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Data Descriptor

Monthly Entomological Inoculation Rate Data for Studying the Seasonality of Malaria Transmission in Africa

Edmund I. Yamba [1,2,*], Adrian M. Tompkins [3], Andreas H. Fink [4], Volker Ermert [2], Mbouna D. Amelie [5], Leonard K. Amekudzi [1] and Olivier J. T. Briët [6,7]

1 Department of Physics, Kwame Nkrumah University of Science and Technology (KNUST), 039-5028 Kumasi, Ghana; lkamekudzi.cos@knust.edu.gh
2 Institute of Geophysics and Meteorology, University of Cologne, 50670 Cologne, Germany; volker.ermert@posteo.de
3 International Centre for Theoretical Physics, Earth System Physics, 34100 Trieste, Italy; tompkins@ictp.it
4 Institute of Meteorology and Climate Research, Karlsruhe Institute of Technology, 76021 Karlsruhe, Germany; andreas.fink@kit.edu
5 Laboratory for Environmental Modelling and Atmospheric Physics (LEMAP), Department of Physics, Faculty of Science, University of Yaounde I, P.O. Box 812 Yaounde, Cameroon; ameldany18@gmail.com
6 Department of Epidemiology and Public Health, Swiss Tropical and Public Health Institute, Socinstrasse 57, P.O. Box, CH-4002 Basel, Switzerland; olivier.briet@swisstph.ch
7 University of Basel, CH–4003, Basel, Switzerland
* Correspondence: eyilimoan48@gmail.com or eiyamba@knust.edu.gh; Tel.: +233-200-876-117

Received: 22 February 2020; Accepted: 24 March 2020; Published: 27 March 2020

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Abstract: A comprehensive literature review was conducted to create a new database of 197 field surveys of monthly malaria Entomological Inoculation Rates (EIR), a metric of malaria transmission intensity. All field studies provide data at a monthly temporal resolution and have a duration of at least one year in order to study the seasonality of the disease. For inclusion, data collection methodologies adhered to a specific standard and the location and timing of the measurements were documented. Auxiliary information on the population and hydrological setting were also included. The database includes measurements that cover West and Central Africa and the period from 1945 to 2011, and hence facilitates analysis of interannual transmission variability over broad regions.

Dataset: https://doi.org/10.1594/PANGAEA.892682

Keywords: malaria; entomological; inoculation; transmission; seasonality; Africa

1. Introduction

Despite increasing international efforts to reduce its burden, malaria is still a major health problem and a significant cause of mortality in low-income countries. In 2018 for instance, Africa alone accounted for 93% of the worldwide malaria cases and 94% of the global malaria deaths, of which 67% occurred in children under five years of age, and nearly 85% of the global malaria burden was concentrated in 20 countries in Sub-Saharan Africa and India [1]. To improve this situation and make effective progress towards malaria control and eradication, a good understanding of the characteristics and drivers of malaria seasonality and interannual variability is required. For this, the availability of reliable datasets of a range of malaria indicators that span multiple months and seasons is fundamental. Such datasets would allow the evaluation and development of improved models of malaria transmission, which can then be used to study malaria predictability, eradication or response to changing external forcing.

One key metric of malaria is counts of clinical cases. These data can be weekly but are usually aggregated at a monthly timescale. One issue with such data is the quality, since often suspected malaria cases are not clinically confirmed in the laboratory by slide film or rapid diagnostic test kit, and the percentage and method of confirmation may change over time [2]. Changes in reporting rate may occur due to access to health facilities and according to the transmission setting, which can be impacted by interventions. In addition to these issues, such data usually spans a relatively short period, covering at most the decade since digital health management information systems started replacing paper-based records [3], confounding efforts to study the impact of interannual and decadal climate variability. Long series of high quality, clinically confirmed cases are usually restricted to isolated locations such as high land tea plantations or sentinel clinics [4].

The second metric of malaria can be derived from cross-sectional surveys of populations to determine the ratio that has malaria parasites present in blood samples, referred to as the parasite ratio (or parasite rate, PR). This metric provides a time-integrated picture of the malaria transmission setting, since it identifies all population members infected over the extended period equivalent to the mean time for parasite clearance [5]. Parasite rate data have been collected over a wide range of locations and span multiple decades although individual surveys usually only cover shorter periods. The data have considerable uncertainties, with sample sizes often less than 20 individuals and with frequent false negative results derived from slide analysis of blood samples taken from infected individuals [6]. Efforts have been made to aggregate literature published and country-lead surveys into databases at country [7] or continental scales. The Malaria Atlas Project (MAP) provides the benchmark database of global PR across the globe, with the majority of the survey data made freely available to the research and operational communities [8,9]. Analogous to the PR for the malaria vector is the CircumSporozoite Protein Rate (CSPR), which is also subject to measurement uncertainties [10] and remains sparse [11].

A useful supplement to the PR and case number is the Entomological Inoculation Rate (EIR) as it provides a direct measure of the intensity of transmission. The EIR is the number of infective bites per person per unit time, and is usually calculated as the product of the Human Biting Rate (HBR) and the CSPR. The former has often been calculated using Human Landing Catches (HLC), and again is subject to considerable uncertainties. Of particular interest for research purposes are longer term records of monthly EIR to study the seasonal cycle and interannual variability of transmission intensity. However, the complexities involved in organizing field campaigns to take EIR measurements over an extended period implies that the availability of this data on monthly resolved timescales is relatively sparse. At best, for individual locations surveys usually cover a few months or at most one or two years. Nevertheless, there are now a considerable number of field surveys from the past three decades reported in open literature, which could collectively describe malaria transmission seasonality and interannual variability and provide a useful supplement to existing malaria databases. This article describes an effort to collect available monthly-resolved EIR data for surveys with a duration of at least a year, available as a public resource for malaria research. It first discusses how the monthly EIR data were compiled from different sources and collated into a database for public access on the internet. It then provides some application use cases of the data and discusses the merits and limitations of the archived data.

2. Methods

2.1. Compiling Sources of Monthly EIR Data

An all-inclusive literature review was conducted using Google Scholar and PubMed search facilities for articles containing monthly EIR (denoted EIR_m hereafter) directly, or measurements of vector related quantities that could be used to derive EIR in Sub-Saharan Africa. Keywords of Hay et al. [12] such as "entomological inoculation rate", "biting rate", "sporozoite index/rate", "human landing catches", "light trap catches", "Pyrethrum spray catches", "malaria transmission", "*Anopheles gambiae*", "*Anopheles funestus*", "malaria vectors" and "vectorial capacity" were used. The papers found from the search engines were scrutinized for EIR_m data. The papers were also searched for article references with potential EIR_m data. The titles of these potential references were re-entered into the search engines and the manuscripts recovered. The search strategy was repeated until no new information was obtained. A list of publications with EIR_m data from the online search was then compiled. The search also consulted the entomological and parasitological-related papers database compiled by Ermert et al. [13]. From this database, only articles containing EIR_m data that were not recovered from the online search were compiled.

2.2. Recording EIR_m Data from Articles

The EIR_m data from the compiled articles were obtained the following ways: Instances where the EIR_m data in the articles were graphically displayed (plotted), they were digitized using an R package "digitize" [14]. This tool is designed to efficiently extract data from graphs whose sources were not available. The package allows the user to load the graphical plot, calibrate it and extract the data from it. Cases where the EIR_m data were presented in tabular forms were manually recorded. There were also articles where only monthly HBR and their corresponding CSPR were available. For such cases, the EIR_m is obtained by multiplying HBR with the respective CSPR monthly value as defined by Macdonald [15]. Olivier J. T. Briët of the Swiss Tropical and Public Health Institute (Swiss TPH), Switzerland who also compiled some entomological parameters into a database by digitizing them from published articles shared the data for use in this work. The EIR_m data utilized from his database were cross-validated from their original articles.

2.3. Inclusion and Exclusion Criteria

The final EIR_m database was built by employing some selection criteria as explained in Beier et al. [16] and Hay et al. [12]. That is, each study location EIR_m data recorded were subjected to all of the following conditions:

1. That the mosquito sampling activity at the location lasted for at least a year;
2. That the mosquitoes were sampled monthly throughout the study period or the transmission season;
3. That the biting rates were estimated from standard methods such as Pyrethrum Spray Catches (PSC), Light Trap Catches (LTC) and HLC;
4. That the proportion of sporozoite-infected mosquitoes were determined using either dissection or Enzyme-Linked Immune Sorbent Assay (ELISA) methods;
5. That the study took place at the time mosquito control operations were not in effect.

EIR_m data from locations that satisfied all of the above conditions were retained and formed the final database; otherwise they were excluded from the final database.

2.4. Study Location Information and Classification

Names and geographical coordinates (latitude and longitude) of locations where mosquitoes were sampled for EIR_m data were generally obtained from the source articles. In the event that the geographical coordinate of a location was not provided in the source article, the location name was searched in www.bing.com/maps and www.google.com online mapping facilities for the coordinates.

Previous work has shown how malaria transmission relates strongly to population density (Urban (U), Peri-Urban (PU) and Rural (R) settings) in Africa [17]. For this reason, the database includes a classification of the study locations as either R, PU or U. There were minority of cases where a description of the field location as either R, PU or U was included in the source articles. In such cases, the information was taken directly from the source articles. Majority of the locations could not be identified in the source articles as R, PU or U. At such instances, the location population density data was extracted from the version 3 of the Gridded Population Density data of the World (GPDWv3, [18]) using the nearest grid point and a linear interpolation/extrapolation from the three time slices of 1990, 1995 and 2000. Using the extracted population density data, the location was then classified as R, PU or U based on population density thresholds of 250 km^{-2} and 1000 km^{-2} as suggested by Hay et al. [19].

Surface hydrology and land cover are also relevant in malaria transmission. Hence, a hydrological classification of each study site was also included in the database. Each location was identified with No Water Body (N), an Ongoing Irrigation (I) or Permanent Water Body (PWB). Study locations characterized by marshlands, lakes, rivers, streams, dams or swamps were considered as PWB areas. Irrigated locations were regarded as locations with irrigation activities going on in the area or double cropping. Locations without water bodies or an ongoing irrigation activity were regarded as Neutral or No Water Body. The types of hydrology characterizing a study location were obtained directly from the source articles of digitized EIR_m data.

3. Results

3.1. Data Records

The spatial coverage of the data and distribution of study locations in Sub-Saharan Africa are displayed in Figure 1. The colored circles indicate the maximum EIR at each location and show that in most cases the EIR does not exceed 50 bites per person per month.

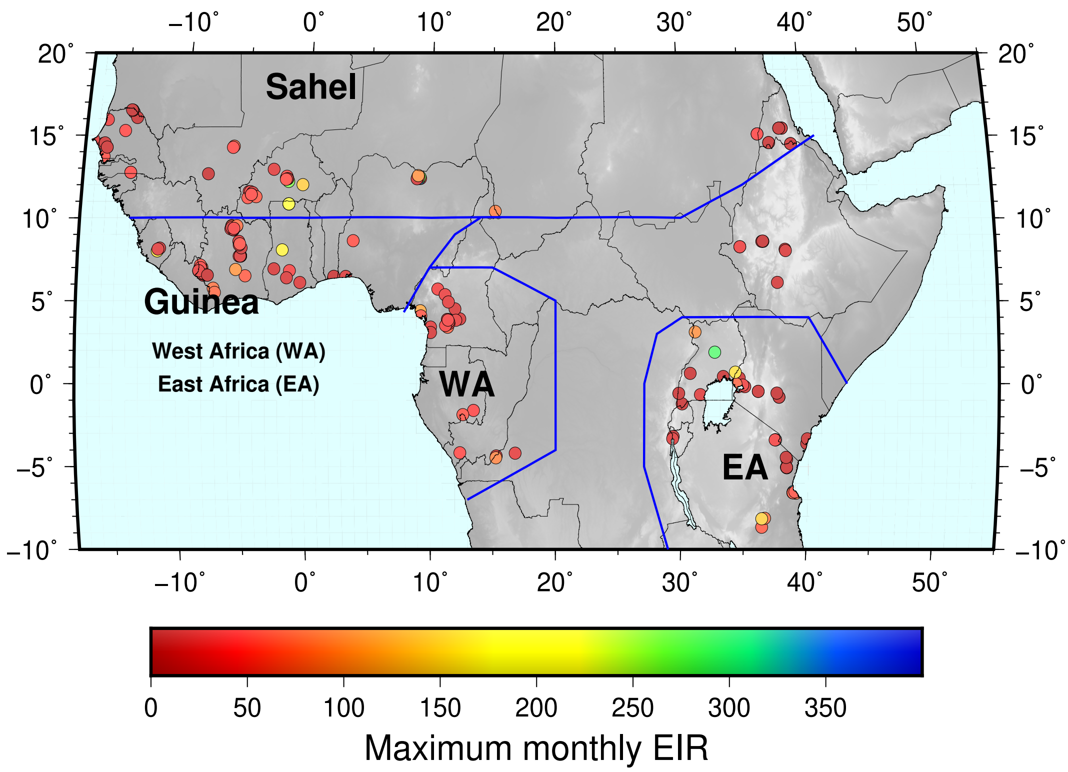

Figure 1. The geographical locations of extracted EIR_m in Sub-Saharan Africa. The colored circles show the maximum EIR_m value recorded for the location. The proximity of many of the locations are very close and hence cannot be explicitly resolved on the map. The blue lines show the boundaries of the sub-regions (Sahel, Guinea, WA and EA).

The temporal coverage of the database is summarized in Table 1 for four key zones as demarcated in Figure 1 namely: Sahel (lat $\geq 10^\circ$, $-20^\circ <$ lon $< 40^\circ$), Guinea ($5^\circ \geq$ lat $< 10^\circ$, $-20^\circ <$ lon $< 20^\circ$), equatorial West Africa (WA) (lat $< 5^\circ$, $10^\circ \geq$ lon $< 20^\circ$) and equatorial East Africa (EA) (lat $< 5^\circ$, $28^\circ <$ lon $< 40^\circ$). The table shows that 127 records were found that covered between 1 and 2 years. A similar number of records were found in each of the zones, allowing for their intercomparison. A much smaller number of studies cover a multiple year period, indicating that studies of interannual variability must resort to the use of multiple sites aggregated over climatic zones. Details of each location record with article references are presented in Tables 2–4. The full data is archived in an online repository at https://doi.org/10.1594/PANGAEA.892682 [20]. The full database includes: the name of country and site of data survey, the geographical location (longitude and latitude) and elevation of the site, the land use type (urban, periurban or rural), the hydrology of the area (permanent water bodies or irrigation activities), vector species identified at the site, the starting year and month of data record. Value1 to value12 are the months with EIR_m records, with value1 corresponding to the starting month and value12 the end month. The data is available for use by researchers and can be freely accessed from the online repository. However, it is important that users duly reference this paper and the repository documentation [20] in their works.

Table 1. Number of locations with a particular length of EIR_m data at each zone.

ZONE	1 Year	2 Years	3 Years	4 Years	5 Years	Total
SAHEL	36	18	4	1	1	60
GUINEA	31	28	2	0	0	61
WA	22	4	0	0	0	26
EA	38	10	2	0	0	50

Table 2. Malaria EIR database entries (Benin–Ghana). Pd = population density type, SY = start year of data, EY = End year of data, SM = start month of data, EM = end month of data, Ref = article from which the data was obtained.

Country	Site	Lon	Lat	Elevation	Pd	Hydrology	Vector Species	SY	SM	EY	EM	Ref
Benin	Gbegame	2.41	6.36	6	U	N	AG	1987	01	1987	12	[21]
Benin	Ladji	2.43	6.39	2	U	N	AG	1987	01	1987	12	[21]
Benin	St. Ritha Nord	2.40	6.38	4	U	N	AG	1987	01	1987	12	[21]
Benin	Ganvie	2.417	6.467	2	PU	PWB	AG	1994	01	1995	12	[21]
Burkina Faso	Balonguen	−1.621	12.403	343	PU	PWB	AF, AG	2000	12	2001	11	[22]
Burkina Faso	Dande	−4.557	11.582	275	R	N	AF, AG	1983	01	1984	12	[23]
Burkina Faso	Guinghin Nord	−1.54	12.35	305	U	N	AG	1984	03	1985	02	[24]
Burkina Faso	Karangaso	−4.64	11.21	366	R	PWB	AF, AG, AN	1985	03	1986	02	[25]
Burkina Faso	Kologh Naba	−1.54	12.38	292	U	N	AG	1984	03	1985	02	[24]
Burkina Faso	Kongodjan	−4.45	11.58	480	R	PWB	AF, AG	1983	01	1984	12	[23]
Burkina Faso	Kou	−4.27	11.52	288	R	I	AG	1985	05	1986	04	[26]
Burkina Faso	Koubri	−1.406	12.198	289	R	N	AGSL	1984	03	1985	02	[24]
Burkina Faso	Lena	−3.98	11.28	307	R	N	AF, AG	1999	01	2001	12	[27]
Burkina Faso	Nongremassm	−1.56	12.40	310	U	N	AG	1984	03	1985	02	[24]
Burkina Faso	Pabre	−1.57	12.505	303	R	N	AGSL	1984	03	1985	02	[24]
Burkina Faso	St Camille	−1.50	12.36	299	U	N	AG	1984	03	1985	02	[24]
Burkina Faso	St Leon	−1.522	12.361	306	U	N	AGSL	1984	03	1985	02	[24]
Burkina Faso	Tago	−2.643	12.932	308	R	N	AF, AG	1983	01	1983	12	[23]
Burkina Faso	Tensobtenga	−0.267	12.00	295	R	PWB	AF, AG	2000	12	2001	11	[22]
Burkina Faso	VK4	−4.37	11.41	288	R	I	AG	1984	01	1984	12	[23]
Burkina Faso	VK6	−4.37	11.41	288	R	I	AF, AG	1983	01	1984	12	[23]
Burkina Faso	Zagtouli	−1.625	12.329	310	U	N	AGSL	1984	03	1985	02	[24]
Burundi	Gihanga	29.29	−3.19	827	R	I	AG	1982	01	1983	12	[28]
Burundi	Katumba	29.237	−3.317	776	R	N	AF, AG	1982	01	1982	12	[28]
Cameroon	Nkol Bikok	11.48	3.87	728	U	PWB	AG	1989	03	1990	02	[29]
Cameroon	Nkol Bisson	11.44	3.87	760	R	PWB	AG	1989	04	1990	03	[29]
Cameroon	Ebogo	11.47	3.40	659	R	N	AG, AMO	1991	04	1992	03	[30]
Cameroon	Ebolakounou	12.44	3.91	701	R	N	AF, AG, AMO	1997	06	1998	05	[31]
Cameroon	Ekombite	11.83	3.12	693	R	PWB	AG, AME, AF	2007	01	2007	12	[32]
Cameroon	Esuke camp	9.31	4.10	279	R	N	AF,AG, AHAN, AN	2004	10	2005	09	[33]
Cameroon	Idenau	9.05	4.21	359	R	N	AG, AF, AN	2001	08	2002	07	[34]
Cameroon	Koundou	12.12	3.90	705	R	N	AF, AG, AMO	1997	06	1998	05	[31]
Cameroon	Likoko	9.31	4.39	1933	R	N	AF, AG, AHAN	2002	10	2003	09	[35]
Cameroon	Limbe	9.18	4.03	185	R	N	AF, AG, AN	2001	08	2002	07	[34]
Cameroon	Mbebe	10.12	3.41	70	R	PWB	AF, AG, AN	1989	04	1990	03	[36]
Cameroon	Nditam	11.26	5.36	712	R	PWB	AG	1995	05	1996	04	[37]
Cameroon	Nkoteng	12.05	4.5	587	R	N	AF, AG	1999	02	2001	01	[38]
Cameroon	Ndogpassi	10.13	3.08	72	R	N	ALL	2011	01	2011	12	[39]
Cameroon	Nsimalen Ekoko	12.12	3.82	699	R	PWB	AME, AG	1991	04	1992	03	[39]
Cameroon	Nsimalen Mefou	11.58	3.63	680	R	PWB	AME	1991	04	1992	03	[39]
Cameroon	Nsimalen (deforested)	11.553	3.723	679	R	PWB	AMO	1991	04	1992	03	[40]
Cameroon	Nsimalen (forested)	11.553	3.723	679	R	PWB	AMO, AG	1991	04	1992	03	[40]
Cameroon	Sanaga river villages	11.52	4.92	474	R	PWB	AN, AG	1989	04	1990	03	[41]
Cameroon	Simbock-Block6	11.30	3.50	717	R	PWB	AF,AG,AME,AN	1999	01	1999	12	[42]
Cameroon	Simbock	11.5	3.83	625	U	N	AF, AG, AMO AN	1998	10	1999	09	[43]
Cameroon	Tiko	9.36	4.08	182	R	N	AG, AF, AN	2001	08	2002	07	[34]
Chad	Goulmoun	15.30	10.39	324	R	I	AA,AF,AP,AZ	2006	06	2007	05	[44]

Table 2. *Cont.*

Country	Site	Lon	Lat	Elevation	Pd	Hydrology	Vector Species	SY	SM	EY	EM	Ref
Congo	Kulila	12.43	−4.17	400	R	PWB	AG	1981	12	1982	11	[45]
DRC	Kimbangu	15.31	−4.36	295	U	N	AG	1988	09	1990	08	[46]
DRC	Kwamutu	15.28	−4.47	346	U	N	AB, AF,AG,AN	1988	09	1990	08	[46]
DRC	Mbansale	16.80	−4.19	289	R	PWB	AG	1990	05	1991	04	[47]
Eritrea	Adibosqual	38.39	15.42	1482	R	N	AG	1999	01	1999	12	[48]
Eritrea	Anseba Adibosqual	38.39	15.42	894	R	N	AA	1999	10	2000	09	[49]
Eritrea	Anseba Hagaz	37.39	15.42	894	R	N	AA	1999	10	2000	09	[49]
Eritrea	Dasse	37.29	14.55	916	R	N	AG	1999	01	1999	12	[48]
Eritrea	Debub Maiaini	39.06	14.48	1809	R	PWB	AA	1999	10	2000	09	[49]
Eritrea	Gash Barka Dasse	37.29	14.55	610	R	N	AA	1999	10	2000	09	[49]
Eritrea	Gash Barka Hiletsidi	36.39	15.07	610	R	N	AA	1999	10	2000	09	[49]
Eritrea	Hagaz	38.17	15.42	883	R	N	AG	1999	01	1999	12	[48]
Eritrea	Hiletsidi	36.39	15.07	586	R	N	AG	1999	01	1999	12	[48]
Eritrea	Maiaini	39.09	14.49	1554	R	N	AG	1999	01	1999	12	[48]
Ethiopia	Baka-Boro	36.52	8.58	1316	R	I	AG	2010	02	2011	01	[50]
Ethiopia	Chano	37.58	6.10	1211	R	N	AA	2009	05	2010	04	[51]
Ethiopia	Dirama	38.25	8.10	2031	PU	PWB	AA	2008	07	2010	06	[52]
Ethiopia	Gambela town	34.67	8.25	551	R	PWB	AF, AG	1968	01	1968	12	[53]
Ethiopia	Gambela villages	34.67	8.25	551	R	PWB	AF, AG	1968	01	1968	12	[53]
Ethiopia	Hobe	38.29	8.02	1834	PU	PWB	AA, AP	2008	07	2010	06	[52]
Ethiopia	Machara	36.42	8.58	1351	R	N	AG	2010	02	2011	01	[50]
Ethiopia	Wama Kusaye	36.49	8.59	1319	R	I	AG	2010	02	2011	01	[50]
Gabon	Benguia	13.52	−1.63	37	R	N	AG	2003	05	2004	04	[54]
Gabon	Dienga	12.68	−1.87	772	R	N	AG	2003	05	2004	04	[54]
Ghana	Abotanso	−0.26	6.09	374	R	N	AF, AG	2004	09	2005	08	[55]
Ghana	Gyidim	−1.11	6.81	408	R	N	AG	2003	11	2005	10	[55]
Ghana	Hwidiem	−2.35	6.93	186	R	N	AG	2003	11	2005	10	[55]
Ghana	Kintampo	−1.73	8.05	354	R	N	AF, AG	2003	11	2006	10	[56]
Ghana	KND Irrigated	−1.33	10.84	212	R	I	AF, AG	2001	06	2002	05	[57]
Ghana	KND Lowland	−1.33	10.84	212	R	N	AF, AG	2001	06	2002	05	[57]
Ghana	KND Rocky Highland	−1.33	10.84	212	R	N	AF, AG	2001	06	2002	05	[57]
Ghana	LowCost	−1.33	6.38	250	U	N	AG	2003	11	2005	10	[55]
Ghana	NHDSS	−1.33	10.84	287	R	PWB	AF, AG	2001	11	2004	10	[58]

Table 3. Malaria EIR database entries (Ivory Coast–Senegal). Pd = population density type, SY = start year of data, EY = End year of data, SM = start month of data, EM = end month of data, Ref = article from which the data was obtained.

Country	Site	Lon	Lat	Elevation	Pd	Hydrology	Vector Species	SY	SM	EY	EM	Ref
Ivory Coast	Alloukoukro	−5.15	7.69	334	R	PWB	AF, AG	1991	01	1992	12	[59]
Ivory Coast	Batouapleu	−8.32	6.79	243	R	I	AF, AG	1998	04	2000	03	[60]
Ivory Coast	Beoue	−7.87	6.55	268	R	N	AG	1998	04	1999	03	[60]
Ivory Coast	Bepleu	−8.05	6.99	285	R	I	AG	1998	04	1999	03	[60]
Ivory Coast	Bietouo	−8.13	6.90	283	R	I	AF, AG	1998	04	2000	03	[60]
Ivory Coast	Binguebougou	−5.81	9.53	357	R	I	AG	1996	12	1997	11	[60]
Ivory Coast	Bouake Dar es Salam	−5.04	7.69	325	PU	N	AG	1991	01	1992	12	[61]
Ivory Coast	Bouake Kennedy	−5.01	7.69	351	PU	N	AG	1991	01	1992	12	[61]
Ivory Coast	Bouake Sokoura	−5.01	7.90	361	PU	N	AG	1991	01	1992	12	[61]
Ivory Coast	Bouake Tolakouadiokro	−5.02	7.68	331	PU	I	AG	1991	01	1992	12	[61]
Ivory Coast	Bouake Zone	−5.02	7.71	367	PU	I	AG	1991	01	1992	12	[61]
Ivory Coast	Bouenneu	−8.23	6.93	251	R	I	AG	1998	04	2000	03	[60]
Ivory Coast	Danta	−8.16	7.02	272	R	N	AG	1998	04	1999	03	[60]
Ivory Coast	Douandrou	−7.92	6.54	237	R	N	AG	1998	04	1999	03	[60]
Ivory Coast	Douedy-Guezon	−7.75	6.57	266	R	N	AG	1998	04	2000	03	[60]
Ivory Coast	Fapaha	−5.83	9.49	361	R	I	AG	1996	12	1997	11	[60]
Ivory Coast	Finneu	−8.15	6.99	274	R	I	AG	1998	04	2000	03	[60]
Ivory Coast	Folofonkaha	−5.21	8.58	328	R	N	AF, AG	1996	12	1997	11	[60]
Ivory Coast	Ganse	3.9	8.617	392	R	N	AF, AGSS, AN	2000	07	2002	06	[62]
Ivory Coast	Gbahouakaha	−5.41	9.50	345	R	I	AG	1996	12	1997	11	[60]
Ivory Coast	Gbontegleu	−8.24	6.97	257	R	I	AG	1998	04	2000	03	[60]
Ivory Coast	Glopaoudy	−7.63	6.55	234	R	N	AG	1998	04	1999	03	[60]
Ivory Coast	Kabolo	−4.99	8.19	268	R	N	AF, AG	1996	12	1997	11	[60]
Ivory Coast	Kafine	−5.67	9.27	322	R	N	AG	1995	01	1995	12	[63]
Ivory Coast	Kaforo	−5.67	9.29	329	R	N	AF,AG	1996	12	1997	11	[60]
Ivory Coast	Kombolokoura	−5.88	9.33	366	R	N	AF, AG	1996	12	1997	11	[60]
Ivory Coast	Meantouo	−8.14	6.89	277	R	I	AG	1998	04	1999	03	[60]
Ivory Coast	Nanbekaha	−5.69	9.29	320	R	I	AF, AG	1996	12	1997	11	[60]
Ivory Coast	Nombolo	−5.83	9.41	379	R	I	AF, AG	1996	12	1997	11	[60]
Ivory Coast	Nongotchenekaha	−5.40	9.52	332	R	I	AF, AG	1996	12	1997	11	[60]
Ivory Coast	Ounandiekaha	−5.17	8.36	286	R	PWB	AF, AG	1996	12	1997	11	[60]
Ivory Coast	Pepleu	−8.20	6.95	256	R	I	AF, AG	1998	04	2000	03	[60]
Ivory Coast	Petionara	−5.12	8.43	277	R	N	AF, AG	1996	12	1997	11	[60]

Table 3. *Cont.*

Country	Site	Lon	Lat	Elevation	Pd	Hydrology	Vector Species	SY	SM	EY	EM	Ref
Ivory Coast	Pohan	−7.93	6.54	249	R	N	AG	1998	04	2000	03	[60]
Ivory Coast	Seileu	−8.17	7.10	337	R	N	AG	1998	04	1999	03	[60]
Ivory Coast	Tai	−7.12	5.75	218	R	N	AF, AG	1995	07	1996	06	[64]
Ivory Coast	Tiemelekro	−4.617	6.5	91	R	N	AF, AG	2002	01	2003	12	[65]
Ivory Coast	Tioroniaradougou	−5.70	9.36	361	R	N	AG	1996	12	1997	11	[60]
Ivory Coast	Vetouo	−8.12	6.96	280	R	I	AG	1998	04	2000	03	[60]
Ivory Coast	Yotta	−8.19	7.15	340	R	I	AF, AG	1998	04	2000	03	[60]
Ivory Coast	Zaïpobly and Gahably	-7.0	5.5	180	R	N	AF,AG	1995	07	1997	06	[64]
Ivory Coast	Zatta	−5.39	6.88	188	R	I	AF	2002	01	2003	12	[65]
Ivory Coast	Zeale	−8.16	6.99	265	R	I	AG	1998	04	2000	03	[60]
Ivory Coast	Ziglo	−7.80	6.57	256	R	N	AF, AG	1998	04	2000	03	[60]
Ivory Coast	Zoleu	−8.31	6.81	236	R	I	AG	1998	04	2000	03	[60]
Kenya	Ahero	34.92	−0.18	1152	PU	I	AF, AG	1989	08	1990	07	[66]
Kenya	Asembo	34.40	−0.18	1148	PU	N	AF AG	1988	03	1989	02	[67]
Kenya	Kameichiri	37.62	−0.82	1188	PU	N	AA	2004	04	2005	03	[68]
Kenya	Kilifi	39.85	−3.62	18	PU	N	AG	1990	12	1991	11	[69]
Kenya	Kisian	34.67	−0.07	1246	PU	PWB	AF, AG	1985	10	1988	09	[70]
Kenya	Loboi	35.98	−0.47	2285	PU	PWB	AF, AG	1994	01	1994	12	[71]
Kenya	Mbuinjeru	37.62	−0.82	1141	PU	I	AA	2004	04	2005	03	[68]
Kenya	Mumias	34.49	0.34	1311	PU	N	AF, AG	1995	05	1996	04	[72]
Kenya	Murinduko	37.45	−0.57	1311	PU	N	AA	2004	04	2005	03	[68]
Kenya	Nyanza	34.76	−0.09	1170	U	PWB	AF, AG	1972	08	1973	07	[73]
Kenya	Perkerra	35.98	−0.47	2285	R	I	AG	1994	01	1994	12	[71]
Kenya	Saradidi	34.24	−0.02	1221	R	PWB	AF, AG	1985	10	1988	09	[70]
Kenya	Sokoke	39.88	−3.33	125	R	N	AG	1990	12	1991	11	[69]
Madagascar	Manarintsoa	47.42	−19.00	1290	R	I	AF, AG	1988	10	1989	09	[74]
Madagascar	Saharevo	48.10	−18.82	873	R	I	AA, AF, AG, AMA	2003	10	2004	09	[75]
Madagascar	St Marie Ambodifotatra	49.88	−17.00	3	R	PWB	AF, AG	1988	11	1990	10	[74]
Mali	Ndebougou Sector	−5.96	14.327	280	R	N	AGSL	1999	04	2000	03	[76]
Mali	Molodo Sector	−6.03	14.257	280	R	N	AGSL	1999	04	2000	03	[76]
Mali	Sotuba	−7.91	12.66	323	R	N	AG	1998	01	1998	12	[77]
Mozambique	CdSLCMPC	32.57	−25.92	35	PU	N	AA, AF	1985	01	1985	12	[78]
Mozambique	Manhica	32.48	−25.44	20	R	PWB	AF, AG	2001	10	2002	09	[79]
Nigeria	Apapa	3.37	6.46	5	U	PWB	AGSS, AME	1945	06	1946	05	[80]
Nigeria	Ajura	8.94	12.48	390	R	N	AF, AG	1970	11	1973	10	[81]
Nigeria	Jaya	9.18	12.38	380	R	N	AF, AG	1970	11	1972	10	[81]
Nigeria	Matsari	9.08	12.38	382	R	N	AF, AG	1970	11	1972	10	[81]
Nigeria	Nasakar	9.12	12.47	379	R	N	AF, AG	1970	11	1972	10	[81]
Nigeria	Rafin Marke	9.03	12.48	382	R	N	AF, AG	1970	11	1972	10	[81]
Nigeria	Sungungun	8.97	12.32	389	R	N	AF, AG	1970	11	1972	10	[81]
Nigeria	Ungua Gaiya Kuwaru	8.89	12.36	395	R	N	AF, AG	1970	11	1973	10	[81]
Nigeria	Unguwar Bako	8.99	12.55	388	R	N	AF, AG	1970	11	1972	10	[81]
Senegal	Aere Lao	−14.32	16.4	13	R	N	AA	1982	05	1983	04	[82]
Senegal	Affiniam Diagobel Tendimane	−16.24	14.28	12	R	N	AG	1985	01	1986	12	[83]
Senegal	Barkedji	−14.88	15.28	349	R	N	AA, AG	1994	06	1996	05	[84]
Senegal	Boke Dialllobe	−14	16.07	28	R	N	AG	1982	05	1983	04	[82]
Senegal	Dielmo	−16.42	13.73	32	R	PWB	AF, AG, AA	1990	04	1995	03	[85]
Senegal	Diohine	−16.50	14.50	8	R	PWB	AG	1995	01	1995	12	[86]

Table 4. Malaria EIR database entries (Senegal–Zambia). Pd = population density type, SY = start year of data, EY = End year of data, SM = start month of data, EM = end month of data, Ref = article from which the data was obtained.

Country	Site	Lon	Lat	Elevation	Pd	Hydrology	Vector Species	SY	SM	EY	EM	Ref
Senegal	Diomandou Dieri	−14.43	16.52	10	R	I	AG	1990	06	1992	05	[87]
Senegal	Diomandou Walo	−14.43	16.52	10	R	I	AG	1990	06	1992	05	[87]
Senegal	Kotiokh	−16.53	14.48	7	R	PWB	AG	1995	01	1995	12	[86]
Senegal	Ndiop	−16.36	15.95	6	R	N	AG, AA	1993	01	1996	12	[85]
Senegal	Ngayokheme	−16.43	14.53	11	R	N	AG	1995	01	1995	12	[86]
Senegal	Pikine	−17.40	14.75	10	U	PWB	AA	1979	10	1981	01	[88]
Senegal	Takeme and Ousseuk	−16.24	14.28	21	R	N	AG	1985	01	1986	12	[83]
Senegal	Toulde Galle	−14.48	16.53	11	R	N	AG	1990	06	1992	05	[87]
Senegal	Wassadou	−14.33	12.75	26	R	PWB	AG	1992	09	1993	08	[89]
Sierra Leone	Bayama	−11.67	8.00	102	R	PWB	AG	1990	11	1991	10	[90]
Sierra Leone	Mendewa	−11.48	8.17	325	R	N	AG	1990	01	1990	12	[91]
Sierra Leone	Nyandeyama	−11.62	8.12	118	R	N	AG	1990	01	1990	12	[91]
Tanzania	Bagamoyo	38.26	−5.04	1093	R	N	AF, AG	1995	10	1996	09	[91]
Tanzania	Balangai	38.28	−4.56	1230	R	N	AF, AG	1995	10	1996	09	[91]
Tanzania	Chasimba	38.82	−6.58	36	R	N	AF,AG	1992	01	1992	12	[92]
Tanzania	Chekereni	37.36	−3.38	763	PU	I	AA	1994	07	1995	06	[93]
Tanzania	Idete	36.42	−8.66	295	R	PWB	AF,AG	1992	07	1994	06	[94]
Tanzania	Kerege	39.05	−6.59	36	R	PWB	AF,AG	1992	01	1992	12	[92]
Tanzania	Kisangasangeni	37.39	−3.39	759	PU	N	AA	1994	07	1995	06	[93]
Tanzania	Kongo	38.83	−6.53	19	R	PWB	AF,AG	1992	01	1992	12	[92]
Tanzania	Kwameta	38.29	−5.08	671	R	N	AF,AG	1995	10	1996	09	[95]
Tanzania	Kwamhanya	38.28	−5.04	596	R	N	AF,AG	1995	10	1996	09	[95]

Table 4. *Cont.*

Country	Site	Lon	Lat	Elevation	Pd	Hydrology	Vector Species	SY	SM	EY	EM	Ref
Tanzania	Magundi	38.28	−5.04	671	R	N	AF, AG	1995	10	1996	09	[95]
Tanzania	Mapinga	39.07	−6.60	59	R	N	AF,AG	1992	01	1992	12	[92]
Tanzania	Matimbwa	38.87	−6.50	21	R	PWB	AF,AG	1992	01	1992	12	[92]
Tanzania	Michenga	36.63	−8.12	258	R	PWB	AG	1990	01	1990	12	[96]
Tanzania	Milungui	38.23	−4.45	1636	R	N	AF, AG	1995	10	1996	09	[95]
Tanzania	Mvuleni	37.33	−3.39	786	PU	N	AA	1994	07	1995	06	[93]
Tanzania	Namawala	36.40	−8.15	289	R	I	AF, AG	1990	08	1991	07	[97]
Tanzania	Pemba Island	39.75	−5.18	36	PU	N	AGSL	1958	01	1958	12	[98]
Tanzania	Yombo	38.85	−6.59	36	R	N	AF, AG	1992	01	1992	12	[97]
Tanzania	Zinga	38.99	−6.52	22	R	N	AF, AG	1992	01	1992	12	[97]
Uganda	Apac-Olami	32.56	1.89	1053	R	N	AF, AG	2001	06	2002	05	[99]
Uganda	Arua-Cilio	31.02	3.11	976	PU	N	AF, AG	2001	06	2002	05	[99]
Uganda	Jinja School	33.21	0.43	1166	U	N	AF, AG	2001	06	2002	05	[99]
Uganda	Kabale villages	29.98	−1.22	1888	PU	N	AG	1997	10	1998	09	[100]
Uganda	Kanungu Kihihi	29.70	0.59	758	R	N	AF, AG	2001	06	2002	05	[99]
Uganda	Kyenjojo Kasiina	30.65	0.62	1361	R	N	AF, AG	2001	06	2002	05	[99]
Uganda	Tororo-Namwaya	34.18	0.68	1143	PU	N	AF, AG	2001	06	2002	05	[99]
Zambia	Chidakwa	26.791	−16.393	1000	R	N	AA	2005	11	2006	10	[101]
Zambia	Lupata	26.791	−16.393	1000	R	N	AA	2005	11	2006	10	[101]

3.2. Application/case use of the Data

3.2.1. EIR Seasonality

A qualitative examination of the data is performed by showing a cursory analysis of the EIR seasonality to confirm if broad relationships with precipitation observed in case data at specific sites are observed. For example, a previous work in Niger, where rains are seasonally associated with the West African monsoon, shows cases following rainfall with a lag of one to two months, confirming general experience of malaria seasonality in the region, which contrasts with that of Central Africa where intense year-round transmission can be sustained [102]. A preliminary examination of the relationship between rainfall and EIR is made in Figure 2. EIR variability is seen to follow that of rainfall closely in the Sahel, Guinea and equatorial EA zones, with a lag of about 2 months in the former two locations, while a longer lag of 3 months is notable in the equatorial EA region. The slower response of EIR is expected there due to the cooler temperatures at the higher altitudes in the latter region. There is little seasonality in the EIR in equatorial WA region, where persistent rainy conditions and warm temperatures sustain year-round transmission. These characteristics of the EIR seasonality in the database confirm findings from previous analysis and provide a qualitative evaluation of its reliability. Further detailed analysis of the link between the observed EIR and climate on seasonal and multi-annual timescales will be pursued in a separate article. The rainfall dataset used in the validation of the dataset is the daily African Rainfall Climatology, version 2 (ARC_2 [103]), a satellite infrared based gridded precipitation product for Africa available from 1983 to date at 0.1° spatial resolution. The temperature data used in the validation is that of the European Center for Medium-Range Weather Forecasts Interim Reanalysis (ERAI) temperature dataset [104] and available from 1979 to date at a spatial resolution of 0.75°.

3.2.2. Vector Type

The geographical distributions of the main malaria vectors identified from the publications were also examined and displayed in Figure 3. The major vectors observed include *Anopheles gambiae* (AG), *Anopheles funestus* (AF), *Anopheles arabiensis* (AA), *Anopheles nili* (AN) and *Anopheles moucheti* (AM). The most dominant and sympatric vectors were found to be AG, AF and AA. These vectors are known to live long and remain stable in the part of Africa where they exist. *Anopheles arabiensis* were observed mostly in markedly seasonal rainfall areas such as the Sahel and in dry Savannah zones of East Africa. While the AG vectors were found adaptive to all the variable ecology, AF vectors were mostly confined to relatively humid areas in West and East Africa. *Anopheles nili* and AM were mostly limited to moist areas around Central and East Africa. The dominant malaria vectors identified corroborate previous works [105–107]. The ecological confinements of the malaria vectors may be an indication of climatic factors having an influence on their choice of habitat. The preference of AA for sunlit breeding sites with limited vegetation may explain their isolation to drier Savannah areas [105,106]. The sympatric association of the observed malaria vectors is also supported by existing literature. The AG vectors for instance mostly live in sympatry with AA and AF with all of them sustaining the perennial inoculation of malaria parasite [54,108]. In such sympatry, AG and AF mostly dominate other vectors year-round with peak population in the rainy and dry season respectively [109,110].

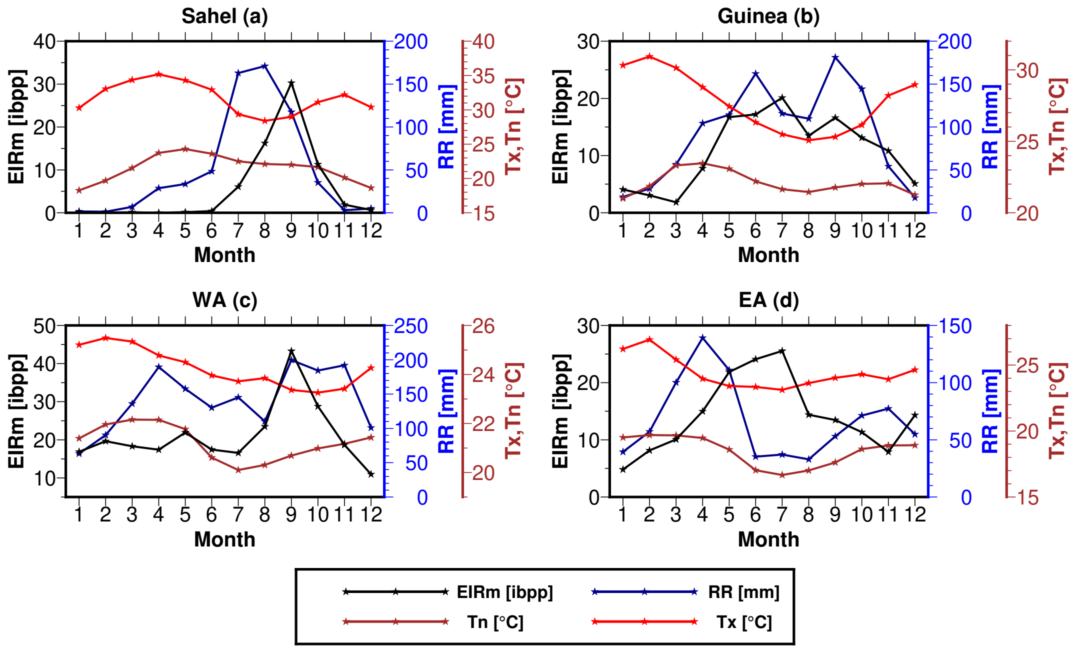

Figure 2. Comparison of monthly EIR and rainfall (ARC_2) and temperature (ERA Interim adjusted to location height for each field survey location). Black line: average EIR; Blue line: average rainfall (RR). Average temperature: minimum (Tn, brown) and maximum (Tx, red).

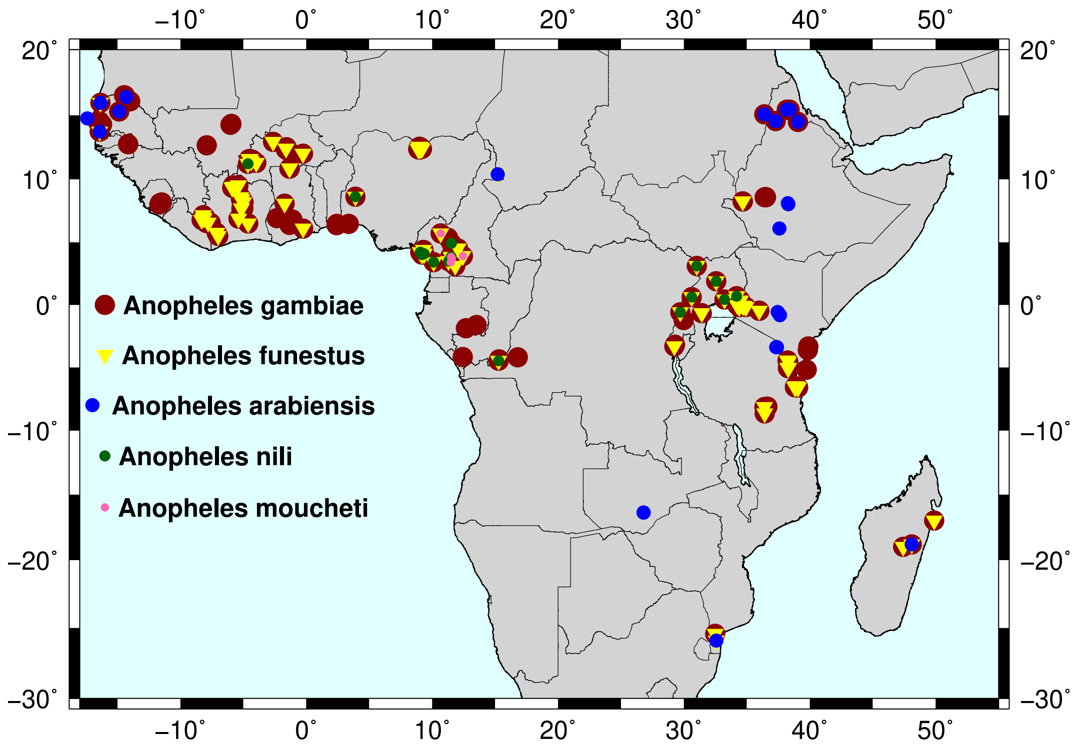

Figure 3. The sympatric association and geographical distribution of dominant malaria vectors in Sub-Saharan Africa.

4. Discussion

The dataset is based on a literature review of field surveys and thus the data is secondary and cross-validation of original samples is not possible. Nevertheless, to ensure that selected surveys were inter-comparable, strict control was made on the methods used in the field studies (see Section 2.3 in the methods above). To guard against errors that may occur during the manual procedures of the digitization process, all database entries were subjected to blind confirmation by a second individual who referred only to the original reference to ensure all EIR values, location coordinates, and population/hydrological classifications were correctly registered.

It is worth noting that the study relied on EIR_m data that could be obtained during the online search and contacts with researchers. It is, therefore, not claiming to have identified all the EIR_m data available in Sub-Saharan Africa. Again, the EIR_m estimates were obtained from WHO recommended standard mosquito sampling techniques namely HLC, PSC and LTC. These sampling techniques are not standardized [111], hence, estimates of HBR from each method differs and may not represent the exact individual exposure levels in a study area [112]. The study also acknowledges that the time series of the EIR_m data are spatially and temporally limited (see Table 1) since they were unavailable for many settings (see Figure 1). The entomological surveys appear to be concentrated at locations where malaria is prevalent. Future estimates of EIR_m should focus on areas with scarce data (see Figure 1) for spatial homogeneity of the EIR_m data distribution. The spatial and temporal limitations of the data is due to the fact that the mosquito sampling methods are both labor and capital intensive. For this reason, the daily HBR and CSPR estimations are usually not conducted each day of the month but mostly limited to just one or two days in the month. An average daily value is then determined and scaled up for the month by multiplying the average daily value by the number of days of the month. In areas where mosquitoes are rarely infected or rare, it is disadvantageous to limit the mosquito sampling to just a few days in a month. It is also worth noting that the EIR_m estimates are also subjected to mosquito collector skills, their attraction to mosquitoes or instrumental errors [113]. These biases and the uncertainties associated with the digitization processes may have an impact on the accuracy of the EIR_m data.

Despite the data collection uncertainties, the results consolidate evidence of the usefulness of the archived EIR_m data for research purposes. The data can inform our understanding of how climate and environment may have an influence on the intensity of seasonal malaria transmission, clinical disease and human mortality risks as well as on malaria vector biology. The data are useful for evaluation, validation and improvement of seasonal malaria outcomes simulated by weather-driven dynamical malaria models in Africa. The data can also serve as a supplement to previous works that have described patterns of clinical malaria and morbidity in Sub-Saharan Africa. Information from the data can support decision makers to design robust frameworks for combating malaria. For instance, the data can inform our understanding of perennial and markedly seasonal malaria transmission settings. This knowledge can serve as a guide in the implementation of control measures such as malaria chemo-prevention in children and pregnant women in such malaria transmission settings [114]. It can also help in spatial targeting of control techniques and resource allocation optimization especially in areas where the diversity of the climate and environment may result in seasonal malaria transmission heterogeneity.

Author Contributions: E.I.Y. compiled the database, conducted the analysis for the figures and co-authored the manuscript; A.M.T. co-authored the manuscript; A.H.F. co-designed the project and funded the APC; V.E. co-designed the project and contributed to the database; M.D.A. blind cross-validated the database; O.J.T.B. contributed to the database; L.K.A. co-designed the project. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding and the APC was funded by Andreas H. Fink.

Acknowledgments: Sincere gratitude to Katholischer Akademischer Ausländer-Dienst (KAAD) and the University of Cologne, Germany for their support during the PhD studies.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations have been used in this manuscript:

PR	Parasite Rate
MAP	Malaria Atlas Project
CSPR	CircumSporozoite Protein Rate
EIR	Entomological Inoculation Rate
HBR	Human Biting Rate
HLC	Human Landing Catches
PSC	Pyrethrum Spray Catches
LTC	Light Trap Catches
PU	Peri-Urban
PWB	Permanent Water Body
GPDWv3	Gridded Population Density data of the World, version 3
AG	Anopheles gambiae
AF	Anopheles funestus
AA	Anopheles arabiensis
AN	Anopheles nili
AM	Anopheles moucheti

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