

Supplemental files

Text S1. Spatial Autocorrelation Statistics

Global Moran's I value

One often used technique for evaluating spatial dependency in spatial lattice data is Moran's test [1]. This test can be directly linked to the data or to the residuals of a few spatial relapses. In this study, let $\{Z_{i(t)}: i = 1, \dots, m = 115\}$ represent spatially referenced data (or residuals) for $m = 115$ spatial locations (regions) at time t , where $t = 2011, \dots, 2020$. Then, we use the formula

$$I(t) = \frac{m \sum_{i=1}^m \sum_{j=1}^m w_{ij} (Z_{i(t)} - \bar{Z}(t))(Z_{j(t)} - \bar{Z}(t))}{(\sum_{i=1}^m \sum_{j=1}^m w_{ij} (\sum_{i=1}^m (Z_{i(t)} - \bar{Z}(t))^2))}, \quad (S1)$$

to Moran's I statistic, where $\bar{Z}(t) = (1/m) \sum_{i=1}^m Z_{i(t)}$ is the spatial mean at each specific year and w_{ij} are spatial adjacency "weights" between locations i and j (where we require $w_{ii} = 0$, for all $i = 1, \dots, 115$). As a result, the formula for calculating the $z_{I(t)}$ - score for the Moran I statistic is $z_{I(t)} = \frac{I(t) - E(I(t))}{\sqrt{V(I(t))}}$, where $E(I(t)) = -1/(m-1)$ and $V(I(t)) = E[I(t)^2] - (E[I(t)])^2$, with $E(I(t))$ representing the expected value and $V(I(t))$ representing the variance.

Equation (SError! Reference source not found.) demonstrates that the Moran's I statistic is essentially a weighted form of the standard Pearson correlation coefficient, with the weights representing the geographic proximity weights. It takes values ranging from -1 to 1. If (SError! Reference source not found.) is positive, surrounding regions likely to have similar values, whereas if (SError! Reference source not found.) is negative, neighboring regions tend to have different values of *P. falciparum* or *P. vivax* malaria incidence in East African countries overall throughout the study period.

Anselin's Local Moran

Luc Anselin (Anselin 1995) established the first LISA statistic, which is known as Anselin's Local Moran [2]. The method uses Moran's "I" statistics to specific regions, allowing them to be classified as comparable or dissimilar from the nearby pattern. The definition of " $I_{i(t)}$ " is from [3]:

$$I_{i(t)} = \frac{(Z_{i(t)} - \bar{Z}(t))}{S_{Z(t)}^2} \sum_{j=1}^{m-1} [w_{ij} (Z_{j(t)} - \bar{Z}(t))] \quad (S2)$$

where $t = 2011, \dots, 2020$, $Z_{i(t)}$ is the intensity of observation i at time t , $\bar{Z}(t)$ is the mean intensity over all observations at time t , $Z_{j(t)}$ is intensity for all other observations, j (where $j \neq i$) at time t , $S_{Z(t)}^2$ is the variance over all observations at time t , and w_{ij} is a distance weight for the interaction between observations i and j during the study period. The first term in (SError!

Reference source not found.) refers only to observation i while the second term is the sum of the weighted values for all other observations (but not including i itself). The expected “ $I_{i(t)}$ ” is formulated as $E(I_{i(t)}) = \frac{\sum_{i=1}^m w_{ij}}{m-1}$, where w_{ij} is the distance weight for the interaction between observations i and j . The variance, standard deviation, and an approximate (pseudo) standardized score of $I_{i(t)}$ is $Var(I_{i(t)}) = \frac{(\sum_{i=1}^m \sum_{j=1}^m w_{ij}^2)(m-b_2)}{m-1} + \frac{2w_{i(kh)}(2b_2-m)}{(m-1)(m-2)} + \frac{(\sum_{i=1}^m \sum_{j=1}^m w_{ij}^2)}{(m-1)^2}$, $S(I_{i(t)}) = \sqrt{Var(I_{i(t)})}$, and $Z(I_{i(t)}) = \frac{I_{i(t)} - E(I_{i(t)})}{S(I_{i(t)})}$. We define $b_2 = \frac{\sum_{i=1}^m \frac{(Z_{i(t)} - \bar{Z}(t))^4}{m}}{\left[\sum_{i=1}^m \frac{(Z_{i(t)} - \bar{Z}(t))^4}{m} \right]^2}$ and $2w_{i(kh)} =$

$\sum_{k=1}^{m-1} \sum_{h=1}^{m-1} W_{ik} W_{ih}$, where $k \neq i$ and $h \neq i$. This term is twice the sum of the cross-products of all weights for i with themselves, using k and h to maintain a strategic distance from the use of indistinguishable subscripts.

There are various applications for Anselin's Local Moran. It can, first, recognize areas that are distinct from those of its neighbors. This can serve as an excellent starting point for identifying regions that either have lower malaria incidence rates (a cold spot) or higher malaria incidence rates (a hot spot) than the neighboring regions. Researchers may focus on the problems that make the area more vulnerable to hot spots or cold spots to determine the factors that reduce or increase the incidence of malaria throughout the study period. Second, identifying "outliers," or areas that differ from their neighbors, is another use of Anselin's Local Moran statistic. In this case, regions with a high negative I esteem (e.g., with an “ $I_{i(t)}$ ” smaller than two standard deviations underneath the mean) are demonstrative of outliers. They either have a high incidence rate relative to the low incidence rate of their neighbors, or they exhibit the opposite pattern, with low incidence rates among high incidence areas.

Getis-Ord Local G^*

The Getis-Ord Local G^* statistic applies the Getis-Ord "G" statistic to individual regions to examine whether certain locations are spatially related to their neighbors. Unlike the global Getis-Ord G^* , the Getis-Ord Local G^* is applied to each region, much like Anselin's Local Moran. The formulation offered here is based on that of Wong and Lee (2005) [4]. In this study, the $G^*(t)$ value at time $t = 2011, \dots, 2020$ is calculated concerning a specified search distance, namely:

$$G^*(t) = \frac{\sum_{i=1}^m \sum_{j=1}^m w_{i,j} x_i x_j}{\sum_{i=1}^m \sum_{j=1}^m x_i x_j}, \forall_{j \neq i} \quad (S3)$$

where $w_{i,j}$ is the spatial weight between features i and j , and x_i and x_j are the attribute values for features i and j , m is the number of features in the dataset (115 regions) and $\forall_{j \neq i}$ indicates that

features i and j cannot be the same feature. Therefore, $z_{G^*(t)} = \frac{G^*(t) - E[G^*(t)]}{\sqrt{V[G^*(t)]}}$ yields the $z_{G^*(t)}$ – score for the statistic, where $V[G^*(t)] = E[G^*(t)^2] - (E[G^*(t)])^2$ and $E[G^*(t)] = \frac{\sum_{i=1}^n \sum_{j=1}^n w_{ij}}{n(n-1)}$, $\forall_{j \neq i}$.

The Getis-Ord Local G^* is excellent at distinguishing hot and cold locations. As previously demonstrated, Anselin's Local Moran can only detect positive or negative spatial autocorrelation, or how similar or unlike the regions are to one another. Those areas with positive spatial autocorrelation may be the result of high-value regions being close to another high-value region, or they may be the result of low-value regions being close to another low-value region of *P. falciparum* or *P. vivax* malaria incidence in East African nations between 2011 and 2020. The Getis-Ord Local G^* is able to differentiate between the two types.

References

1. Waller LA, Gotway CA. Applied Spatial Statistics for Public Health Data. Hoboken, NJ, USA: John Wiley & Sons, Inc.; 2004.
2. Anselin L. Local Indicators of Spatial Association-LISA. Geogr Anal. 1995;27:93–115.
3. Getis A, Ord J. Local spatial statistics: an overview. In: Longley P, Batty M, editors. Spatial Analysis: Modelling in a GIS Environment. New York: John Wiley & Sons; 1996. p. 261–77.
4. Wong DWS, Lee J. Statistical analysis of geographic information with ArcView GIS and ArcGIS. Hoboken, N.J.: John Wiley & Sons; 2005.

Table S1 Global Moran’s I autocorrelation value for annual malaria incidence cases of *Plasmodium falciparum* and *P. vivax* in the East Africa countries, 2011–2020

Year	<i>P. falciparum</i>				<i>P. vivax</i>			
	Moran’s I	Variance	Z-score	P-value	Moran’s I	Variance	Z-score	P-value
2011	0.489689	0.001770	11.84711	0.001	0.330101	0.001713	8.18826	0.001
2012	0.505370	0.001784	12.17196	0.001	0.382063	0.001702	9.47248	0.001
2013	0.514200	0.001807	12.30381	0.001	0.395372	0.001659	9.92337	0.001
2014	0.501608	0.001801	12.02499	0.001	0.409395	0.001686	10.18368	0.001
2015	0.517609	0.001799	12.40971	0.001	0.401972	0.001708	9.93723	0.001
2016	0.496624	0.001797	11.92337	0.001	0.339546	0.001729	8.37707	0.001
2017	0.537914	0.001788	12.92825	0.001	0.237993	0.001310	6.81792	0.001
2018	0.512486	0.001802	12.27989	0.001	0.211645	0.000996	6.98380	0.001
2019	0.431367	0.001737	10.55943	0.001	0.217911	0.001029	7.06811	0.001
2020	0.454563	0.001719	11.17513	0.001	0.211244	0.000960	7.09921	0.001

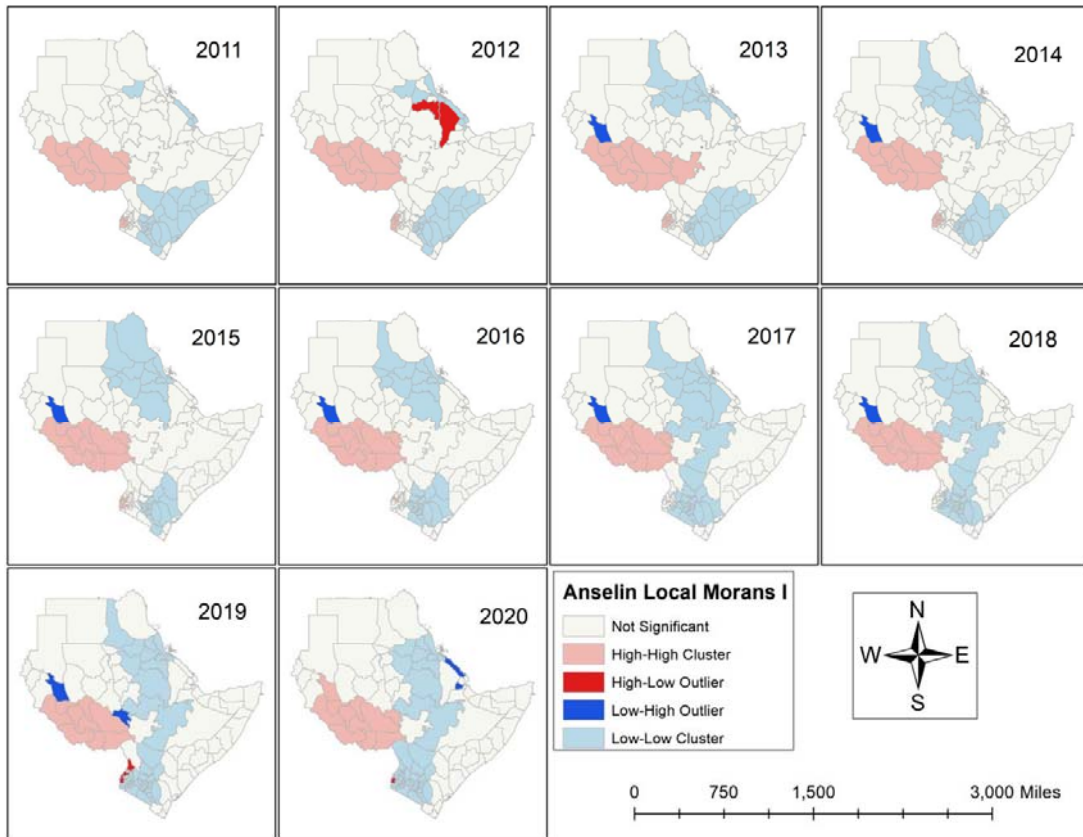


Fig. S1 Cluster and outlier analysis of the *Plasmodium falciparum* at regional level in Eastern Africa countries from 2011 to 2020

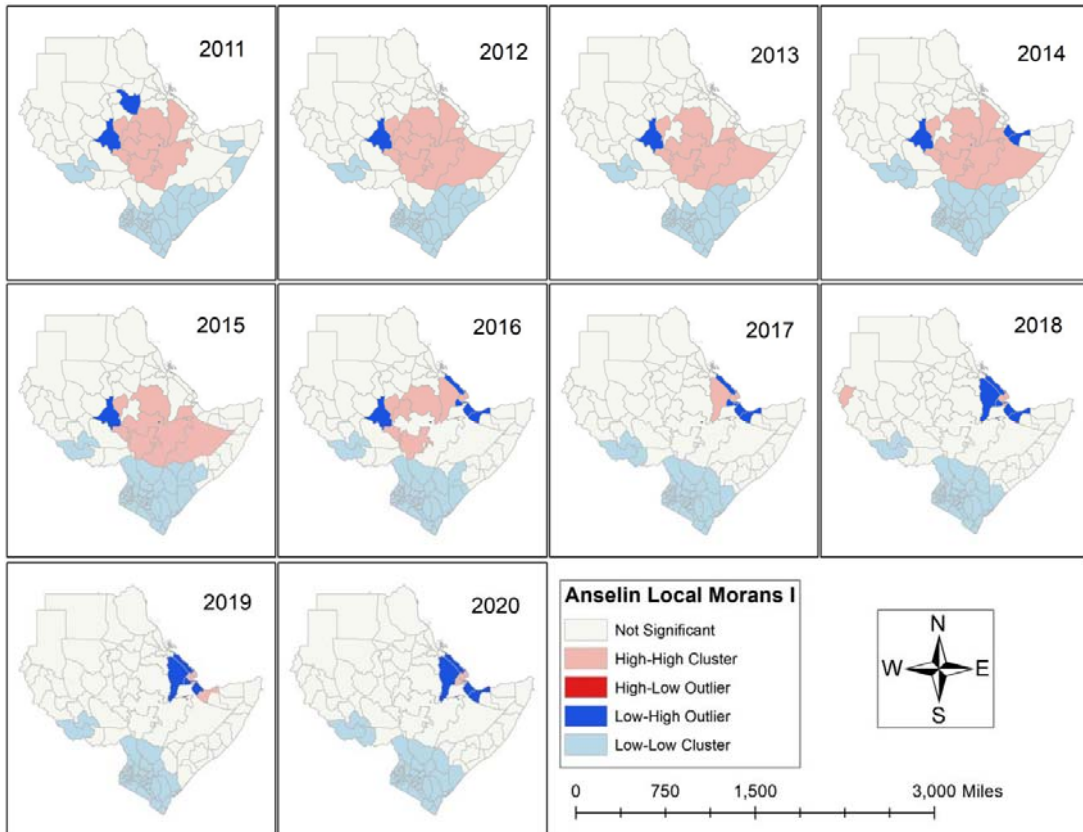


Fig. S2 Cluster and outlier analysis of the *Plasmodium vivax* at regional level in Eastern Africa countries from 2011 to 2020

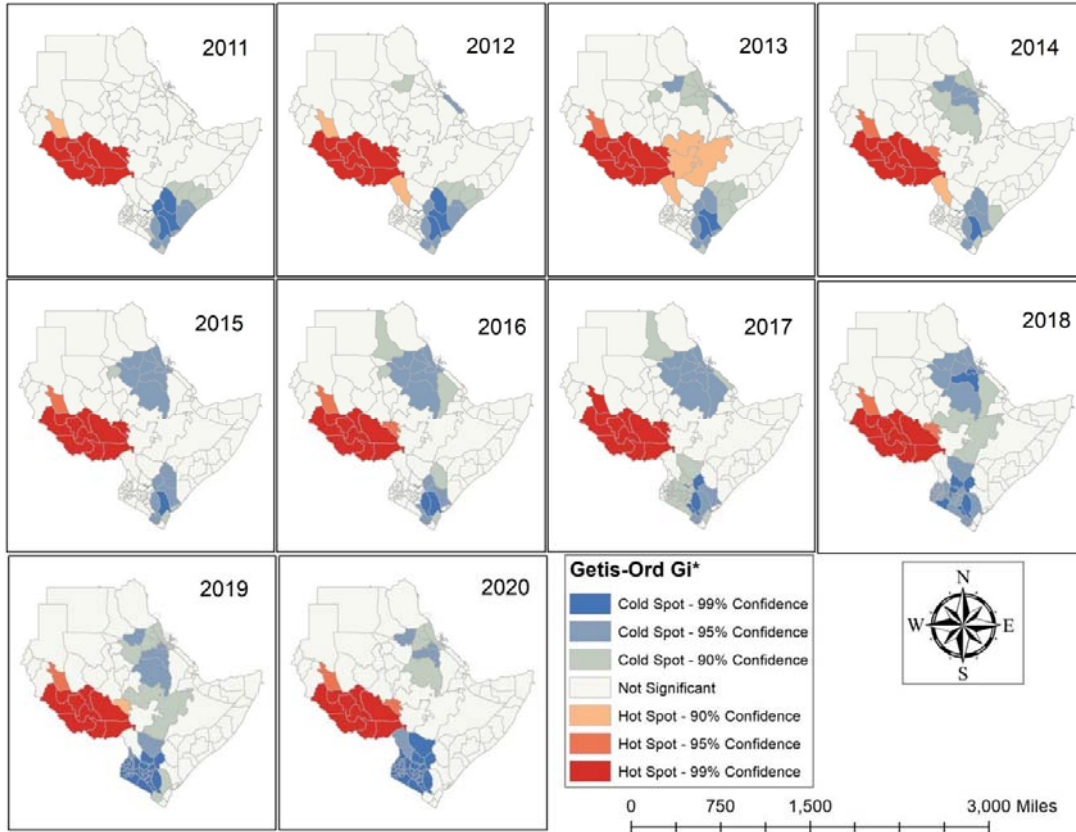


Fig. S3 Hot Spot Analysis of the *Plasmodium falciparum* at regional level in Eastern Africa countries from 2011 to 2020

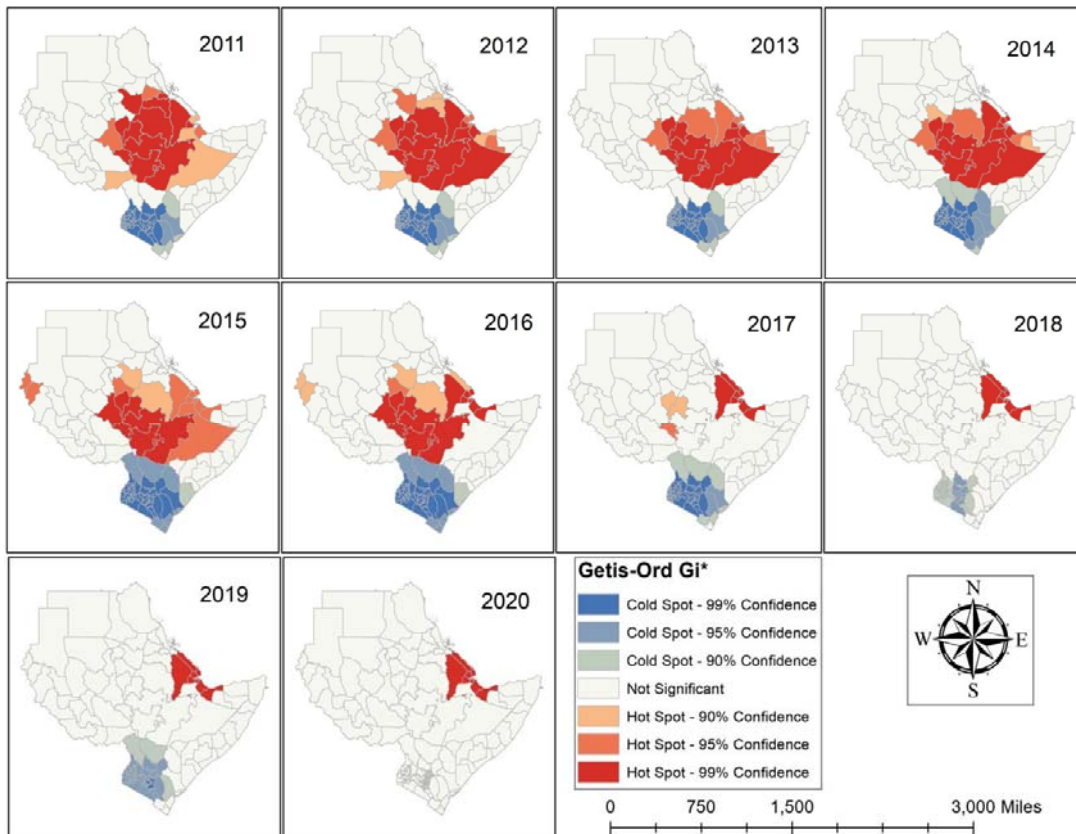


Fig. S4 Hot Spot Analysis of the *Plasmodium vivax* at regional level in Eastern Africa countries from 2011 to 2020

Table S2 Observed value of the *P. falciparum* yearly malaria incidence rates

RID	Country	Region	<i>P. falciparum</i> yearly malaria incidence rates									
			2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
1	Djibouti	Ali Sabieh	0.029	0.019	1.104	8.650	7.837	9.838	8.183	12.394	25.797	28.244
2	Djibouti	Dikhil	0.018	0.011	0.776	5.891	5.368	5.977	4.123	6.671	17.543	19.054
3	Djibouti	Djibouti	0.001	0.001	0.031	0.292	0.276	0.400	0.323	0.537	1.049	1.204
4	Djibouti	Obock	0.988	0.498	25.562	195.540	175.264	225.279	181.640	293.475	564.791	577.906
5	Djibouti	Tadjourah	0.520	0.313	18.503	159.214	148.138	188.850	150.466	240.826	464.459	475.873
6	Eritrea	Anseba	10.817	5.218	3.068	7.432	5.204	8.445	9.995	9.760	21.318	18.493
7	Eritrea	Debub	16.876	7.219	3.590	7.961	5.419	9.430	11.888	11.929	27.247	23.523
8	Eritrea	Debubawi Keyih Bahri	20.039	11.383	8.051	21.167	14.368	22.729	27.981	26.938	49.283	38.858
9	Eritrea	Gash Barka	25.223	20.156	17.246	46.979	28.853	32.427	25.971	19.743	37.881	31.834
10	Eritrea	Maekel	8.508	3.645	1.914	4.530	3.061	5.078	5.952	5.747	12.641	11.188
11	Eritrea	Semenawi Keyih Bahri	12.619	5.400	2.935	7.030	5.050	8.902	11.386	11.494	25.331	21.942
12	Ethiopia	Addis Abeba	9.626	15.346	20.996	10.605	9.445	5.558	3.125	1.851	1.210	2.096
13	Ethiopia	Afar	103.034	83.537	73.561	32.471	31.047	26.445	28.201	28.456	24.955	47.345
14	Ethiopia	Amhara	170.748	94.370	55.129	19.485	16.871	15.363	18.462	19.544	17.970	35.671
15	Ethiopia	Benshangul-Gumaz	158.665	164.143	180.352	92.433	100.060	96.476	103.058	83.124	62.840	108.373
16	Ethiopia	Dire Dawa	111.106	161.693	207.417	102.640	91.223	53.527	33.617	21.022	15.560	34.157
17	Ethiopia	Gambela Peoples	157.130	170.130	185.380	97.120	109.692	111.700	129.791	110.600	81.550	129.663
18	Ethiopia	Harari People	105.712	153.463	194.802	93.083	79.083	41.391	22.781	14.031	10.808	25.305
19	Ethiopia	Oromia	79.098	145.622	212.199	109.411	109.465	78.336	53.684	35.482	25.100	45.196
20	Ethiopia	Somali	79.617	75.989	82.024	43.266	48.328	47.370	57.575	57.495	46.801	78.538
21	Ethiopia	Southern Nations, Nationalities and Peoples	112.149	115.495	123.224	60.760	62.178	52.077	51.407	44.520	35.464	59.471
22	Ethiopia	Tigray	136.260	75.251	44.366	16.732	16.094	18.689	28.559	32.819	27.861	44.951
23	Kenya	Baringo	12.848	16.579	23.560	26.825	27.341	27.968	28.962	32.537	37.334	40.041
24	Kenya	Bomet	7.318	8.443	9.936	10.872	11.565	11.472	11.878	14.063	18.153	22.518
25	Kenya	Bungoma	149.956	154.375	151.371	148.956	151.582	153.870	145.955	123.769	92.918	49.163

26	Kenya	Busia	370.526	338.746	298.963	273.741	269.342	279.227	272.407	235.897	169.331	81.657
27	Kenya	Elgeyo-Marakwet	6.668	8.008	10.900	12.537	13.631	16.315	19.149	21.328	22.416	19.374
28	Kenya	Embu	12.834	18.377	27.725	34.529	37.346	36.378	36.949	43.015	53.876	67.980
29	Kenya	Garissa	13.795	15.600	19.627	23.517	27.980	33.621	41.354	56.133	73.832	92.590
30	Kenya	Homa Bay	178.546	194.427	220.191	216.948	195.083	159.007	120.861	82.063	55.528	40.450
31	Kenya	Isiolo	12.380	17.893	28.751	35.771	38.250	39.976	41.495	49.493	58.696	69.295
32	Kenya	Kajiado	20.519	23.259	27.189	29.897	31.853	33.737	36.765	43.722	53.639	60.487
33	Kenya	Kakamega	193.916	207.657	207.477	195.733	178.420	152.783	123.311	96.285	73.402	43.100
34	Kenya	Kericho	26.236	33.327	38.895	38.822	33.496	23.868	17.463	16.299	18.800	22.079
35	Kenya	Kiambu	13.042	15.863	18.614	19.513	18.406	15.723	14.313	15.398	18.534	22.212
36	Kenya	Kilifi	70.789	64.695	62.122	66.117	78.053	98.980	118.227	134.424	144.289	140.920
37	Kenya	Kirinyaga	14.298	20.739	31.211	38.093	39.663	37.063	36.036	40.150	49.086	60.770
38	Kenya	Kisii	47.805	56.920	64.648	65.514	62.004	50.453	39.815	34.660	33.661	30.466
39	Kenya	Kisumu	220.011	246.157	258.666	239.966	198.231	138.105	86.293	60.481	46.800	37.038
40	Kenya	Kitui	14.954	18.032	23.808	26.582	27.173	29.220	32.923	42.698	59.570	80.613
41	Kenya	Kwale	109.308	113.824	124.344	131.792	137.053	143.067	140.607	139.619	136.572	126.184
42	Kenya	Laikipia	8.621	11.903	17.962	20.224	19.133	17.055	16.102	16.847	20.314	23.045
43	Kenya	Lamu	17.112	18.893	23.584	26.843	30.596	41.527	57.444	77.621	103.153	129.521
44	Kenya	Machakos	19.144	21.752	25.568	27.880	28.727	28.870	30.968	37.860	49.849	62.894
45	Kenya	Makueni	14.120	16.860	22.582	27.084	30.177	34.904	40.823	52.128	69.029	84.456
46	Kenya	Mandera	12.710	15.372	21.646	28.550	36.436	46.856	59.432	79.635	99.197	110.999
47	Kenya	Marsabit	18.255	20.115	25.246	30.287	36.048	43.534	52.466	65.426	74.327	78.845
48	Kenya	Meru	12.643	18.302	28.813	37.204	41.199	40.595	40.744	45.825	54.374	63.493
49	Kenya	Migori	134.709	149.322	163.051	160.901	149.612	123.262	91.886	65.143	49.139	38.413
50	Kenya	Mombasa	127.992	104.508	85.325	79.301	84.491	100.542	113.275	118.410	112.947	93.035
51	Kenya	Murang'a	17.057	23.165	31.450	36.286	35.886	31.431	29.033	31.772	38.931	48.362
52	Kenya	Nairobi	0.746	0.829	0.902	0.903	0.862	0.737	0.718	0.783	0.967	1.130
53	Kenya	Nakuru	11.202	14.760	19.324	21.051	20.075	16.410	13.864	13.820	15.876	17.854
54	Kenya	Nandi	102.027	126.655	142.038	135.266	109.195	67.948	39.534	28.086	24.100	21.015
55	Kenya	Narok	5.758	7.519	10.583	12.315	12.671	12.221	12.017	13.404	16.427	18.730
56	Kenya	Nyamira	32.515	38.611	42.728	42.049	38.705	31.422	26.288	25.322	28.075	30.087
57	Kenya	Nyandarua	0.171	0.251	0.330	0.327	0.275	0.202	0.166	0.167	0.197	0.234

58	Kenya	Nyeri	11.995	16.553	23.182	27.259	27.428	24.045	21.599	22.616	26.477	31.752
59	Kenya	Samburu	10.863	14.504	21.539	28.161	33.387	36.655	39.077	44.249	49.666	50.999
60	Kenya	Siaya	402.703	376.785	339.092	304.549	289.919	295.882	285.524	247.345	183.539	96.160
61	Kenya	Taita Taveta	23.330	27.238	35.846	41.519	45.074	51.754	58.087	68.343	81.656	89.660
62	Kenya	Tana River	15.765	20.192	30.025	36.154	40.374	45.914	52.948	66.022	85.473	110.913
63	Kenya	Tharaka-Nithi	14.017	19.822	29.460	36.388	39.603	38.851	39.508	45.652	55.493	68.291
64	Kenya	Trans Nzoia	28.490	27.844	28.344	32.069	40.835	57.984	75.231	78.417	68.741	39.997
65	Kenya	Turkana	56.904	54.548	55.188	61.279	77.713	108.976	133.313	136.033	102.055	52.411
66	Kenya	Uasin Gishu	13.993	16.722	19.712	21.899	23.560	24.084	25.055	25.015	24.748	18.803
67	Kenya	Vihiga	273.325	289.041	286.800	265.399	229.108	173.034	119.061	84.325	63.068	41.648
68	Kenya	Wajir	10.965	13.165	16.640	20.365	24.564	30.845	40.235	56.843	73.749	86.502
69	Kenya	West Pokot	30.396	33.796	45.096	58.443	77.976	116.177	148.139	150.577	120.731	60.513
70	Somalia	Awdal	31.915	30.462	30.776	32.573	35.857	41.870	51.728	59.411	64.426	69.832
71	Somalia	Bakool	22.198	25.235	35.249	48.420	67.191	93.382	123.716	150.329	154.857	152.198
72	Somalia	Banaadir	22.948	22.373	22.292	25.755	32.623	48.508	71.040	90.319	102.355	108.313
73	Somalia	Bari	39.572	34.879	34.638	39.757	47.879	63.952	86.781	102.687	102.581	97.528
74	Somalia	Bay	18.688	21.397	30.597	43.896	63.791	93.448	126.233	154.396	162.472	162.182
75	Somalia	Galguduud	30.644	27.005	26.930	28.835	32.564	41.482	55.128	67.652	69.654	69.444
76	Somalia	Gedo	16.508	19.721	28.162	40.717	58.923	86.712	117.817	144.780	148.644	143.366
77	Somalia	Hiiraan	37.429	35.438	38.192	43.164	52.317	68.838	88.538	106.770	108.726	108.442
78	Somalia	Jubbada Dhexe	25.752	29.858	41.019	56.236	75.122	103.523	136.439	161.084	165.217	156.806
79	Somalia	Jubbada Hoose	38.011	36.969	41.009	50.363	64.682	91.095	123.879	146.304	146.053	132.920
80	Somalia	Mudug	29.986	28.964	30.837	35.321	41.613	53.461	69.123	81.418	81.823	78.815
81	Somalia	Nugaal	34.097	31.556	31.089	34.197	39.744	52.889	72.479	87.167	86.394	79.237
82	Somalia	Sanaag	31.924	28.802	28.341	31.180	36.890	47.579	62.852	71.950	70.594	68.187
83	Somalia	Shabeellaha Dhexe	19.796	21.649	25.923	32.318	41.570	57.057	77.907	97.955	108.501	116.098
84	Somalia	Shabeellaha Hoose	17.812	20.914	27.641	37.554	52.826	76.494	105.153	129.922	138.832	141.318
85	Somalia	Sool	34.141	30.473	30.056	33.424	39.781	52.788	72.060	85.212	84.169	79.610
86	Somalia	Togdheer	55.959	42.952	35.129	33.650	38.420	50.189	68.875	81.590	82.124	79.332
87	Somalia	Woqooyi Galbeed	45.031	33.666	25.760	24.452	28.458	39.558	58.153	71.401	76.724	76.000
88	South Sudan	Central Equatoria	485.838	464.997	425.742	381.944	360.892	354.233	372.940	374.183	409.856	401.786
89	South Sudan	Eastern Equatoria	361.644	365.467	370.234	352.710	342.706	337.645	346.149	334.763	355.233	331.106

90	South Sudan	Jungoli	191.880	202.534	218.515	222.060	220.571	211.188	215.461	212.211	235.797	233.158
91	South Sudan	Lakes	275.409	264.393	258.021	247.970	241.556	234.031	246.050	249.301	286.164	287.232
92	South Sudan	North Bahr-al-Ghazal	205.873	205.198	212.134	213.303	210.104	201.474	203.536	199.843	220.955	217.175
93	South Sudan	Unity	156.672	156.875	164.265	168.614	169.903	168.740	179.084	181.598	210.823	211.606
94	South Sudan	Upper Nile	139.745	158.538	184.186	195.374	195.383	184.396	183.605	178.197	195.555	194.102
95	South Sudan	Warap	199.671	194.304	195.966	194.846	192.440	188.257	198.809	201.500	232.711	232.471
96	South Sudan	West Bahr-al-Ghazal	328.350	321.021	313.315	301.440	290.763	281.590	291.098	292.061	327.437	327.157
97	South Sudan	West Equatoria	491.131	477.066	455.807	428.471	412.703	401.849	412.766	409.962	455.398	456.670
98	Sudan	Al Jazirah	21.450	18.974	16.617	16.748	19.426	25.849	35.809	44.999	54.815	62.833
99	Sudan	Al Qadarif	43.771	43.167	41.989	41.345	39.179	40.623	45.652	47.689	52.905	58.947
100	Sudan	Blue Nile	70.231	55.797	47.025	45.677	48.691	58.714	74.507	83.265	92.919	99.610
101	Sudan	Central Darfur	61.801	62.121	68.238	75.570	79.018	81.199	85.282	85.974	91.359	96.771
102	Sudan	East Darfur	39.237	36.641	36.890	41.322	48.413	57.439	70.221	78.985	88.783	97.145
103	Sudan	Kassala	37.768	44.504	50.015	53.684	52.728	51.456	52.375	51.929	55.359	61.775
104	Sudan	Khartoum	16.915	17.815	16.871	17.329	19.366	20.602	23.959	25.973	29.263	36.197
105	Sudan	North Darfur	28.737	32.408	40.282	48.975	56.447	59.157	62.247	68.598	70.305	76.213
106	Sudan	North Kurdufan	34.297	27.623	21.754	21.877	26.507	32.928	43.176	53.069	58.857	65.947
107	Sudan	Northern	8.698	6.711	6.366	7.326	10.108	11.958	13.421	16.101	16.534	19.198
108	Sudan	Red Sea	15.036	13.207	12.463	13.430	15.169	18.292	24.127	27.525	31.970	36.257
109	Sudan	River Nile	12.927	11.564	10.229	10.576	13.316	14.124	18.459	22.209	25.448	32.517
110	Sudan	Sennar	24.374	26.309	28.319	32.643	37.143	44.848	55.583	63.298	73.078	77.533
111	Sudan	South Darfur	52.435	62.156	76.761	87.600	90.730	86.581	84.756	83.872	89.273	98.035
112	Sudan	South Kurdufan	34.579	34.126	36.413	41.883	47.760	55.810	66.956	72.422	80.334	85.516
113	Sudan	West Darfur	44.148	41.828	44.198	49.509	55.800	62.160	71.311	76.794	81.277	83.003
114	Sudan	West Kurdufan	42.606	48.128	56.693	67.523	74.505	78.555	81.747	83.624	87.394	96.236
115	Sudan	White Nile	25.692	24.334	24.058	27.083	31.659	39.819	51.805	58.792	65.181	70.014

RID: Regional Identification number

Table S3 Observed value of the *P.vivax* yearly malaria incidence rates

RID	Country	Region	<i>P. vivax</i> yearly malaria incidence rates									
			2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
1	Djibouti	Ali Sabieh	0.002	0.000	0.076	0.638	0.567	1.407	3.760	5.560	8.273	17.410
2	Djibouti	Dikhil	0.001	0.000	0.055	0.460	0.390	0.782	1.838	2.831	4.504	11.549
3	Djibouti	Djibouti	0.000	0.000	0.002	0.018	0.017	0.053	0.148	0.243	0.348	0.743
4	Djibouti	Obock	0.066	0.000	1.703	13.071	11.612	30.627	82.389	131.235	183.922	355.614
5	Djibouti	Tadjourah	0.045	0.012	1.243	10.579	9.896	26.070	68.203	107.700	152.120	293.514
6	Eritrea	Anseba	4.056	3.200	1.515	1.820	1.416	0.987	3.275	2.766	3.441	1.515
7	Eritrea	Debub	6.165	4.357	1.776	1.960	1.495	1.087	3.751	3.305	4.238	1.872
8	Eritrea	Debubawi Keyih Bahri	6.580	6.006	3.349	4.385	3.324	2.291	7.675	6.516	7.279	2.873
9	Eritrea	Gash Barka	8.757	10.261	6.409	8.581	6.069	3.180	7.492	5.140	5.741	2.485
10	Eritrea	Mackel	3.216	2.262	0.970	1.135	0.864	0.596	1.906	1.628	2.027	0.922
11	Eritrea	Semenawi Keyih Bahri	4.642	3.314	1.469	1.745	1.384	1.023	3.591	3.157	3.979	1.754
12	Ethiopia	Addis Abeba	5.503	8.083	6.949	4.038	3.033	1.680	0.857	0.161	0.194	0.279
13	Ethiopia	Afar	64.479	51.404	31.113	15.897	12.220	9.326	8.527	2.692	4.222	3.484
14	Ethiopia	Amhara	99.828	56.606	23.412	9.627	6.717	5.384	5.404	1.784	2.964	4.626
15	Ethiopia	Benshangul-Gumaz	97.577	98.932	73.779	43.401	37.235	31.780	28.713	7.487	10.220	4.934
16	Ethiopia	Dire Dawa	67.228	94.166	79.587	45.048	32.417	18.185	9.623	1.966	2.614	6.235
17	Ethiopia	Gambela Peoples	92.566	97.695	70.555	41.776	37.436	33.342	32.760	8.959	11.928	6.352
18	Ethiopia	Harari People	65.083	91.814	77.097	42.423	29.258	14.529	6.785	1.334	1.839	6.656
19	Ethiopia	Oromia	50.231	87.669	85.489	50.746	40.530	26.021	15.339	3.268	4.191	8.218
20	Ethiopia	Somali	50.172	47.800	35.749	21.627	19.105	16.792	16.786	5.287	7.814	11.030
21	Ethiopia	Southern Nations, Nationalities and Peoples	69.594	70.923	51.197	29.080	23.660	17.800	14.931	4.074	5.791	14.793
22	Ethiopia	Tigray	82.606	46.306	19.256	8.344	6.507	6.713	8.478	2.927	4.557	16.250
23	Kenya	Baringo	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
24	Kenya	Bomet	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
25	Kenya	Bungoma	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
26	Kenya	Busia	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

27	Kenya	Elgeyo-Marakwet	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
28	Kenya	Embu	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
29	Kenya	Garissa	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
30	Kenya	Homa Bay	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
31	Kenya	Isiolo	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
32	Kenya	Kajiado	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
33	Kenya	Kakamega	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
34	Kenya	Kericho	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
35	Kenya	Kiambu	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
36	Kenya	Kilifi	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
37	Kenya	Kirinyaga	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
38	Kenya	Kisii	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
39	Kenya	Kisumu	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
40	Kenya	Kitui	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
41	Kenya	Kwale	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
42	Kenya	Laikipia	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
43	Kenya	Lamu	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
44	Kenya	Machakos	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
45	Kenya	Makueni	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
46	Kenya	Mandera	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
47	Kenya	Marsabit	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
48	Kenya	Meru	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
49	Kenya	Migori	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
50	Kenya	Mombasa	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
51	Kenya	Murang'a	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
52	Kenya	Nairobi	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
53	Kenya	Nakuru	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
54	Kenya	Nandi	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
55	Kenya	Narok	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
56	Kenya	Nyamira	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
57	Kenya	Nyandarua	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
58	Kenya	Nyeri	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

59	Kenya	Samburu	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
60	Kenya	Siaya	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
61	Kenya	Taita Taveta	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
62	Kenya	Tana River	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
63	Kenya	Tharaka-Nithi	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
64	Kenya	Trans Nzoia	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
65	Kenya	Turkana	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
66	Kenya	Uasin Gishu	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
67	Kenya	Vihiga	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
68	Kenya	Wajir	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
69	Kenya	West Pokot	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
70	Somalia	Awdal	0.000	0.360	0.363	0.384	0.422	0.490	0.604	0.693	5.956	0.824
71	Somalia	Bakool	0.000	0.297	0.414	0.569	0.789	1.094	1.445	1.755	14.402	1.819
72	Somalia	Banaadir	0.000	0.264	0.263	0.304	0.386	0.574	0.841	1.074	9.622	1.258
73	Somalia	Bari	0.000	0.411	0.408	0.467	0.562	0.757	1.035	1.221	9.621	1.168
74	Somalia	Bay	0.000	0.253	0.361	0.517	0.749	1.090	1.466	1.797	15.061	1.904
75	Somalia	Galguduud	0.000	0.317	0.315	0.337	0.381	0.485	0.644	0.787	6.400	0.817
76	Somalia	Gedo	0.000	0.232	0.332	0.479	0.691	1.010	1.362	1.668	13.648	1.699
77	Somalia	Hiiraan	0.000	0.416	0.447	0.505	0.613	0.809	1.043	1.256	10.087	1.278
78	Somalia	Jubbada Dhexe	0.000	0.353	0.484	0.663	0.887	1.223	1.597	1.863	15.098	1.817
79	Somalia	Jubbada Hoose	0.000	0.434	0.480	0.588	0.754	1.066	1.455	1.710	13.439	1.551
80	Somalia	Mudug	0.000	0.340	0.362	0.415	0.491	0.633	0.819	0.961	7.645	0.947
81	Somalia	Nugaal	0.000	0.374	0.369	0.406	0.472	0.627	0.855	1.024	8.072	0.955
82	Somalia	Sanaag	0.000	0.337	0.333	0.367	0.436	0.565	0.750	0.856	6.625	0.816
83	Somalia	Shabeellaha Dhexe	0.000	0.254	0.303	0.379	0.490	0.678	0.927	1.163	10.136	1.357
84	Somalia	Shabeellaha Hoose	0.000	0.247	0.327	0.444	0.624	0.900	1.233	1.521	12.810	1.625
85	Somalia	Sool	0.000	0.361	0.358	0.399	0.475	0.629	0.854	1.007	7.896	0.957
86	Somalia	Togdheer	0.000	0.506	0.417	0.400	0.457	0.597	0.819	0.974	7.821	0.961
87	Somalia	Woqooyi Galbeed	0.000	0.396	0.303	0.289	0.337	0.470	0.695	0.855	7.268	0.911
88	South Sudan	Central Equatoria	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
89	South Sudan	Eastern Equatoria	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
90	South Sudan	Jungoli	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

91	South Sudan	Lakes	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
92	South Sudan	North Bahr-al-Ghazal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
93	South Sudan	Unity	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
94	South Sudan	Upper Nile	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
95	South Sudan	Warap	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
96	South Sudan	West Bahr-al-Ghazal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
97	South Sudan	West Equatoria	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
98	Sudan	Al Jazirah	3.629	3.209	2.828	2.869	3.321	3.420	3.446	4.700	7.324	7.900
99	Sudan	Al Qadarif	7.365	7.271	7.116	7.069	6.773	5.608	4.719	5.381	7.544	7.792
100	Sudan	Blue Nile	11.911	9.424	7.840	7.548	8.039	7.708	7.367	9.115	13.145	13.421
101	Sudan	Central Darfur	10.450	10.478	11.436	12.643	13.284	10.941	8.783	9.855	13.354	12.984
102	Sudan	East Darfur	6.580	6.177	6.219	6.940	8.105	7.605	7.011	8.815	12.888	13.248
103	Sudan	Kassala	6.348	7.494	8.427	9.035	8.833	6.779	5.182	5.694	7.810	8.205
104	Sudan	Khartoum	2.857	3.003	2.850	2.936	3.267	2.698	2.284	2.693	3.877	4.520
105	Sudan	North Darfur	4.845	5.456	6.739	8.162	9.448	8.031	6.583	8.088	10.507	10.345
106	Sudan	North Kurdufan	5.809	4.683	3.706	3.742	4.550	4.497	4.453	6.065	8.619	9.046
107	Sudan	Northern	1.473	1.127	1.063	1.223	1.697	1.631	1.427	1.923	2.514	2.705
108	Sudan	Red Sea	2.535	2.233	2.115	2.281	2.593	2.527	2.571	3.267	4.820	5.100
109	Sudan	River Nile	2.187	1.947	1.720	1.775	2.225	1.865	1.832	2.432	3.563	4.309
110	Sudan	Sennar	4.124	4.457	4.821	5.577	6.350	6.021	5.499	6.838	10.188	10.347
111	Sudan	South Darfur	8.824	10.493	12.959	14.748	15.214	11.394	8.341	9.212	12.815	13.326
112	Sudan	South Kurdufan	5.859	5.786	6.206	7.166	8.185	7.585	6.880	8.271	11.776	11.743
113	Sudan	West Darfur	7.501	7.088	7.441	8.331	9.450	8.405	7.242	8.551	11.530	11.010
114	Sudan	West Kurdufan	7.193	8.133	9.573	11.434	12.697	10.724	8.526	9.786	13.203	13.541
115	Sudan	White Nile	4.337	4.104	4.083	4.617	5.394	5.334	5.162	6.421	9.082	9.136

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