USAID
FROM THE AMERICAN PEOPLE

DHS WORKING PAPERS

Design-based Small Area Estimation: A Nearest Neighbor Method for HIV Prevalence Estimation

Ruilin Ren

2022 No. 189

DEMOGRAPHIC AND HEALTH SURVEYS

September 2022

This document was produced for review by the United States Agency for International Development.

DHS Working Papers No. 189

Design-based Small Area Estimation: A Nearest Neighbor Method for HIV Prevalence Estimation

Ruilin Ren[1]

ICF
Rockville, Maryland, USA

September 2022

[1] The DHS Program, ICF

Corresponding author: Ruilin Ren, International Health and Development, ICF, 530 Gaither Road, Suite 500, Rockville, MD 20850, USA; phone: 301-572-0833; email: Ruilin.Ren@icf.com

Editor: Diane Stoy
Document Production: Joan Wardell

The DHS Working Papers series is a prepublication series of papers reporting on research in progress that is based on Demographic and Health Surveys (DHS) data.

This study was carried out with support provided by the United States Agency for International Development (USAID) through The DHS Program (#720-OAA-18C-00083). The views expressed are those of the authors and do not necessarily reflect the views of USAID or the United States Government.

The DHS Program assists countries worldwide in the collection and use of data to monitor and evaluate population, health, and nutrition programs. Additional information about The DHS Program can be obtained from ICF, 530 Gaither Road, Suite 500, Rockville, MD 20850 USA; telephone: +1 301-407-6500, fax: +1 301-407-6501, email: info@DHSprogram.com, internet: www.DHSprogram.com.

Recommended citation:

Ren, Ruilin. 2022. *Design-based Small Area Estimation: A Nearest Neighbor Method for HIV Prevalence Estimation*. DHS Working Papers No. 189. Rockville, Maryland, USA: ICF.

CONTENTS

TABLES

FIGURES

ABSTRACT

In 2021, Ren proposed a design-based methodology on small area estimation, the nearest neighbor method, based on survey data collected in a single target survey or in a series of similar surveys conducted in recent years from the same population. In household-based surveys, sampling units geographically close to the small area or sampling units from a social and economic environment similar to the small area may share similar characteristics. The concept involves pooling these sampling units together with the sampling units selected from the small area to form a "nearest neighborhood" with adequate sample size, and then to treat this as a survey domain that represents the small area. A survey domain created in this way is easier to analyze based on the survey design, variance estimation, and confidence intervals. This study is an application of the methods proposed by Ren (2021), in which Ren proposed five nearest neighbor methods: the time-space method, cluster center method, district center method, nearest neighbor with composite distance measure, and the hybrid nearest neighbor. In the 2021 study, Ren applied the proposed methods to produce district level total fertility rates and childhood mortality rates by using the Rwanda 2010 and 2014–2015 DHS survey data. In this study, we use the same survey data and apply the proposed methods to produce district level HIV prevalence estimates for women and men age 15–49. These data were not published in the 2014–2015 survey report because of the insufficient sample size at the district level. The methods are also applicable to HIV prevalence by single sex with an increased neighborhood size.

Key words: small area estimation; design-based; survey domain; nearest neighbor; HIV prevalence

ACRONYMS AND ABBREVIATIONS

ANC	antenatal care
CV	coefficient of variation
DEFT	design effect
DHS	Demographic and Health Survey
GPS	global positioning system
HIV	human immunodeficiency virus
RSE	relative standard error
SAE	small area estimation

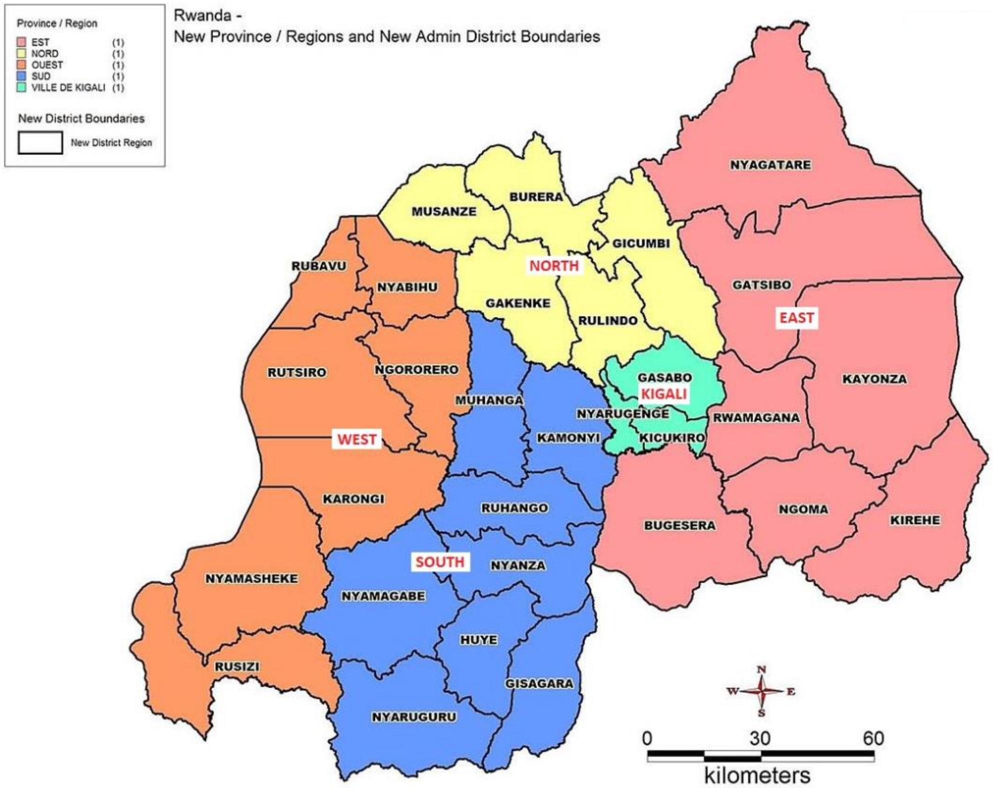
1 DATA USED IN THIS STUDY

This study used the Rwanda Demographic and Health Survey (DHS) 2010 and 2014–2015 survey data. These surveys included human immunodeficiency virus (HIV) testing in a subsample of 50% of households selected for the male survey. All males, age 15–59 and females, age 15–49, who were eligible for the survey were asked to consent to participate in HIV testing. Blood samples were collected from all eligible respondents who provided informed consent. The survey data provided an anonymous link of HIV testing results with key behavioral and sociodemographic characteristics of both the male and female respondents. In Rwanda, national HIV prevalence is usually derived from the antenatal care (ANC) sentinel surveillance system. However, surveillance data do not provide estimates of HIV prevalence for the general population, and only provide results specific to women who are attending the antenatal clinics. The inclusion of HIV testing in the 2010 and 2014–2015 DHS surveys offered the opportunity to better understand the magnitude and patterns of the HIV epidemic in the general population of reproductive age in Rwanda. The final survey reports presented the HIV prevalence for Rwanda, for the urban and rural areas separately, and for each of the five survey domains that included the four provinces of Rwanda and the capital city of Kigali. However, HIV prevalence for each of the 30 districts was not presented in the DHS final survey reports because of insufficient sample size at the district level.

Rwanda is a low HIV prevalence country, with a national prevalence of 3% among the adult population age 15–49, according to the DHS 2010 and 2014–2015 surveys. Therefore, HIV testing was conducted in a subsample selected for the male survey, and not in the full sample. This is the standard strategy for DHS surveys that include HIV testing in low prevalence countries: conduct HIV testing in a subsample and present only aggregated level prevalence to reduce survey costs. In Rwanda, the districts are autonomous administrative entities with legal status, administrative and financial autonomy, and responsibility for their own socioeconomic development. Therefore, district level data are desired by data users and the local governments. District level HIV prevalence may reveal where and how the epidemic is spreading and clustering, and can help governments fight the epidemic more effectively. See Figure 1 for a map of Rwanda with the provinces and districts.

The Rwanda DHS 2010 and DHS 2014–2015 surveys share the same design; both are household-based, two-stage cluster surveys, with a sample size of 492 clusters, 12,792 households, and 26 households per cluster. The sample allocation was an equal size allocation with 16 clusters and 416 households per district, except for the three districts in Kigali City where 20 clusters and 520 households per district were allocated. Table 1 presents the detailed sample allocation of number of clusters and households selected, and number of women and men age 15–49 interviewed and tested for HIV. The two surveys conducted a very similar number of tests, with a total number of 12,618 tests of women and men age 15–49 in the 2010 survey: an average of 420 tests per district; a total number of 12,309 tests of women and men age 15–49 in the 2014–2015 survey, and an average of 410 tests per district. The 400 cases make this too small to produce reliable estimations for a proportion of about 3%. Table 2 presents the direct estimates of HIV prevalence for each of the 30 districts with their sampling errors. In Table 2, we can see that the relative standard error (RSE) or the coefficient of variation (CV) of the direct prevalence estimates at district level varies from 16.6% to 65.9%, with an average of 36.2%. The DHS Program standard is to report indicators only if the RSE of the estimate is less than 20%, which indicates acceptable precision at the domain level. This is why the district level HIV prevalence was not reported in the surveys' final report because the RSE for most of the estimates was greater than 20%.

Figure 1 Map of Rwanda's provinces and districts



Source: Wikimedia

Table 1 Sample allocation of clusters, households, and number of women and men age 15–49 interviewed and tested for HIV

		Rwanda DHS 2010			Rwanda DHS 2014–2015		
Province	**District**	**Clusters selected**	**Households selected**	**Women and men tested**	**Clusters selected**	**Households selected**	**Women and men tested**
Kigali	Nyarugenge	20	260	595	20	260	591
Kigali	Gasabo	20	260	579	20	260	541
Kigali	Kicukiro	20	260	645	20	260	598
South	Nyanza	16	208	366	16	208	367
South	Gisagara	16	208	402	16	208	365
South	Nyaruguru	16	208	386	16	208	392
South	Huye	16	208	387	16	208	410
South	Nyamagabe	16	208	390	16	208	438
South	Ruhango	16	208	389	16	208	375
South	Muhanga	16	208	343	16	208	397
South	Kamonyi	16	208	369	16	208	408
West	Karongi	16	208	378	16	208	401
West	Rutsiro	16	208	425	16	208	358
West	Rubavu	16	208	413	16	208	408
West	Nyabihu	16	208	394	16	208	372
West	Ngororero	16	208	376	16	208	370
West	Rusizi	16	208	452	16	208	478
West	Nyamasheke	16	208	406	16	208	383
North	Rulindo	16	208	425	16	208	370
North	Gakenke	16	208	376	16	208	369
North	Musanze	16	208	416	16	208	393
North	Burera	16	208	358	16	208	386
North	Gicumbi	16	208	422	16	208	398
East	Rwamagana	16	208	432	16	208	408
East	Nyagatare	16	208	411	16	208	393
East	Gatsibo	16	208	442	16	208	402
East	Kayonza	16	208	429	16	208	391
East	Kirehe	16	208	394	16	208	368
East	Ngoma	16	208	381	16	208	419
East	Bugesera	16	208	437	16	208	360
	Rwanda	**492**	**6,396**	**12,618**	**492**	**6,396**	**12,309**

Table 2 Direct estimates of HIV prevalence for women and men age 15–49 by district, Rwanda DHS 2014–2015

District	HIV	Standard error	Number of cases		Design effect (DEFT)	RSE	95% confidence interval	
			Unweighted	Weighted			R-2SE	R+2SE
Nyarugenge	0.069	0.012	591	425	1.102	0.166	0.046	0.092
Gasabo	0.058	0.013	541	803	1.315	0.228	0.032	0.085
Kicukiro	0.066	0.012	598	453	1.220	0.188	0.041	0.091
Nyanza	0.037	0.010	367	359	1.023	0.273	0.017	0.057
Gisagara	0.021	0.009	365	354	1.167	0.414	0.004	0.039
Nyaruguru	0.015	0.007	392	271	1.184	0.481	0.001	0.030
Huye	0.030	0.012	410	389	1.440	0.403	0.006	0.055
Nyamagabe	0.016	0.007	438	399	1.135	0.422	0.003	0.030
Ruhango	0.050	0.010	375	375	0.847	0.191	0.031	0.069
Muhanga	0.021	0.007	397	366	1.045	0.361	0.006	0.036
Kamonyi	0.017	0.008	408	408	1.248	0.467	0.001	0.033
Karongi	0.023	0.008	401	384	1.093	0.356	0.007	0.039
Rutsiro	0.024	0.006	358	300	0.806	0.275	0.011	0.036
Rubavu	0.029	0.008	408	459	0.933	0.268	0.013	0.045
Nyabihu	0.027	0.010	372	289	1.144	0.356	0.008	0.046
Ngororero	0.016	0.008	370	369	1.187	0.488	0.000	0.031
Rusizi	0.024	0.008	478	506	1.175	0.347	0.007	0.040
Nyamasheke	0.022	0.008	383	378	1.110	0.377	0.005	0.039
Rulindo	0.025	0.013	370	338	1.587	0.518	0.000	0.051
Gakenke	0.022	0.007	369	368	0.866	0.304	0.008	0.035
Musanze	0.023	0.007	393	441	0.968	0.319	0.008	0.038
Burera	0.009	0.006	386	357	1.264	0.659	0.000	0.022
Gicumbi	0.034	0.010	398	452	1.107	0.295	0.014	0.055
Rwamagana	0.034	0.014	408	409	1.525	0.403	0.007	0.062
Nyagatare	0.017	0.007	393	574	1.119	0.432	0.002	0.031
Gatsibo	0.028	0.013	402	552	1.577	0.462	0.002	0.055
Kayonza	0.033	0.011	391	373	1.157	0.316	0.012	0.054
Kirehe	0.025	0.009	368	347	1.105	0.362	0.007	0.043
Ngoma	0.018	0.006	419	441	0.881	0.318	0.007	0.030
Bugesera	0.016	0.006	360	361	0.962	0.399	0.003	0.029
Rwanda	**0.030**	**0.002**	**12,309**	**12,302**	**1.221**	**0.063**	**0.026**	**0.033**

2 CONSTRUCTION OF THE NEAREST NEIGHBORHOODS

In this section, we present the construction of the nearest neighborhoods using the methods described in Ren (2021). In Table 2, with about 400 tests of women and men age 15–49, the average RSE of the direct prevalence estimates at district level varies from 16.6% to 65.9%, with an overall average RSE of 36.2%. For a prevalence of about 3% and an average design effect (DEFT) of about 1.15, a simple calculation shows that we need an estimated 1,100 tests of women and men age 15–49 per district to obtain an RSE of about 20%. Conversion of the number of tests to the number of clusters shows that we need about 43 clusters per district. For simplicity, we decided to construct nearest neighbors with a sample size of 46 clusters, that is, for each of the 30 districts, we borrow 30 clusters from other districts. We could have determined the neighborhood size by districts based on the HIV prevalence obtained from the direct estimates, but we did not apply different neighborhood size in this study for simplicity.

The first method uses a time-space nearest neighbor by simply combining the 2010 and 2014–2015 data together, so that the sample size is doubled for each district. Since the HIV epidemic changes very slowly in Rwanda at national level, the 2010 and 2014–2015 surveys found the same prevalence at 3% for the adult population age 15–49, with small variations at the province level. (See Table 4.) Therefore, the time-space nearest neighbor method is applicable to the HIV prevalence estimation from consecutive surveys. After combining the data from the two DHS surveys, the sample size is still insufficient for a precise estimation of HIV prevalence at the district level. (See Table 5). As noted, we needed about 1,100 tests of women and men age 15–49 per district, and combining the two surveys' data together resulted in a sample size of only 830 tests per district.

The second method uses the geographical nearest neighbor based on the target survey Rwanda DHS 2014–2015. This involved selecting "donor" clusters from the neighboring districts within the same province or from other provinces based on the geographical distance measure to the target cluster center. This was calculated with the Global Positioning System (GPS) information collected at each cluster center. A list of donor clusters was identified based on their distance to each target cluster center. The final nearest neighborhood for the target district includes only different donor clusters. Therefore, it is difficult to control the exact neighborhood size. For most of the districts, we borrowed more than 30 clusters, except for the three districts in Kigali City. (See panel 1 of Table 3.)

The third method is similar to the second, but uses the target district center as the neighborhood center. Donor clusters from the neighboring districts within the same province or from other provinces are identified based on their geographical distance to the target district center. The first 30 clusters closest to the target district center are identified as the nearest neighborhood for the target district. (See Panel 2 of Table 3.)

The fourth method is similar to the third method, but uses a more complex distance measure, which is a composite distance measure that created a profile for each district and each cluster by using cluster GPS coordinates, women's individual demographic characteristics, and the wealth quintile. The district center method was then applied with this composite distance measure. We call this method "district center nearest neighbor with a composite distance measure." (See panel 3 of Table 3).

The fifth method is a hybrid method that uses nearest neighborhoods constructed with the other four methods to form hybrid nearest neighborhoods that for a specific district use the "best performed" nearest neighborhood created by the other four methods. For simplicity, the hybrid method in this study used the provincial level neighborhoods. This means that all the districts in the same province have the nearest neighborhoods created by the same method. In this study, we used the nearest neighborhoods created with the cluster center method for all districts in South and West provinces, and the nearest neighborhoods created by the district center with the composite distance measure for the remainder of the districts. Therefore, panel 1 for South and West provinces, and panel 3 for the remainder of the districts in Table 3 show the hybrid nearest neighborhoods.

The methods for the construction of nearest neighborhoods were explained in detail in Ren (2021). Here we present the results by number of clusters borrowed from other districts within the same province and from other provinces. Some districts borrowed a small number of clusters from other provinces, while other districts borrowed a larger number of clusters from the neighboring provinces. This was determined by the topography of the districts. The Bugesera district is a typical example that borrows more clusters from other provinces than from the province in the district in which it is located.

Table 3 Number of clusters borrowed from other districts, within same province, and from other provinces

	Number of clusters borrowed								
	Cluster center			District center			District center composite distance		
District	WP	OP	Total	WP	OP	Total	WP	OP	Total
Nyarugenge	16	12	28	27	3	30	19	11	30
Gasabo	22	5	27	30		30	21	9	30
Kicukiro	22	5	27	30		30	24	6	30
Nyanza	31	2	33	29	1	30	28	2	30
Gisagara	30		30	30		30	30		30
Nyaruguru	30		30	30		30	27	3	30
Huye	33		33	30		30	25	5	30
Nyamagabe	21	10	31	21	9	30	20	10	30
Ruhango	29	3	32	29	1	30	28	2	30
Muhanga	14	19	33	15	15	30	15	15	30
Kamonyi	12	21	33	6	24	30	15	15	30
Karongi	17	17	34	16	14	30	10	20	30
Rutsiro	33	1	34	30		30	20	10	30
Rubavu	26	7	33	28	2	30	17	13	30
Nyabihu	19	15	34	16	14	30	13	17	30
Ngororero	20	13	33	16	14	30	11	19	30
Rusizi	18	14	32	19	11	30	22	8	30
Nyamasheke	27	7	34	23	7	30	21	9	30
Rulindo	19	15	34	19	11	30	16	14	30
Gakenke	22	11	33	18	12	30	19	11	30
Musanze	16	17	33	13	17	30	23	7	30
Burera	32		32	30		30	27	3	30
Gicumbi	16	16	32	17	13	30	21	9	30
Rwamagana	23	11	34	18	12	30	21	9	30
Nyagatare	14	18	32	14	16	30	12	18	30
Gatsibo	21	13	34	13	17	30	17	13	30
Kayonza	32		32	30		30	27	3	30
Kirehe	30		30	30		30	30		30
Ngoma	33		33	30		30	28	2	30
Bugesera	7	27	34	5	25	30	11	19	30

WP = within same province
OP = from other provinces

Table 4 HIV prevalence for women and men age 15–49 by province, Rwanda DHS 2010 and 2014–2015 surveys

	DHS 2010		DHS 2014–2015	
Province	**HIV**	**RSE**	**HIV**	**RSE**
Kigali	0.073	0.101	0.063	0.122
South	0.024	0.128	0.026	0.123
West	0.027	0.139	0.024	0.132
North	0.025	0.173	0.023	0.171
East	0.021	0.139	0.024	0.161
Rwanda	**0.030**	**0.060**	**0.030**	**0.063**

3 NUMERICAL RESULTS

In this section, we summarize the results of this study that used the Rwanda DHS 2010 and Rwanda DHS 2014–2015 survey data and the SAE methods proposed in Ren (2021) to estimate district level HIV prevalence. We restricted the study to the estimation of HIV prevalence for both women and men age 15–49. The methods are applicable to HIV prevalence by single sex. For single sex prevalence, we must double the neighborhood size.

Table 5 presents the estimated HIV prevalence for women and men age 15–49 using the direct estimate and the various consistency adjusted SAE estimate, together with their RSE. A consistency adjusted SAE is a small adjustment for SAE. (See Ren 2021 for details of the consistency adjustment SAE.) We see that the direct estimates have poor precision, with most of the estimates having an RSE greater than 20%, with an overall average RSE of 36.2%. The time-space nearest neighbor or the combined estimates improved the survey precision considerably. However, for most of the districts, the RSE is still greater than 20%, with an overall average RSE of 25.1%. We could apply the geographical nearest neighbor methods to the combined data, which is a complex nearest neighbor that combines the time-space and the geographical nearest neighbor, to improve the precision for the HIV prevalence estimates at district level. In this study, we did not use that approach because the purpose of this study is to investigate each of the proposed nearest neighbor methods proposed by Ren (2021), and the purpose is not to produce the most reliable HIV prevalence estimation for a specific district. We could explore the complex nearest neighbor method in a later study.

For the cluster center method, most of the estimates either have a RSE under 20% or very close to 20%. However, there are still a few estimates with an RSE greater than 20%, with an overall average RSE of 20.2%, which reaches the upper limit of the DHS-controlled precision. Compared to the direct estimates and the time-space nearest neighbor estimates, there is a significant improvement in survey precision. The district center nearest neighbor is comparable to the cluster center nearest neighbor, but with more variations with a slightly larger overall average RSE of 20.4%. The district center nearest neighbor with the composite distance measure appeared to have better performance compared to the cluster center nearest neighbor, with an overall average RSE of 20%, and quite a few districts with an RSE greater than 20%. The hybrid method uses the cluster center nearest neighborhoods for the South and West provinces, and the nearest neighborhoods created by the district center nearest neighbor with composite distance measure for the rest.

Figure 2 is a plot of the various estimations in Table 5 against the provincial level estimates in Table 4. A visual inspection shows that the cluster center nearest neighbor, the district center nearest neighbor with composite distance measure, and the hybrid method produce estimations with fewer variations compared to their provincial estimate. We do not have a numerical criterion to judge the different methods, although we believe that estimates should have moderate variations compared to their provincial level estimates and be consistent with their provincial level estimates, that is, district level estimates can be aggregated to the provincial level estimate and match the provincial estimate.

Figure 2 Line plot of the various small area estimates of HIV prevalence against the provincial level estimates

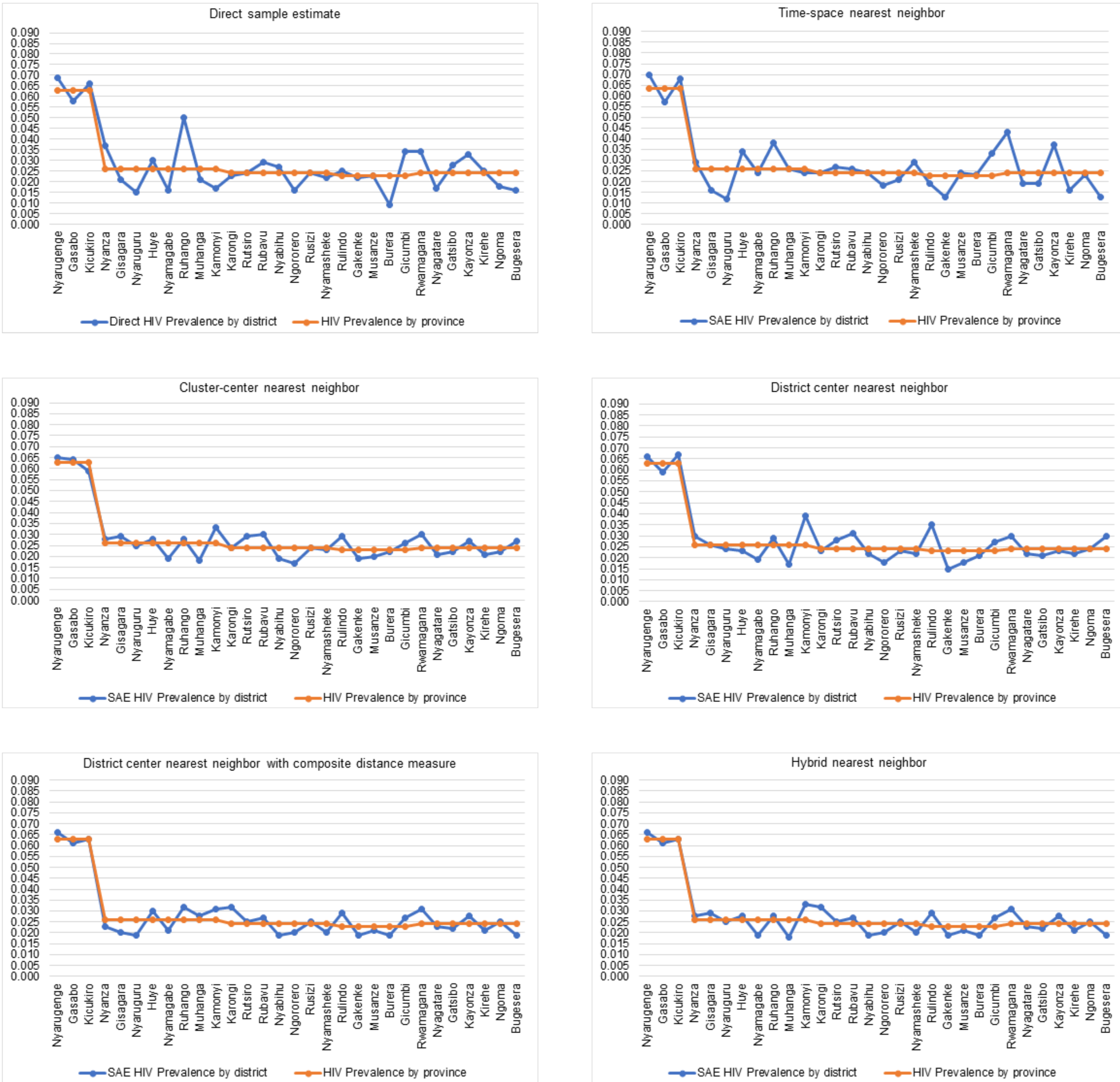


Table 5 Rwanda DHS 2014–2015 HIV prevalence by district, direct estimates, and the various consistency adjusted small area estimates

	Direct estimate		Combined estimate		Cluster center		District center		Composite distance		Hybrid estimate	
District	**HIV**	**RSE**	**HIV**	**RSE**	**HIV**	**RSE**	**HIV**	**RSE**	**HIV**	**RSE**	**HIV**	**RSE**
Nyarugenge	0.069	0.166	0.070	0.106	0.065	0.136	0.066	0.123	0.066	0.122	0.066	0.122
Gasabo	0.058	0.228	0.057	0.150	0.064	0.142	0.059	0.137	0.061	0.123	0.061	0.123
Kicukiro	0.066	0.188	0.068	0.123	0.059	0.124	0.067	0.120	0.063	0.130	0.063	0.130
Nyanza	0.037	0.273	0.029	0.226	0.028	0.157	0.030	0.152	0.023	0.208	0.028	0.157
Gisagara	0.021	0.414	0.016	0.312	0.029	0.201	0.026	0.207	0.020	0.223	0.029	0.201
Nyaruguru	0.015	0.481	0.012	0.437	0.025	0.224	0.024	0.224	0.019	0.222	0.025	0.224
Huye	0.030	0.403	0.034	0.257	0.028	0.208	0.023	0.239	0.030	0.167	0.028	0.208
Nyamagabe	0.016	0.422	0.024	0.227	0.019	0.241	0.019	0.249	0.021	0.233	0.019	0.241
Ruhango	0.050	0.191	0.038	0.176	0.028	0.168	0.029	0.164	0.032	0.167	0.028	0.168
Muhanga	0.021	0.361	0.026	0.207	0.018	0.207	0.017	0.220	0.028	0.156	0.018	0.207
Kamonyi	0.017	0.467	0.024	0.234	0.033	0.124	0.039	0.127	0.031	0.163	0.033	0.124
Karongi	0.023	0.356	0.024	0.278	0.024	0.201	0.023	0.228	0.032	0.163	0.032	0.163
Rutsiro	0.024	0.275	0.027	0.198	0.029	0.185	0.028	0.176	0.025	0.204	0.025	0.204
Rubavu	0.029	0.268	0.026	0.224	0.030	0.170	0.031	0.184	0.027	0.177	0.027	0.177
Nyabihu	0.027	0.356	0.024	0.266	0.019	0.243	0.022	0.223	0.019	0.248	0.019	0.248
Ngororero	0.016	0.488	0.018	0.325	0.017	0.253	0.018	0.257	0.020	0.220	0.020	0.220
Rusizi	0.024	0.347	0.021	0.229	0.024	0.211	0.023	0.220	0.025	0.199	0.025	0.199
Nyamasheke	0.022	0.377	0.029	0.271	0.023	0.230	0.022	0.228	0.020	0.228	0.020	0.228
Rulindo	0.025	0.518	0.019	0.336	0.029	0.251	0.035	0.223	0.029	0.231	0.029	0.231
Gakenke	0.022	0.304	0.013	0.272	0.019	0.254	0.015	0.241	0.019	0.196	0.019	0.196
Musanze	0.023	0.319	0.024	0.231	0.020	0.203	0.018	0.221	0.021	0.217	0.021	0.217
Burera	0.009	0.659	0.023	0.259	0.022	0.208	0.021	0.214	0.019	0.213	0.019	0.213
Gicumbi	0.034	0.295	0.033	0.230	0.026	0.218	0.027	0.220	0.027	0.244	0.027	0.244
Rwamagana	0.034	0.403	0.043	0.210	0.030	0.187	0.030	0.195	0.031	0.191	0.031	0.191
Nyagatare	0.017	0.432	0.019	0.286	0.021	0.254	0.022	0.253	0.023	0.259	0.023	0.259
Gatsibo	0.028	0.462	0.019	0.353	0.022	0.238	0.021	0.265	0.022	0.251	0.022	0.251
Kayonza	0.033	0.316	0.037	0.208	0.027	0.236	0.023	0.222	0.028	0.213	0.028	0.213
Kirehe	0.025	0.362	0.016	0.305	0.021	0.208	0.022	0.192	0.021	0.220	0.021	0.220
Ngoma	0.018	0.318	0.023	0.288	0.022	0.244	0.024	0.229	0.025	0.226	0.025	0.226
Bugesera	0.016	0.399	0.013	0.298	0.027	0.150	0.030	0.158	0.019	0.196	0.019	0.196
Average RSE		0.362		0.251		0.202		0.204		0.200		0.200

REFERENCES

Asian Development Bank. 2020. *Introduction to Small Area Estimation Techniques: A Practical Guide for National Statistics Offices.* http://dx.doi.org/10.22617/TIM200160-2

Ghosh, M. and J. N. K. Rao. 1994. “Small Area Estimation: An Appraisal.” *Statistical Science* 9 (1): 55–93.

Marker, D. A. 1999. “Organization of Small Area Estimators using a Generalized Linear Regression Framework.” *Journal of Official Statistics* 15 (1): 1–24.

National Institute of Statistics of Rwanda (NISR) [Rwanda], Ministry of Health (MOH) [Rwanda], and ICF International. 2012. *Rwanda Demographic and Health Survey 2010*. Calverton, Maryland, USA: NISR, MOH, and ICF International. http://dhsprogram.com/pubs/pdf/FR259/FR/259.pdf

National Institute of Statistics of Rwanda (NISR) [Rwanda], Ministry of Health (MOH) [Rwanda], and ICF International. 2015. *Rwanda Demographic and Health Survey 2014–15*. Rockville, Maryland, USA: NISR, MOH, and ICF International. http://dhsprogram.com/pubs/pdf/FR316/FR/316.pdf

Ren, R. 2021. *Design-based Small Area Estimation: An Application to the DHS Surveys.* DHS Working Papers No. 180. Rockville, Maryland, USA: ICF. https://dhsprogram.com/pubs/pdf/WP180/WP180.pdf

Särndal, C. E. 1984. “Design-consistent versus Model-dependent Estimation for Small Domains.” *Journal of the American Statistical Association* 79 (387): 624–631. https://doi.org/10.2307/2288409

Schirm, A. L., A. M. Zaslavsky, and L. Czajka. 1997. “Large Numbers of Estimates for Small Areas.” *Mathematica Policy Research Report.* Washington, DC, USA: Mathematica Policy Research. https://www.mathematica.org/-/media/publications/pdfs/largenumbers.pdf