Indo-Pacific Global Health Case Competition

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Malaria in PNG

THE UNIVERSITY OF MELBOURNE

A Race Against Resistance: Eradicating Malaria in Papua New Guinea

2024 University of Melbourne Emory team

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Disclaimer: The characters and story described within this case are fictional and serve a purely illustrative purpose. Background information reflects real data and events from Papua New Guinea. All teams are responsible for justifying the accuracy and validity of any data used in the case prompt and in their presentations.

Introduction

Ruth is at home today, feeling unwell with a headache and fever. She lives in the Enga province located in the Northern region of Papua New Guinea, which has many mountains and high-altitude valleys.

Her village was recently hit by a landslide, causing significant losses to her community; friends and family were hurt by the landslide, and many homes and critical infrastructure were destroyed. Their community has always been fairly isolated from others, making access to food, other supplies, and medical care difficult. This access has worsened significantly since the landslide with important roads blocked off. Ruth was lucky yesterday; the local health workers visited her village, even though they have been coming less frequently since the landslide. They gave her some medication for malaria and told her to rest at home. Though Ruth knows many people who have recovered from malaria, her close friend Rose recently passed away because her malaria medication did not work. Her brother David also passed away a few months ago because he could not get access to malaria medication in time to treat his disease. Ruth does not know why this happened and is scared the medication might not work for her either. She is particularly worried about what this might mean for her family.

Peter and Joseph are two infectious disease health experts currently working in Port Moresby for the WHO Western Pacific division. They have been tasked to oversee the “Malaria Free by 2030” program and are especially concerned that the recent landslide may cause an outbreak of malaria in an already vulnerable community; landslides often result in abnormal pooling of water and attraction of mosquitoes (Kekatos, 2024). Despite the best efforts of PNG over the last decade, malaria remains a major public health problem and increasing temperatures have exacerbated this problem.

Peter and Joseph have identified that inadequate health infrastructure, a shortage of skilled health workers, limited access to health services in rural areas, and inadequate funding for malaria control (thus a shortage of commodities) are some of the biggest issues they face when trying to eradicate malaria in PNG. Insecticide resistance in mosquitoes and antimalarial drug resistance are also growing concerns of theirs.

The implications of poor malarial control are profound. Treatment failures are becoming more common, leading to prolonged illness, higher transmission rates and more severe disease outcomes. This not only affects individual patients but also places a significant strain on the already limited healthcare resources in PNG. The economic burden is substantial, exacerbated by the high costs of second-line or combination therapies required to treat resistant malaria strains. The healthcare system, struggling with limited infrastructure and resources, faces additional challenges in managing drug-resistant malaria cases effectively.

An opportunity arises.

After Peter and Joseph's quarterly meeting with the head of WHO Western Pacific, they have managed to procure an extra $3 million AUD of funding to address malaria in PNG. This grant has been pledged to support a three-year project which supports innovative interventions aimed at reducing the incidence and prevalence of malaria in PNG. This aligns with the WHO’s targets to be ‘malaria free by 2030’. They are currently seeking proposals from external consultants.

You are an NGO, composed of an interdisciplinary team of public health, medical, legal, business, administrative, and research personnel who have heard about the grant through numerous colleagues. Your organisation specialises in infectious disease control and have previously worked on malaria reduction campaigns in other countries around the world. You are aware of the current situation in Papua New Guinea and believe that, in winning this grant, your team could save many lives.

Your proposal

Details of the request for proposals

- **Solution focus:** Solutions must aim to reduce the incidence and prevalence of malaria in PNG, in line with current goals to accelerate malaria elimination by 2030. Teams must identify and justify a specific and measurable metric to track this progress, highlighting immediate and ongoing impact of the intervention. The solution must be evidence-based, feasible and demonstrate a clear understanding of the local context and culture.
- **Innovation and Integration:** The chosen intervention will be one that considers existing infrastructure and initiatives, whilst also prioritising a fresh and novel solution. If building on existing initiatives, the solution must add a new facet to the program.
- **Multidisciplinary Approach:** Solutions should consider perspectives from a wide range of disciplines. Collaboration with local stakeholders will be highly regarded.
- **Sustainability and Community Engagement:** This proposal must provide evidence that the program will build local capacity and provide tangible impact long beyond the initial three-year period. Leveraging existing community resources and obtaining community members buy-in is crucial to achieving this.
- **Social Determinants of Health (SDoH):** Solutions should consider the role that non-medical factors have on influencing health and how this may apply to malaria care in PNG.
- **Financial Value:** Teams may apply for grants of $3 million USD. A highly favoured proposal will be one which can justify a highly impactful solution within their chosen budget. Additional in-kind and cash contributions may be leveraged but must be realistic. Some preference will be given to teams that consider the role of internal funding in their proposal. However, the sustainability of the program should not rely on ongoing WHO financing after the three-year intervention period.
- **Targeted Intervention:** Teams should focus on **at least two** of PNG's 22 provinces for their intervention and provide rationale for its selection, whilst also considering the scalability of their intervention.

Case prompt: deliverables

Your proposal will be submitted in the form of a total twenty-minute presentation (12 minutes to present your proposal, and 8 minutes of judges' questions) to the panel of reviewers that WHO Western Pacific has assembled for evaluation, including representatives from the PNG government, health experts, community leaders, and other stakeholders. It is imperative to include your NGO's name and information about established partnerships and stakeholder relationships in your chosen province.

Components of your submission

PowerPoint Presentation

- Descriptive title
  - Provide a clear and concise title that encapsulates the essence of your proposed solution.
- Your team
  - Include a slide with a photo and the name and position of each member of your team.
- Project narrative
  - Describe the problem you intend to address: outline the current malaria situation in PNG, highlighting key challenges and statistics.
  - Explain your proposed intervention: describe the strategies and activities you plan to implement to combat malaria in PNG.
  - Provide supporting evidence for your specific approach: include references to studies, reports, and data that support your proposed intervention. Use the APA citation style for referencing.
- Timeline
  - Provide a detailed timeline of the intervention, depicting all components of the proposed project across the three-year grant period.
  - Justify why this timeframe is appropriate for achieving the desired outcomes.
- Budget
  - Describe the budget allocation corresponding to the intervention and timeline. *Ensure the entire budget is accounted for, including costs for personnel and resources. The budgets do not need to be definitive, but rather include educated and justifiable estimations*.
- Sustainability strategy
  - Describe how your project can build capacity in the local community so that your intervention can be sustainable beyond the grant period.
- Monitoring and Evaluation strategy
  - Describe what measures your project targets and what data you will collect.
  - Detail the metrics you will use to evaluate the project's impact on malaria reduction and hoe these align with your intended goals.
  - Justify why these measures are relevant and necessary for assessing the project's success.
- Appendix
  - You may include slides that provide additional information useful to answer questions the panel may ask following your 12-minute proposal. This material will not be included in your proposal.

Executive summary

- Provide a concise, **one-page** (A4) overview of your project, including the most important elements of your PowerPoint submission and presentation.

Background

Overview of Malaria

Global and regional prevalence and incidence of malaria

In 2022, an estimated 249 million cases of malaria occurred worldwide, and the disease claimed an estimated 631,000 lives, mostly children in sub-Saharan Africa. Globally, the malaria case incidence (cases per 1000 population at risk) reduced from 81 in 2000 to 58 in 2022. The WHO African Region continues to carry a disproportionately high share of the global malaria burden. In 2022, the region was home to 94% of malaria cases and 96% of malaria deaths. Children under 5 accounted for about 80% of all malaria deaths in the region.

Malaria is endemic in most of Papua New Guinea (PNG), and it has the highest burden of malaria in the Western Pacific Region. In 2022, PNG reported 1,660,000 cases of malaria, accounting for 90% of all cases in the Western Pacific Region. Between 2021 and 2022, incidence increased by 32% in PNG (from 124.3 to 163.7 cases per 1000 population at risk, significantly higher than the regional average of 2.4 cases per 1,000 population. Deaths in the Western Pacific Region increased by 29% between 2021 and 2022 due to the increases in PNG which accounted for 94% of deaths in the region.

Malaria transmission occurs year-round in PNG with seasonal peaks that vary across the country. The Highlands Region experiences an increase in cases towards the end of the wet season, while the Momase and Southern Regions see higher case numbers at the beginning of the wet season.

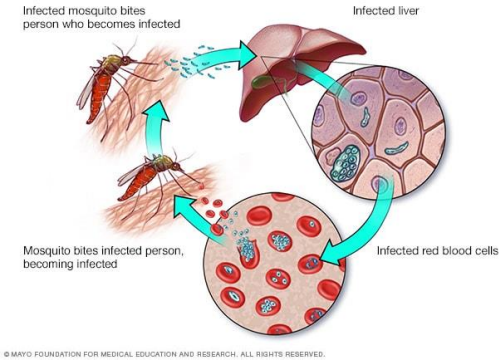
Pathogenesis of malaria

Malaria is a vector-borne infectious disease. There are four key species of malaria-causing parasites that are endemic in PNG: *Plasmodium falciparum*, *Plasmodium vivax*, *Plasmodium malariae* and *Plasmodium ovale* (Dayananda et al., 2018). Plasmodium is the name of the overarching genus that groups together the different species of protozoan parasites which cause malaria. *P. falciparum* is responsible for the majority of malaria infections and deaths in PNG, with *P. vivax* being responsible for a high burden of morbidity, especially in young children. Both *P. falciparum* and *P. vivax* rapidly adapt to environmental changes, making control of disease difficult (Seidahmed et al., 2022).

The life cycle of malaria requires two hosts - Anopheline mosquitoes and humans. This means that a human must be bitten by an infected female mosquito in order to become infected. Additionally, for an unaffected mosquito to become infected with malaria it must bite a human who is infected. Malaria is not contagious and cannot spread directly from one person to another, except for in particular circumstances (blood transfusions, organ transplantation, sharing of infected needles, congenitally from mother to unborn child) (CDC, 2024a).

The incubation period for malaria ranges from 7 to 30 days after infection, however some species of the parasite can remain dormant in a human for months or years after initial infection (CDC, 2024b).

Individuals infected with malaria can exhibit signs of intermittent fever, chills, headache, nausea, and vomiting; all symptoms that can be confused with a viral infection (CDC, 2024b). This clinical picture is common of ‘uncomplicated malaria,’ which the vast majority of patients can recover from if treated with antimalarials specific



to the infecting parasite (Milner, 2018). However, a subset of patients may progress to 'severe malaria,' in which infection can cause severe anaemia, organ dysfunction, respiratory distress, seizures, coma, or death (Dayananda et al., 2018).

Note: During your case presentation, please take care to distinguish between the terms malaria (the name of the disease acquired from Plasmodium protozoa), Plasmodium protozoa (the genus name of the infecting parasite) and Anopheles mosquitoes (the disease vector (EFSA, 2024)). Malaria is not an infecting agent, and mosquitoes cannot cause malaria if they have not been infected with the parasite.

Figure 1. Malaria Transmission Cycle

Country profile

Location and geography

Papua New Guinea is an island nation located in the southwestern Pacific Ocean, north of Australia (World Bank, 2021a). It comprises the eastern half of the island of New Guinea (the world's second largest island) and numerous offshore islands. PNG has a total land area of 462,840 square kilometres, making it the 54th largest country in the world (World Bank, 2021a). The country shares a land border with Indonesia to the west and maritime borders with Australia to the south and Solomon Islands to the east.

PNG is one of the most geographically diverse countries in the world (UNDP, 2021). It features a rugged mountainous interior, dense tropical rainforests, large rivers, coastal plains, and coral reefs. The central highlands region includes the country's highest peak, Mount Wilhelm (4,509 meters). PNG is situated on the Pacific Ring of Fire and experiences frequent earthquakes and volcanic eruptions (World Bank, 2021b). PNG is divided into four regions (Highlands, Momase, Southern, and New Guinea Islands) with 22 provinces, including the Bougainville autonomous region and the National Capital District.

Language and ethnic groups

PNG is one of the most ethnically and linguistically diverse countries in the world. It is home to over 1,000 distinct ethnic groups which can be broadly categorised into two main groups: the Papuans and the Austronesians which are further divided into hundreds of smaller ethnic groups, each with its own distinct language and culture.

The official languages of PNG are English, Tok Pisin (a creole language), and Hiri Motu (an Austronesian language) (Encyclopaedia Britannica, 2021). Additionally, it has over 800 Indigenous languages.

Demographics of PNG

As of 2021, PNG had an estimated population of 11.7 million people (National Statistics Office of Papua New Guinea). The population is predominantly rural, with only 13% living in urban areas (World Bank, 2021a). The capital and largest city is Port Moresby, with a population of around 513,918. Other major urban centres include Lae, Mount Hagen, and Madang.

The median age in PNG is 21.2 years, with over half of the population under the age of 24. The population growth rate is 1.95% per year, and the average fertility rate is 3.51 children born per woman (World Bank, 2021a). Life expectancy at birth is 64.5 years for males and 68.8 years for females (World Bank, 2021a).

Economy of PNG

PNG is classified as a lower-middle-income economy by the World Bank (2021a). The country has a GDP of US$24.97 billion (2020) and a GDP per capita of US$2,637 (2020) (World Bank, 2021a). The economy is largely based on the export of natural resources, including minerals (gold, copper, oil), agricultural products (coffee, cocoa, palm oil), and timber (World Bank, 2021b). The agricultural sector employs around 85% of the labour force (World Bank, 2021b).

Despite its natural resource wealth, PNG faces significant development challenges. Around 37% of the population lives below the national poverty line (World Bank, 2021a). Access to basic services is limited, especially in rural areas (UNDP, 2021). Only 55% of the population has access to electricity, 41% to basic sanitation services and 41% to basic drinking water services (World Bank, 2021a). The adult literacy rate is 63.4% (World Bank, 2021a).

PNG's rugged geography, dispersed population, and limited infrastructure pose challenges for service delivery and economic development (World Bank, 2021b). The country is also vulnerable to natural disasters, including earthquakes, volcanic eruptions, tsunamis, and tropical cyclones (World Bank, 2021b).

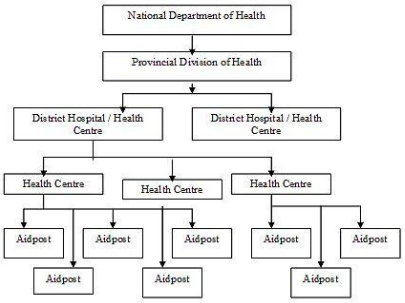
Changing climate in PNG

Already highly susceptible to natural disasters and environmental hazards, climate change poses many challenges for a country like Papua New Guinea. Maximum and minimum temperatures in PNG are slated to rise at a much quicker rate than average temperatures, which can place great risks to human health and ecosystems (World Bank). PNG’s disaster risk in the wake of climate change suggests that flash flooding, coastal flooding and landslides may intensify; doubling the population affected by 2030. These hazards will disproportionately affect impoverished and rural communities.

Health system and associated challenges

Healthcare infrastructure in PNG

Healthcare in Papua New Guinea (PNG) is delivered through a comprehensive system that consists of community aid posts, rural health centres, and provincial hospitals. The network comprises over 2400 aid posts, 500 health centres, and 45 urban clinics, all backed by 18 provincial hospitals and one national hospital. The healthcare providers include community health workers, nursing officers, health extension officers, and doctors.



One of the significant barriers to effective malaria control in Papua New Guinea (PNG) is the limited healthcare infrastructure. The sparse distribution of healthcare facilities, particularly in rural areas, means that many communities lack nearby access to clinics or hospitals. This scarcity is exacerbated by the poor condition of many existing facilities, which are often under-equipped and lack essential diagnostic and treatment tools necessary for managing malaria effectively.

The shortage of trained healthcare professionals further compounds the issue. PNG has one of the lowest ratios of healthcare workers per capita in the Asia-Pacific region. The limited capacity and resources for training and retaining healthcare professionals result in a workforce that may not be adequately prepared to handle malaria cases.

Access to care is another critical challenge. The country's challenging terrain, including mountains and dense forests, makes it difficult for many rural communities to reach healthcare facilities. The lack of reliable transportation infrastructure exacerbates this problem, as many communities rely on infrequent and expensive transport options to access medical services. Additionally, the high out-of-pocket costs for transportation and healthcare services can deter individuals from seeking timely medical care.

Existing interventions for malaria elimination

National Malaria Strategic Plan, 2021-25

The Papua New Guinea National Malaria Strategic Plan for 2021-25 outlines measures and objectives for strengthening malaria control and progressing towards elimination in Papua New Guinea by 2030. The plan emphasises strengthening leadership and governance, ensuring political commitment, adequate domestic and external financial support, and developing cross-border collaboration in preparation for elimination. It also highlights the importance of conducting economic research, non-malaria fever illness studies, and annual reviews of research. The plan includes a budget for the five-year period, with a focus on financing strategies for 2021-2023, including national financing and Global Fund allocation. The plan aims to maintain political support and leverage funding through the development of a 'Malaria Road Map' and regular briefings to government ministers and opinion leaders. Additionally, it emphasises the importance of infrastructure and capacity development for the National Malaria Control Programme, Central Public Health Laboratory, and PNG Institute of Medical Research.

The National Malaria Control Program

The National Malaria Control Program (NMCP), under the leadership of the Program Manager, is responsible for coordinating activities related to malaria and other vector-borne diseases in the country. The Program Manager and their team, based in Port Moresby, provide policy direction, coordination, and technical assistance for the implementation of activities across all of PNG. The team includes four Regional Malaria Coordinators (RMC) who focus on monitoring and evaluation (M&E) and providing technical support to provincial partners. At the provincial level, the Provincial Malaria Supervisors (PMS) work closely with the Provincial Disease Control Officers and health facility staff to monitor, measure, and improve malaria control activities, such as diagnostic services, treatment, and routine reporting. The NMCP is not a vertical program, and the planning, implementation, coordination, and monitoring of control activities are integrated into the health systems at all levels.

The Australia-China-Papua New Guinea Pilot Cooperation on Malaria Control

The Australia-China-Papua New Guinea Pilot Cooperation on Malaria Control, also known as the 'Trilateral Malaria Project,' is an initiative involving the governments of these three countries. It began in December 2015 and marked the first significant trilateral collaboration in the Asia Pacific region focused on fighting malaria. Since

2016, the three countries have been working to enhance malaria diagnosis in Papua New Guinea by strengthening laboratory diagnostic services and conducting operational research, in line with various priorities outlined in the strategic plan. They have committed to continuing their collaboration in malaria and health security for the next 10 years (2020 to 2029), with the second phase of collaboration running from 2020 to 2023.

Barriers to effective control of malaria

Anti-malarial drug resistance

Antimalarial drug resistance poses a significant challenge to malaria control in Papua New Guinea (PNG). Historically, chloroquine was the primary treatment for malaria until resistance emerged in the 1950s and reached PNG by the 1980s (Marfurt et al., 2010). This widespread resistance led to the discontinuation of chloroquine as a first-line treatment, necessitating a switch to more expensive and complex treatment regimens (Marfurt et al., 2010). Currently, PNG relies heavily on artemisinin-based combination therapies (ACTs) as the recommended treatment. While ACTs have been effective, there are growing concerns about the potential emergence of artemisinin resistance. This resistance, first reported in Southeast Asia, involves delayed clearance of parasites from the bloodstream, reducing the effectiveness of treatments. Continuous monitoring for artemisinin resistance in PNG is crucial, although no widespread resistance has been confirmed yet (Patel et al., 2023). Other antimalarials, such as sulphadoxine-pyrimethamine (SP) and mefloquine, have also shown increasing resistance, further complicating treatment options.

Several factors contribute to the development and spread of antimalarial drug resistance in PNG. Incomplete treatments are a major issue, often resulting from patients failing to complete the full course of treatment due to lack of education, side effects, or financial constraints (Hetzel et al., 2014). The use of substandard or counterfeit antimalarial drugs, which do not contain the correct dosage, also promotes resistance. Overuse and misuse of antimalarials, such as self-medication without proper diagnosis or prescription and prophylactic use in high-transmission areas, increase selective pressure on the parasite. Additionally, cross-border movement of people from regions with different resistance patterns introduces resistant strains to new areas, facilitated by increased travel and trade between PNG and neighbouring countries (Hetzel et al., 2014).

Climate change

Risks relating to climate change also include malaria transmission. Uninterrupted bodies of water make prime breeding sites for the mosquito vectors responsible for the spread of malaria (United Nations, n.d.). As floods and landslides increase in number and intensity as a result of climate change, it is likely to directly affect the transmission of malaria.

Mosquitoes are ectotherms, and thus prefer warmer temperatures. This means that increasing temperatures may affect the geographic spread of malaria and its transmission dynamics, disrupting current global health efforts that are aiming to prevent malaria through control of Anopheles mosquito vectors (Campbell et al, 2023). Anopheles mosquitoes are restricted in their regions of survival due to their limited temperature distribution range. As temperatures increase, their region will expand, thus allowing mosquito populations to migrate to infect new populations with malaria. Moreover, as temperatures increase, mosquitoes can digest blood meals at a faster rate, thus allowing them to increase frequency of human biting. This in turn will lead to greater and more efficient transmission of malaria.

Cultural and social barriers

In PNG, there is a preference for traditional healers and remedies over modern medical treatments, driven by deep-rooted cultural beliefs. Misconceptions about the causes and transmission of malaria, often attributing the illness to supernatural forces or environmental factors, further complicate efforts to promote modern healthcare solutions.

These cultural beliefs influence healthcare-seeking behaviour, leading to delays in seeking medical treatment. Many individuals rely on traditional medicine or are unaware of the severity of malaria, resulting in delays in accessing appropriate care. Self-medication with over-the-counter drugs or traditional remedies is also common, often leading to incomplete or inappropriate treatment. Such practices contribute to the persistence of malaria and hinder efforts to control its spread effectively (Rodríguez-Rodríguez et al., 2021).

Community engagement is another area where cultural and social barriers are evident. Limited involvement of community members in malaria control programs is often due to a lack of awareness or distrust of external interventions. This disengagement hampers the effectiveness of preventive measures and public health campaigns. Additionally, there is resistance to adopting preventive measures, such as using bed nets or participating in indoor residual spraying programs (Jops et al., 2023).

Funding and resources

A critical challenge to effective malaria control in Papua New Guinea (PNG) is the inadequacy of funding. The government's budget allocation for health is limited, with health spending comprising only about 4.3% of GDP. This insufficient allocation constrains the implementation and sustainability of comprehensive malaria control measures. Consequently, PNG relies heavily on fluctuating international aid, with key donors such as the Global Fund and the World Health Organization (WHO) providing the bulk of the funding. However, this dependence on external aid introduces vulnerabilities, as funding levels can vary based on donor priorities and global economic conditions. As a result, significant funding gaps persist, hindering the ability to cover essential preventive and treatment resources, leaving many communities under-protected and underserved.

Compounding the issue of inadequate funding is the inefficient allocation of resources. Misallocation often arises from a lack of data-driven prioritisation, leading to funds not reaching the areas most affected by malaria. Additionally, high administrative and operational costs consume a significant portion of the available funding, reducing the amount that can be directed towards direct malaria control activities. Furthermore, poor coordination among different levels of government and between governmental and non-governmental organisations exacerbates the problem, resulting in duplication of efforts and wastage of resources. This fragmentation undermines the overall effectiveness of malaria control programs in PNG.

References

Campbell, H., Haldar, S., Patel, C., & Greenwood, B. (2023). Malaria control and elimination in Africa: Progress, trends, and future challenges. The Lancet. https://doi.org/10.1016/S0140-6736(23)01569-6

Centers for Disease Control and Prevention (CDC). (2024a). *How Malaria Spreads.* *https://www.cdc.gov/malaria/causes/index.html#:~:text=Malaria%20is%20not%20contagious*

Centers for Disease Control and Prevention (CDC). (2024b). *Symptoms of Malaria.* *https://www.cdc.gov/malaria/symptoms/index.html#:~:text=This%20time%20between%20mosquito%20bite,shorter%20or%20longer%20incubation%20periods*

Dayananda, K. K., Achur, R. N., Gowda, D. C. (2018). Epidemiology, drug resistance, and pathophysiology of *Plasmodium vivax* malaria. *Journal of Vector Borne Diseases, 55(1).* 1-8. doi: 10.4103/0972-9062.234620

Encyclopaedia Britannica. (2021). Papua New Guinea. https://www.britannica.com/place/Papua-New-Guinea

European Food Safety Authority (EFSA). (2024). *Vector-Borne Diseases.*https://www.efsa.europa.eu/en/topics/topic/vector-borne-diseases#:~:text=A%20vector%20A%20carrier%20of,viruses)%20that%20transmits%20an%20infectious

Hetzel, M. W., Page-Sharp, M., Bala, N., Pulford, J., Betuela, I., Davis, T. M., & Lavu, E. K. (2014). Quality of antimalarial drugs and antibiotics in Papua New Guinea: A survey of the health facility supply chain. *PloS One, 9*(5), e96810. https://doi.org/10.1371/journal.pone.0096810

Jops, P., Cowan, J., Kupul, M., Trumb, R. N., Graham, S. M., Bauri, M., … Kelly-Hanku, A. (2023). Beyond patient delay, navigating structural health system barriers to timely care and treatment in a high burden TB setting in Papua New Guinea. *Global Public Health, 18*(1). https://doi.org/10.1080/17441692.2023.2184482

Kekatos, M. (2024, May 30) Papua New Guinea landslide raises risk of disease outbreaks, mental health impacts. *ABC News.* https://abcnews.go.com/Health/papua-new-guinea-landslide-raises-risk-disease-outbreaks/story?id=110604699

Mayo Clinic. (2024). *Malaria Transmission Cycle.* https://www.mayoclinic.org/diseases-conditions/malaria/multimedia/malaria-transmission-cycle/img-20006373

Marfurt, J., Smith, T. A., Hastings, I. M., Mueller, I., Sie, A., & Reeder, J. C. (2010). Plasmodium falciparum resistance to anti-malarial drugs in Papua New Guinea: Evaluation of a community-based approach for the molecular monitoring of resistance. Malaria Journal, 9, 8. https://doi.org/10.1186/1475-2875-9-8

Milner, D. A., Jr. (2018). Malaria Pathogenesis. *Cold Spring Harbor Perspectives in Medicine, 8(1),* a025569. doi: 10.1101/cshperspect. a025569

National Statistical Office of Papua New Guinea. (2021) Population. https://www.nso.gov.pg/statistics/population/

Patel, C. A., Pande, S., Shukla, P., Ranch, K., Al-Tabakha, M. M., & Boddu, S. H. S. (2023). Antimalarial drug resistance: Trends, mechanisms, and strategies to combat antimalarial resistance. In R. Shegokar & Y. Pathak (Eds.), *Malarial drug delivery systems* (pp. 33-55). Springer, Cham. https://doi.org/10.1007/978-3-031-15848-3_3

Rodríguez-Rodríguez, D., Katusele, M., Auwun, A., Marem, M., Robinson, L. J., Laman, M., Hetzel, M. W., & Pulford, J. (2021). Human behavior, livelihood, and malaria transmission in two sites of Papua New Guinea. *The Journal of Infectious Diseases, 223*(Supplement_2), S171–S186. https://doi.org/10.1093/infdis/jiaa402

Seidahmed, O., Jamea, S., Kurumop, S., Timbi, D., Makita, L., Ahmed, M., Freeman, T., Pomat, W., Hetzel, M, W. (2022). Stratification of malaria incidence in Papua New Guinea (2011-2019): Contribution towards a sub-national control policy. *PLOS Global Public Health, 2(11),* e747. doi: 10.1371/journal.pgph.0000747

Seidu, A.-A., Agbaglo, E., Dadzie, L. K., Ahinkorah, B. O., Ameyaw, E. K., & Tetteh, J. K. (2021). Individual and contextual factors associated with barriers to accessing healthcare among women in Papua New Guinea: Insights from a nationwide demographic and health survey. *International Health, 13*(6), 573–585. https://doi.org/10.1093/inthealth/ihaa097

United Nations. (n.d.). Climate change and malaria: A complex relationship. United Nations Chronicle. https://www.un.org/en/chronicle/article/climate-change-and-malaria-complex-relationship

UNDP. (2021). About Papua New Guinea. https://www.pg.undp.org/content/papua_new_guinea/en/home/countryinfo.html

World Bank. (2021a). Papua New Guinea Overview. https://www.worldbank.org/en/country/png/overview

World Bank. (2021b). Papua New Guinea: Systematic Country Diagnostic. https://openknowledge.worldbank.org/handle/10986/35802

World Bank. (n.d.). Papua New Guinea: Vulnerability. Climate Change Knowledge Portal. https://climateknowledgeportal.worldbank.org/country/papua-new-guinea/vulnerability

World Malaria Report 2023. Geneva: World Health Organization; 2023. License: CC BY-NC-SA 3.0 IGO.