.O., Mukumbang, F.C., Cloete, L.G. and Beytell, A.M., 2018. Exploring service providers' perspectives on the prevention and management of fetal alcohol spectrum disorders in South Africa: a qualitative study. *BMC public health*, *18*(1), p.1238.

21. Okuneye, K., Abdelrazec, A. and Gumel, A.B., 2018. Mathematical analysis of a weather-driven model for the population ecology of mosquitoes. *Mathematical Biosciences & Engineering*, *15*(1), pp.57-93.
22. Abiodun, G.J., Maharaj, R., Witbooi, P. and Okosun, K.O. (2016) 'Modelling the influence of temperature and rainfall on the population dynamics of Anopheles arabiensis', *Malaria journal*, *15*(1), p.364.
23. Abiodun, G.J., Witbooi, P. and Okosun, K.O., 2018a. Modelling the impact of climatic variables on malaria transmission. *Hacettepe Journal of Mathematics and Statistics*, *47*(2), pp.219-235.
24. Abiodun, G.J., Witbooi, P.J., Okosun, K.O. and Maharaj, R., 2018b. Exploring the impact of climate variability on malaria transmission using a dynamic mosquito-human malaria model. *The Open Infectious Diseases Journal*, *10*(1).
25. Komen, K., Olwoch, J., Rautenbach, H., Botai, J. and Adebayo, A., 2015 'Long-run relative importance of temperature as the main driver to malaria transmission in Limpopo Province, South Africa: A simple econometric approach', *EcoHealth*, *12*(1), pp.131-143.
26. Behera, S.K., Morioka, Y., Ikeda, T., Doi, T., Ratnam, J.V., Nonaka, M., Tsuzuki, A., Imai, C., Kim, Y., Hashizume, M. and Iwami, S., 2018 'Malaria incidences in South Africa linked to a climate mode in southwestern Indian Ocean', *Environmental development*, *27*, pp.47-57.
27. Kapwata, T. and Gebreslasie, M.T., 2016 'Random forest variable selection in spatial malaria transmission modelling in Mpumalanga Province, South Africa', *Geospatial health*, *11*(3).
28. Ebi, K.L., Hartman, J., Chan, N., Mcconnell, J., Schlesinger, M. and Weyant, J., 2005. Climate suitability for stable malaria transmission in Zimbabwe under different climate change scenarios. *Climatic Change*, *73*(3), p.375.
29. Mabaso, M.L., Vounatsou, P., Midzi, S., Da Silva, J. and Smith, T., 2006. Spatio-temporal analysis of the role of climate in inter-annual variation of malaria incidence in Zimbabwe. *International Journal of Health Geographics*, *5*(1), p.20.
30. Abellana, R., Ascaso, C., Aponte, J., Saute, F., Nhalungo, D., Nhacolo, A. and Alonso, P., 2008. Spatio-seasonal modeling of the incidence rate of malaria in Mozambique. *Malaria Journal*, *7*(1), p.228.
31. Zacarias, O.P. and Andersson, M., 2011. Spatial and temporal patterns of malaria incidence in Mozambique. *Malaria journal*, *10*(1), p.189.
32. Thomson, M.C., Mason, S.J., Phindela, T. and Connor, S.J., 2005. Use of rainfall and sea surface temperature monitoring for malaria early warning in Botswana. *The American journal of tropical medicine and hygiene*, *73*(1), pp.214-221.
33. Hay, S.I., Cox, J., Rogers, D.J., Randolph, S.E., Stern, D.I., Shanks, G.D., Myers, M.F. and Snow, R.W., 2002. Climate change and the resurgence of malaria in the East African highlands. *Nature*, *415*(6874), p.905.
34. Zhou, G., Minakawa, N., Githeko, A.K. and Yan, G., 2004. Association between climate variability and malaria epidemics in the East African highlands. *Proceedings of the National Academy of Sciences*, *101*(8), pp.2375-2380.
35. Omumbo, J.A., Lyon, B., Waweru, S.M., Connor, S.J. and Thomson, M.C., 2011. Raised temperatures over the Kericho tea estates: revisiting the climate in the East African highlands malaria debate. *Malaria Journal*, *10*(1), p.12.
36. Agusto, F.B., Gumel, A.B. and Parham, P.E., 2015. Qualitative assessment of the role of temperature variations on malaria transmission dynamics. *Journal of Biological Systems*, *23*(04), p.1550030.
37. Mutegeki, E., Chimbari, M.J. and Mukaratirwa, S., 2017. Assessment of individual and household malaria risk factors among women in a South African village. *Acta tropica*, *175*, pp.71-77.
38. Malahlela, O.E., Olwoch, J.M. and Adjorlolo, C., 2018 'Evaluating Efficacy of Landsat-Derived Environmental Covariates for Predicting Malaria Distribution in Rural Villages of Vhembe District, South Africa', *EcoHealth*, *15*(1), pp.23-40.
39. Abiodun, G.J., Witbooi, P. and Okosun, K.O., 2017. Modelling and analyzing the impact of temperature and rainfall on mosquito population dynamics over Kwazulu-Natal, South Africa. *International Journal of Biomathematics*, *10*(04), p.1750055.
40. Davies, C., Coetzee, M. and Lyons, C.L., 2016. Effect of stable and fluctuating temperatures on the life history traits of Anopheles arabiensis and An. quadriannulatus under conditions of inter-and intra-specific competition. *Parasites & vectors*, *9*(1), p.342.
41. Lukwa, N., Nyazema, N.Z., Curtis, C.F., Mwaiko, G.L. and Chandiwana, S.K., 1999. People's perceptions about malaria transmission and control using mosquito repellent plants in a locality in Zimbabwe. *The Central African journal of medicine*, *45*(3), pp.64-68.
42. Munhenga, G., Masendu, H.T., Brooke, B.D., Hunt, R.H. and Koekemoer, L.K., 2008. Pyrethroid resistance in the major malaria vector Anopheles arabiensis from Gwave, a malaria-endemic area in Zimbabwe. *Malaria Journal*, *7*(1), p.247.
43. Mendis, C., Jacobsen, J.L., Gamage-Mendis, A., Bule, E., Dgedge, M., Thompson, R., Cuamba, N., Barreto, J., Begtrup, K., Sinden, R.E. and Høgh, B., 2000. Anopheles arabiensis and An. funestus are equally important vectors of malaria in Matola coastal suburb of Maputo, southern Mozambique. *Medical and veterinary entomology*, *14*(2), pp.171-180.
44. Munguambe, K., Pool, R., Montgomery, C., Bavo, C., Nhacolo, A., Fiosse, L., Sacoor, C., Nhalungo, D., Mabunda, S., Macete, E. and Alonso, P., 2011. What drives community adherence to indoor residual spraying (IRS) against malaria in Manhiça district, rural Mozambique: a qualitative study. *Malaria journal*, *10*(1), p.344.
45. Chanda, E., Ameneshewa, B., Angula, H.A., Iitula, I., Uusiku, P., Trune, D., Islam, Q.M. and Govere, J.M., 2015. Strengthening tactical planning and operational frameworks for vector control: the roadmap for malaria elimination in Namibia. *Malaria journal*, *14*(1), p.302.

46. Hlongwana, K.W. and Tsoka-Gwegweni, J., 2016. From malaria control to elimination in South Africa: The researchers' perspectives. *African journal of primary health care & family medicine*, *8*(1).
47. Hlongwana, K.W. and Tsoka-Gwegweni, J., 2017. Towards the implementation of malaria elimination policy in South Africa: the stakeholders' perspectives. *Global health action*, *10*(1), p.1288954.
48. Tusting, L.S., Bottomley, C., Gibson, H., Kleinschmidt, I., Tatem, A.J., Lindsay, S.W. and Gething, P.W., 2017. Housing improvements and malaria risk in sub-Saharan Africa: a multi-country analysis of survey data. *PLoS medicine*, *14*(2), p.e1002234.
49. Manana, P.N., Kuonza, L., Musekiwa, A., Mpangane, H.D. and Koekemoer, L.L., 2018. Knowledge, attitudes and practices on malaria transmission in Mamfene, KwaZulu-Natal Province, South Africa 2015. *BMC public health*, *18*(1), p.41.
50. Lowe, R., Chirombo, J. and Tompkins, A.M., 2013. Relative importance of climatic, geographic and socio-economic determinants of malaria in Malawi. *Malaria journal*, *12*(1), p.416.
51. Koram, K.A., Bennett, S., Adiamah, J.H. and Greenwood, B.M., 1995. Socio-economic risk factors for malaria in a peri-urban area of The Gambia. *Transactions of the royal society of tropical medicine and hygiene*, *89*(2), pp.146-150.
52. Biritwum, R.B., Welbeck, J. and Barnish, G., 2000. Incidence and management of malaria in two communities of different socio—economic level, in Accra, Ghana. *Annals of Tropical Medicine & Parasitology*, *94*(8), pp.771-778.
53. Kapwata, T. and Gebreslasie, M.T., 2016. Random forest variable selection in spatial malaria transmission modelling in Mpumalanga Province, South Africa. *Geospatial health*.
54. Adeola, A.M., Botai, O.J., Olwoch, J.M., Rautenbach, C.D.W., Adisa, O.M., Taiwo, O.J. and Kalumba, A.M., (2016) 'Environmental factors and population at risk of malaria in Nkomazi municipality, South Africa', *Tropical Medicine & International Health*, *21*(5), pp.675-686.
55. Patz, J.A., 1998. Predicting key malaria transmission factors, biting and entomological inoculation rates, using modelled soil moisture in Kenya. Tropical Medicine & International Health, 3(10), pp.818-827.
56. Funk, C. and Budde, M.E., 2009. Phenologically-tuned MODIS NDVI-based production anomaly estimates for Zimbabwe. *Remote Sensing of Environment*, *113*(1), pp.115-125.
57. Mabaso, M. L. H., M. Craig, P. Vounatsou, and T. Smith. "Towards empirical description of malaria seasonality in southern Africa: the example of Zimbabwe." *Tropical Medicine & International Health*10, no. 9 (2005): 909-918.
58. Ceccato, P., Ghebremeskel, T., Jaiteh, M., Graves, P.M., Levy, M., Ghebreselassie, S., Ogbamariam, A., Barnston, A.G., Bell, M., del Corral, J. and Connor, S.J., 2007. Malaria stratification, climate, and epidemic early warning in Eritrea. *The American journal of tropical medicine and hygiene*, *77*(6_Suppl), pp.61-68.

Figures

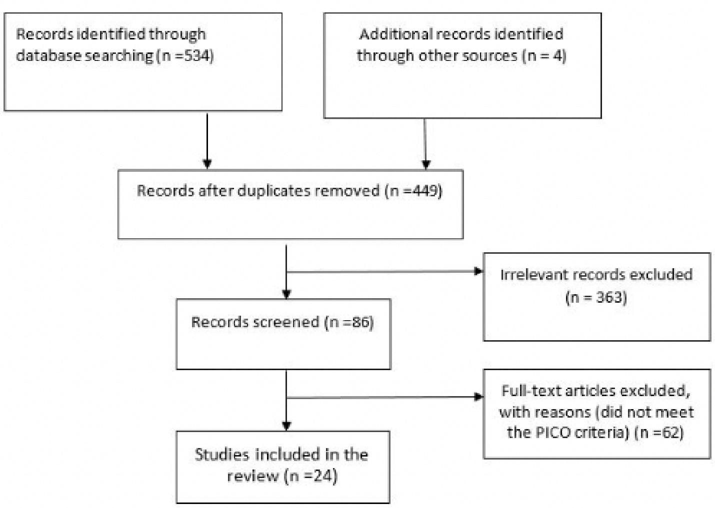

Figure 1

PRISMA flow diagram for included articles

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Supplementarytable.docx