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1 **Needs and Challenges in Modelling Malaria for Emergency Contexts**

2

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12

13 **Keywords:** epidemiology; emergency; malaria; modelling; relief; vector

14

15 **Abstract**

16 While modelling is an essential component in understanding malaria epidemiology and
17 design of better control measures, it rarely considers the particular contexts
18 encountered in emergency settings. By linking these situations with the transmission
19 parameters our aim is to correct this bias and call for a better collaboration between
20 relief actors.

21

22

23 In 2018, approximately 70 million people were considered to be forcibly displaced,
24 whether internally displaced, returnees or people living in humanitarian emergencies
25 [1]. A quarter of these were located in sub-Saharan Africa. At the same time, 90% of
26 worldwide malaria-associated deaths currently occur in sub-Saharan Africa, about a
27 third of which take place within complex humanitarian emergency settings ^{i,ii,iii} [1, 2, 3].

28
29 Different from normative contexts where malaria control is routine and even
30 elimination strategies are being implemented, in unstable conditions malaria incidence
31 is poorly understood and subject to composite short-term changes. Controlling malaria
32 in such settings requires tools with particular target profiles, amongst which rapid
33 deployment, adaptability, practicality and ease of implementation are paramount. While
34 modelling is often considered essential in determining if and how a strategy or a
35 combination of strategies can impact the malaria burden [4,5], the case of emergency
36 settings is rarely considered. Our aim is here to highlight, through defining an
37 emergency setting, how modelling approaches could help designing more efficient and
38 effective malaria control programmes while fostering collaboration between the actors
39 involved in humanitarian aid.

40

41 **What defines an emergency situation?**

42 According to the World Health Organization, complex emergencies are situations of
43 disrupted livelihoods and threats to life produced by warfare, civil disturbance and
44 large-scale movements of people, in which any emergency response has to be conducted
45 in a difficult political and security environment. Complex emergencies combine internal
46 conflict with large-scale displacements of people, mass famine or food shortage, and

47 fragile or failing economic, political, and social institutions. Often, complex emergencies
48 are also exacerbated by natural disasters [6].

49

50 **Adapting malaria modelling to emergency settings: What can be done?**

51 It is unlikely that a 'one size fits all' modelling approach will work in emergency settings,
52 and a variety of scenarios would need to be considered. Even more than in less complex
53 contexts, the adaptation to heterogeneous and unstable situations and the ability to
54 provide long-term sustainable solutions are major aspects to conduct an efficient
55 programme aiming at decreasing malaria mortality and morbidity.

56 Proposed models would require a number of parameters ranging from relevant
57 epidemiological and medical population information, and consider the type and quality
58 of tools and their potential combinations. Some examples of this include population
59 composition and movement, human ecology, pre-existing local activities of malaria
60 control, diagnosis and access to healthcare. This should ultimately allow a determination
61 on which specific tools would be more adapted to the situation (e.g. Insecticide-Treated
62 Cover and Blankets, repellents, IRS campaigns). The approaches should also
63 acknowledge that there might be some context-specific challenges in emergency settings
64 to use some of these approaches, whether classical or innovative.

65

66 **Translation into parameters**

67 In the definition of an emergency setting, a number of aspects can be translated into
68 parameters to feed epidemiological models of malaria (Figure 1). The most
69 straightforward manner is to consider the classical basic reproductive number, R_0 ,
70 describing the number of secondary cases of malaria arising from a single case in an

71 otherwise uninfected population [7] and it's more recent neoclassical assumptions
72 taking into account a variety of parameters affecting malaria transmission [8,9].

73

74 *The impact of large-scale displacement of people*

75 One of the major aspects associated with emergency settings is large-scale population
76 displacement, which in terms of malaria epidemiology can affect transmission in a
77 variety of ways. Such changes may not only be in absolute numbers but in other major
78 determinants of malaria epidemiology [9], such as age distribution, with often more
79 children, young adults and women of childbearing age; the migration [10] and the
80 malaria immune status [11], affecting the spread of the disease. As a corollary using
81 spatially-explicit models can be particularly useful in scenarios where heterogeneity is
82 important in the environment (e.g. disturbed landscapes), interactions in the human
83 populations (e.g. differences in immunity in long-term nearby residents vs newly
84 displaced people) as well as the vector or the parasites ones (e.g. vectorial capacity
85 varying over short distances and potentially different parasite species).

86

87 *Mass famine or food shortage*

88 When herd immunity can be impaired due to an influx of malaria-susceptible
89 populations arriving from an area with no or little malaria transmission, the
90 compounding effect of mass famine and food shortage leading to acute or chronic
91 malnutrition may have an important impact on disease incidence and evolution [12, 13].
92 This will typically lead to a diminished immunity (affecting then the recovery rate, the
93 factor r in R_0) and an increased malaria-related mortality.

94

95 *Fragile or failing economic, political, and social institutions*

96 Often emergency settings are closely linked with a fragile social and socio-economical
97 system as well as inadequate infrastructures with limited access to rapid diagnosis and
98 where the risk of misdiagnosis is high [14]. This can then lead to a number of aspects
99 that could be considered in models whose aim is to include the access to treatment and
100 infrastructures, the quality of medical care as well as to the presence or absence of
101 vector control activities that will influence several mosquito-related parameters (m , a
102 and μ).

103

104 *Natural disasters*

105 Natural disasters typically exacerbate and amplify pre-existing challenges encountered
106 in complex humanitarian settings. This can imply changes in ecological conditions (*e.g.*
107 flooding) and may result in the initial destruction of breeding sites but also in the
108 creation of new ones that can result in an 'off-season' malaria peak. In addition, natural
109 disasters are likely to deepen logistic constraints affecting the delivery of control tools.

110

111 *Data collection*

112 One of the major challenges in emergency humanitarian contexts, particularly in the
113 acute phase, is the difficulty to get accurate data, which would be important in the
114 calibration of models [15]. Typically, most emergency assessments are 'quick and dirty',
115 and as such the number, type and characteristics of data parameters and points to be
116 collected need to be carefully considered and prioritised, including that of the
117 resident/host populations.

118

119 *Implementation*

120 Time-efficiency of implementation is also an essential aspect of tackling malaria in an
121 emergency setting. The speed and the quality of the tool and the subsequent control
122 strategy deployment are critical to prevent avoidable malaria-associated deaths.
123 Choosing between a less effective strategy that can be quickly implemented, and more
124 efficacious options that require more time to develop, resulting in significant
125 implementation delay, is where such a tool will have the greatest value. Models could be
126 a real asset to guide such decisions, particularly if operationalizable through easily
127 accessed and user-friendly interfaces with minimum prior training.

128

129 **Conclusion**

130 Overall there is a need for modelling approaches that would not only consider the
131 biological and epidemiological parameters for malaria control in emergency settings but
132 also the various factors, often difficult to estimate, that are unique to such situations.
133 Such models should build upon existing tools and available solutions (low-hanging
134 fruits) to analyse and suggest improved designs that consider the whole range of tools
135 available for malaria control (*e.g.* case management, drugs, vector control). This could
136 also lead to improved planning, budgeting and collaboration between the actors
137 providing emergency relief and assistance. The use of models and a better collaboration
138 and service delivery between the various actors involved in relief in emergency settings
139 should develop beyond malaria in multiple other conditions in a more holistic and
140 multisectorial manner.

141

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145 situations.

146

147 **Resources**

148 ⁱ <https://malariaatlas.org/>

149 ⁱⁱ <https://www.severemalaria.org/>

150 ⁱⁱⁱ <http://popstats.unhcr.org/en/overview>

151

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182

183 **Figure 1. Parameters related to the definition of emergency settings and their**
184 **potential impact on the transmission of malaria.** R_0 , basic reproductive ratio; m ,
185 number of mosquitoes per human host; a , biting rate of the mosquitoes on their human
186 host; b , infectivity of mosquitoes to humans; c , infectivity of humans to mosquitoes; μ ,
187 mortality of adult mosquitoes; T , incubation period of parasites within the mosquito
188 vector; r , rate of recovery of infected humans.

Mass famine or food shortage

Immunity functions

- General immunity
- Transmission-blocking immunity that may affect infectivity of humans to mosquitoes [c]
- Pre-erythrocytic immunity that may affect infection of mosquitoes to humans [b]

Fragile or failing economic, political and social institutions

Socio-economic factors

- Access to treatment and infrastructures
- Quality of medical care
- Vector control programme
- Dysfunctional normative social institutions
- Disrupted social welfare mechanisms

The diagram features a central equation for the basic reproduction number, $R_0 = \frac{mbca^2 e^{-mT}}{rm}$. Four arrows point towards this equation from the surrounding boxes: one from the top-left box (Immunity functions), one from the top-right box (Socio-economic factors), one from the bottom-left box (Demographic effects), and one from the bottom-right box (Environmental factors).

$$R_0 = \frac{mbca^2 e^{-mT}}{rm}$$

Large-scale displacement of people

Demographic effects

- Size of human population (noting R_0 considers an infinite population in its classical form)
- Human population density
- Age distribution

Natural disasters

Environmental factors

- Seasonality & rainfall
- Temperature
- Humidity
- Increased pools of stagnant water

Essential tool characteristics for malaria in emergency settings

- Speed of deployment
- Adaptability
- Practicality
- Ease of implementation