Calculation of smoking rates by dong/eup/myeon unit using small-area estimation in the Community Health Survey

Kay O Lee¹, Jong Seok Byun², Yang Wha Kang³, Yun Sil Ko³, Hyo Jin Kim³

¹Gallup Korea, Seoul; ²Department of Applied Statistics, Hanshin University, Osan; ³Division of Chronic Disease Control, Korea Centers for Disease Control and Prevention, Cheongju, Korea

INTRODUCTION

The Korean Community Health Survey (CHS), a community-based nationwide annual survey with the objective of providing important health indicators, is conducted through stratified cluster sampling and computer-assisted personal interviewing. Using the dong/eup/myeon administrative units (hereafter units) and residential structures (apartment or single house) as stratification variables, 900 adults (age ≥ 19 years) per community health center district (hereafter district) are sampled and proportionally distributed across the units and according to residential structures, followed by selecting tong/ban/ri-level sample points via probability proportionate sampling based on the number of households. From each selected sample point, five households on average are selected by systematic sampling, and individual interviews are conducted with all adults in each household [1]. Although district-level health indicators are produced with a specific level of precision, there is an increasing demand for producing unit-level health indicators. However, the unit sample size varies considerably ranging between tens and several hundreds, and health indicators such as smoking rate for units with fewer than 30 samples produced using conventional statistical estimation methods cannot be used, owing to an exceedingly large sample variance of the estimates. This problem can be addressed by calculating unit-level statistics using a special estimation method such as small-area estimation [2]. This paper presents an optimized estimation method using Statistical Analysis System (SAS) codes.

Small-area estimation

Small-area estimation is an estimation method designed to produce statistics for small survey areas not included in the sample design for statistics and having unusable high-variance estimates owing to excessively small sample sizes, through supplementary use of surrounding area survey information, auxiliary information from other sources, or statistical model of the population [3,4].

Given that the sample design for the Community Health Service is intended to produce district-level health indicators, small-area estimation is needed for producing reliable unit-level health indicators. The following describes the small-area estimation methods for producing unit-level health indicators [5].

Direct estimator

A direct estimator uses only data obtained from the units concerned to produce unit-level health indicators. Each observation included in the survey data sets is given a weight item by item; the sample design-based direct estimator and its variance can be expressed by the following estimation equation, using weighted and observed values:

$$\hat{Y}_D^i = \frac{\sum_{j=1}^{n_i} w_j^i y_j^i}{\sum_{j=1}^{n_i} w_j^i} \quad (1)$$

where n_i is the sample size of unit i , w_j^i is the multiplier reflecting sample and response rates, and y_j^i is the observed value.

The variance of the estimator shown in Equation (1) can be obtained using Equation (2), as follows:

$$\widehat{Var}(\hat{Y}_D^i) = \frac{1}{n_i(n_i-1)\bar{w}_i^2} \sum_{j=1}^{n_i} (w_j^i)^2 (y_j^i - \hat{R}_i)^2 \quad (2)$$

where $\hat{R}_i = \frac{\sum_{j=1}^{n_i} w_j^i y_j^i}{\sum_{j=1}^{n_i} w_j^i}$ and $\bar{w}_i = \frac{1}{n_i} \sum_{j=1}^{n_i} w_j^i$

Synthetic estimator

A synthetic estimator can yield more accurate unit-level estimates by using various auxiliary data, such as sex, age, and reg-

Correspondence: Kay O Lee

Gallup Korea, 70 Sajik-ro, Jongno-gu, Seoul 110-054, Korea
Tel: +82-2-3702-2582, Fax: +82-2-3702-2628, Email: kolee575@hanmail.net

Received: Jan 22, 2015, Accepted: Mar 2, 2015, Published: Mar 2, 2015

This article is available from: <http://e-epih.org/>

© 2015, Korean Society of Epidemiology

© This is an open-access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/3.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

istered population, for each unit within a district [4,5]. After grouping the units into 2 to 3 homogeneous clusters, using their social environments and population ratios as clustering variables, under the assumption that the units of the same cluster might have similar sex-dependent/age-dependent health indicators, such as smoking rate, unit-level smoking rates can be calculated as follows, by combining smoking rates by sex and age group and by the number of people registered:

$$\hat{Y}_S^i = \frac{\sum_{k=1}^{n_c} r_{jk} N_{jk}^i}{\sum_{j=1}^{n_g} N_{jk}^i} \quad (3)$$

where $r_{jk} = \frac{\sum_{l=1}^{n_g} w_{jkl} y_{jkl}}{\sum_{l=1}^{n_g} w_{jkl}}$ is the average estimate of category k

within cluster j , N_{jk}^i is unit i within cluster j , registered population of category k , n_g is the number of samples in category k within cluster j , and n_c is the number of categories within cluster j .

The variance of the estimate shown in Equation (3) can be obtained using Equation (4):

$$\begin{aligned} \widehat{Var}(\hat{Y}_S^i) &= \sum_{k=1}^{n_c} (Z_{jk}^i)^2 \widehat{Var}(r_{jk}^i) \\ &= \sum_{k=1}^{n_c} \frac{(Z_{jk}^i)^2}{n_g(n_g-1)\bar{w}_{jk}^2} \sum_{l=1}^{n_g} (w_{jkl})^2 (y_{jkl} - r_{jk})^2 \end{aligned} \quad (4)$$

where $Z_{jk}^i = \frac{N_{jk}^i}{\sum_{k=1}^{n_c} N_{jk}^i}$

While a synthetic estimator is potentially biased, the bias is considered negligible, given that the clustering of units within the same district ensures the sex/age category characteristics across units. If the bias exceeds a negligible level, attention must be paid to the clustering, because the equation for estimating the variance shown in Equation (4) tends to underestimate the estimation error of the estimator of Equation (3).

Composite estimator

Although the direct estimator shown in Equation (1) is unbiased, its estimates are not reliable, with unacceptably large standard error resulting from the small sample size, whereas the synthetic estimator shown in Equation (3) is biased. These problems can be addressed using a hybrid approach of obtaining more reliable estimates from the weighted average of the two estimators. The formula of weighted estimate average shown in Equations (1) and (3) is referred to as a composite estimator and can be calculated as follows:

$$\hat{Y}_C^i = \alpha \hat{Y}_D^i + (1 - \alpha) \hat{Y}_S^i \quad (5)$$

where α is the weight that minimizes $MSE(\hat{Y}_C^i)$ and can be calculated as follows:

$$\alpha = \frac{\widehat{Var}(\hat{Y}_S^i)}{\widehat{Var}(\hat{Y}_D^i) + \widehat{Var}(\hat{Y}_S^i)} \quad (6)$$

While the optimal value of α is expected to be the one that minimizes the root mean square error of $\hat{Y}_C^i$, α is calculated using Equation (6) under the assumption that clustered units are sufficiently homogeneous to ignore the bias of the synthetic estimator $\hat{Y}_S^i$, and that the direct and synthetic estimators are independent of each other.

Calculation of smoking rate using statistical analysis system

The following describes the calculation process of the unit-level smoking rates using the 2013 CHS data by applying small-area estimation to the calculation of smoking rates for the 22 dong in Gangnam-gu, Seoul.

Direct estimator

The sample size distribution of the 22 dong of Gangnam-gu included in the 2013 CHS shows that the dong with the smallest and largest sample sizes are Gaepo 4-dong ($n=24$) and Yeoksam 1-dong ($n=58$). The smoking rates by dong were calculated using the direct estimators shown in Equation (1) and the variance estimation Equation (2) using SAS code as follows. The R-code program was presented in a previous study [6].

```
/*Generating the variables age groups and
smoking/non-smoking from the Gangnam health
center data*/
data abc.seoul_gangnam_data;
  set abc.chs13;
  length age_group $8.0
  keep josa_year dong sm_a0100 sma_01z2
sma_03z2 age age_group sex wt;
  rename dong=eup/myeon/dong;;\
  if 19<=age<=39 then age_group="19-39
years";
  if 40<=age<=59 then age_group="40-59
year";
  if 60<=age then age_group="60 years
and over";
  ** Current smoking rate (refer to [7] for
other survey item variables)
  =====
  Variable name: sm_a0100 (current smok-
ing rate calculation variable)
  Analysis data variable name:
sma_01z2(permanent smoking or not)
```

```

sma_03z2(current smoking or not)
=====;
if sma_01z2 = 1 then do;
    if sma_03z2 in (1,2) then sm_
a0100=1;
    else if sma_03z2 = 3 then sm_
a0100=0;
end ;
else if sma_01z2 = 2 then do;
    sm_a0100 = 0;
end ;
if bogun_cd=001; (Gangnam-gu health
center code)
run;

/*Direct estimator and variance estimation
of Gangnam-gu, Seoul*/
proc survey means data=abc.seoul_gangnam_
data;
    var sm_a0100; (current smoking rate
calculation variable)
    domain eup/myeon/dong;
    weight wt; (sample design weight)
    ods output Domain=abc.direct_estimator;
run;

```

Synthetic estimator

To calculate the synthetic estimators of smoking rates by dong, the 22 dongs of Gangnam-gu were grouped into three clusters. After calculating the smoking rates of each cluster by sex and age group (19 to 39, 40 to 59, ≥ 60), the smoking rates and variances by dong were calculated using Equations (3) and (4), respectively, as follows:

- ① Calculation of the registered population ratios by sex and age group of 22 dongs as of the end of July 2013
- ② Grouping 22 dongs in three clusters using the k-means method, with the population ratio and smoking rate as clustering variables, and with a homogeneity check of the clustered groups against the registered population size and socioeconomic environment

```

/*Cluster analysis according to the smoking
rates of population ratios by sex and age group
in Gangnam-gu, Seoul as of 2013*/
/*Data retrieval*/

proc import out=abc.seoul_gangnam_cluster_
data datafile="D:\2014_research_activities\sas_
lecture\seoul_gangnam-gu_cluster_data"
datafile=dbms=excel replace; rage="Seoul$"
getnames=yes; mixed=no; scantext=yes;

```

Table 1. Registered population ratios by sex and age group for each dong

Dong	Male			Female		
	19-39	40-59	≥ 60	19-39	40-59	≥ 60
Shinsa-dong	0.188	0.174	0.094	0.243	0.192	0.109
Nonhyeon 1-dong	0.241	0.149	0.066	0.309	0.155	0.080
Nonhyeon 2-dong	0.220	0.158	0.083	0.268	0.175	0.095
Apgujeong-dong	0.172	0.178	0.106	0.209	0.206	0.128
Cheongdam-dong	0.198	0.182	0.085	0.228	0.209	0.098
Samsung 1-dong	0.203	0.191	0.091	0.200	0.217	0.099
Samsung 2-dong	0.203	0.189	0.069	0.257	0.198	0.084
Daechi 1-dong	0.140	0.262	0.073	0.159	0.287	0.078
Daechi 2-dong	0.175	0.238	0.074	0.173	0.259	0.080
Daechi 4-dong	0.211	0.188	0.058	0.257	0.216	0.069
Yeoksam 1-dong	0.256	0.155	0.064	0.310	0.145	0.070
Yeoksam 2-dong	0.194	0.199	0.067	0.247	0.210	0.083
Dogok 1-dong	0.198	0.195	0.081	0.223	0.214	0.090
Dogok 2-dong	0.167	0.211	0.090	0.203	0.239	0.091
Gaepo 1-dong	0.193	0.193	0.087	0.189	0.234	0.105
Gaepo 2-dong	0.209	0.204	0.061	0.211	0.233	0.083
Gaepo 4-dong	0.207	0.204	0.070	0.208	0.226	0.085
Segok-dong	0.188	0.193	0.105	0.188	0.194	0.132
Ilwonbon-dong	0.182	0.226	0.065	0.195	0.253	0.079
Ilwon 1-dong	0.209	0.179	0.091	0.196	0.205	0.120
Ilwon 2-dong	0.205	0.189	0.077	0.193	0.221	0.114
Sooseo-dong	0.205	0.144	0.101	0.185	0.191	0.173

```

usedate=yes; scantime=yes;
run;
Imported data set is given Table 1.
/*k-average clustering*/
proc fastclus data=abc.seoul_gangnam_cluster_
data
    maxc=3 out=abc.seoul_gangnam_kcluster;
    var male_2013_19_39_years
male_2013_40_59_years male_2013_60_over fe-
male_2013_19_39_years female_2013_40_59_years
female_2013_60_over;
    id eup/myeon/dong;
run;

/*Export clusters to Excel*/
proc expout data=abc.seoul_gangnam_kcluster
OUTFILE= "D:\2014research_activities\sas_
lecture\Seoul_gangnam-gu_cluster_analysis" la-
bel dbms=excel replace;
run;

/*Cluster correction*/
proc import out=abc.seoul_gangnam_rcluster
datafile="D:\2014research_activities\sas_
lecture\Seoul_gangnam-gu_corrected_clustering"
dbms=excel replace; rage="seoul$"
getnames=yes;
mixed=no; scantext=yes; usedate=yes;
scantime=yes;
run;

③ Smoking rates of each cluster by sex and age group
/*Corrected cluster integration in data from
Gangnam-gu, Seoul*/
proc sort data=abc.seoul_gangnam_data; by eup/
myeon/dong; run;
proc sort data=abc.seoul_gangnam_rcluster;

```

```

by eup/myeon/dong; run;
data abc.seoul_gangnam_data2;
merge abc.seoul_gangnam_data abc.seoul_
gangnam_rcluster;
by eup/myeon/dong;
group1=corrected_
cluster||"_"||sex||"_"||age_group;
group1=compress(group1);
run;
proc print data=abc.seoul_gangnam_data2; run;
The corrected data set is displayed in Table 2.
/*Calculation of the estimated smoking rates
of each cluster by sex and age group*/
proc surveymeans data=abc.seoul_gangnam_data2
mean;
var sm_a0100;
domain group1;
weight wt;
ods output Domain=abc.com_estimator_r;
run;
The results of calculation are contained in
Table 3.

```

④ Calculation of synthetic estimates and variances of the smoking rates in 22 dong

```

/*Preparation of the data for the cluster-
level sex/age-dependent smoking rate estima-
tion*/
/*Corrected cluster integration in data from
Gangnam-gu, Seoul*/
proc sort data=abc.seoul_gangnam_data; by
eup/myeon/dong; run;
proc sort data=abc.seoul_gangnam_rcluster;
by eup/myeon/dong; run;
data abc.seoul_gangnam_data2;
merge abc.seoul_gangnam_data abc.seoul_
gangnam_rcluster;

```

Table 2. Examples of data structure, including corrected cluster, sex and age group, and variables for calculation smoking rate

Observation	Eup/myeon/dong	Sex	sma_01z2	sma_03z2	Age	wt	Age_group	sma_0100	Cluster	Corrected cluster	Group1 (age)
1	Nonhyeon 1-dong	M	1	1	26	592.15	19-39	1	2	1	1_1_19-39
2	Nonhyeon 1-dong	M	1	1	36	647.70	19-39	1	2	1	1_1_19-39
3	Nonhyeon 1-dong	M	1	1	35	647.46	19-39	1	2	1	1_1_19-39
4	Nonhyeon 1-dong	M	1	1	25	592.15	19-39	1	2	1	1_1_19-39
5	Nonhyeon 1-dong	M	2	.	19	592.15	19-39	0	2	1	1_1_19-39
6	Nonhyeon 1-dong	M	2	.	32	647.46	19-39	0	2	1	1_1_19-39
7	Nonhyeon 1-dong	M	1	1	32	647.46	19-39	1	2	1	1_1_19-39
8	Nonhyeon 1-dong	M	1	1	39	647.46	19-39	1	2	1	1_1_19-39

sma, smoking variable; wt, weight; M, male.

Table 3. Current smoking rate estimates and standard errors by group (cluster, sex/age)

Group (age)	Variable	Mean	Standard error
1_1_19-39	sm_a0100	0.465	0.074
1_1_40-59	sm_a0100	0.474	0.076
1_1_≥60	sm_a0100	0.242	0.085
1_2_19-39	sm_a0100	0.168	0.056
1_2_40-59	sm_a0100	0.075	0.032
1_2_≥60	sm_a0100	0.032	0.031
2_1_19-39	sm_a0100	0.364	0.074
2_1_40-59	sm_a0100	0.419	0.062
2_1_≥60	sm_a0100	0.160	0.062
2_2_19-39	sm_a0100	0.137	0.048
2_2_40-59	sm_a0100	0.057	0.030
2_2_≥60	sm_a0100	0.0	0.0
3_1_19-39	sm_a0100	0.413	0.068
3_1_40-59	sm_a0100	0.317	0.065
3_1_≥60	sm_a0100	0.207	0.085
3_2_19-39	sm_a0100	0.065	0.038
3_2_40-59	sm_a0100	0.0	0.0
3_2_≥60	sm_a0100	0.134	0.056

```

by eup/myeon/dong;
group1=corrected
cluster||"_"||sex||"_"||age_group;
group1=compress(group1);
run;

/*Synthetic estimator for the 22 dong in
Gangnam-gu, Seoul*/
proc surveymeans data=abc.seoul_gangnam_com
mean;
    domain eup/myeon/dong;
    var mean;
    weighted population;
    ods output domain=abc.seoul_gangnam_com-
mestimator_mean;
run;
Synthetic estimates are displayed in Table 4.
/*Variance estimation of the synthetic esti-
mators for each dong*/
proc sort data=abc.seoul_gangnam_data2; by
group1; run;
data abc.seoul_gangnam_comvar;
    merge abc.seoul_gangnam_data2 abc.com-
estimator_r;
    by group1;
    sum_wj_yj_rj=((wt*wt)*((sm_a0100-
mean)*(sm_a0100-mean)));
run;
/*Total weights of the k-category within a

```

Table 4. Current smoking rate estimates and standard errors

Dong	Mean	Standard error
Gaepo 1-dong	0.185	0.071
Gaepo 2-dong	0.188	0.074
Gaepo 4-dong	0.190	0.073
Nonhyeon 1-dong	0.265	0.074
Nonhyeon 2-dong	0.259	0.073
Daechi 1-dong	0.211	0.076
Daechi 2-dong	0.214	0.072
Daechi 4-dong	0.213	0.066
Dogok 1-dong	0.210	0.066
Dogok 2-dong	0.205	0.068
Samsung 1-dong	0.260	0.077
Samsung 2-dong	0.261	0.075
Segok-dong	0.190	0.066
Sooseo-dong	0.187	0.066
Shinsa-dong	0.251	0.073
Apgujeong-dong	0.245	0.073
Yeoksam 1-dong	0.219	0.062
Yeoksam 2-dong	0.211	0.066
Ilwon 1-dong	0.190	0.070
Ilwon 2-dong	0.189	0.071
Ilwonbon-dong	0.184	0.073
Cheongdam-dong	0.256	0.075

```

cluster*/
proc surveymeans data=abc.seoul_gangnam_com-
var;
    domain group1;
    var wt;
    ods output domain=abc.seoul_gangnam_
comvar_1;
run;

/*Total for the intragroup k-category vari-
ance estimation*/
proc tabulate data=abc.seoul_gangnam_comvar;
    class group1;
    var sum_wj_yj_rj;
    table group1*sum_wj_yj_rj;
    ods output table=abc.seoul_gangnam_com-
var_2;
run;
data abc.seoul_gangnam_comvar_data1;
    merge abc.seoul_gangnam_pop abc.seoul_
gangnam_comvar_1 abc.seoul_gangnam_comvar_2;
    by group1;
    keep eup/myeon/dong cluster sex age-
group population N Mean sum_wj_yj_rj_sum
group1;
run;
Table 5 contains the generated data set.

```

```

proc surveymeans data=abc.seoul_gangnam_com-
var_data1 sum;
    domain eup/myeon/dong;
    var population;
    ods output domain=abc.seoul_gangnam_
comvar_data2;
run;

proc sort data=abc.seoul_gangnam_comvar_
data1; by eup/myeon/dong; run;
proc sort data=abc.seoul_gangnam_comvar_
data2; by eup/myeon/dong; run;

/*Synthetic estimator variance estimation*/
data abc.seoul_gangnam_comvar_data;
    merge abc.seoul_gangnam_comvar_data1
abc.seoul_gangnam_comvar_data2;
    by eup/myeon/dong;
    drop varname varlabel stddev DomainLa-
bel;

    Zjk=Population/Sum;
    Var= ((Zjk*Zjk) / ((N*(N-
1)) * (mean*mean))) * sum_wj_yj_rj_sum;
run;
Table 6 contains variance of syntytic esti-
mate.
proc surveymeans data=abc.seoul_gangnam_com-
var_data sum;

```

```

domain eup/myeon/dong;
var var;
ods output domain=abc.seoul_gangnam_
comvariance;
run;

⑤ Data set generation by integrating the synthetic estimates
and variance estimates for the smoking rates in all 22 dong
/*Data integration of dong-level synthetic
estimates and variance estimates*/
/*Synthetic estimator and variance*/
data abc.seoul_gangnam_estimator_com;
    merge abc.seoul_gangnam_comestimator_mean
abc.seoul_gangnam_comvariance;
    by eup/myeon/dong;
    drop DomainLabel VarName stderr StdDev;
    rename mean=Y_s sum=var_Y_s;
run;

```

Composite estimator

The dong-level direct and synthetic estimates of smoking rates are combined as weighted averages to calculate the composite estimates, thereby applying the following three methods for calculating weighted values.

First, α_i for minimizing the mean square error of the composite estimator $MSE(\hat{Y}_c^i)$ shown in Equation (5) is expressed as follows:

Table 5. Variance of synthetic estimates by group (cluster, sex/age group)

Observation	Eup/myeon/dong	Corrected cluster	Sex	Age	Population	Group1 (age)	n	Mean (wt)	sum_wj_yj_rj_Sum
1	Shinsa-dong	1	M	19-39	3,071	1_1_19-39	47	629.36	4825692
2	Nonhyeon 1-dong	1	M	19-39	5,629	1_1_19-39	47	629.36	4825692
3	Nonhyeon 2-dong	1	M	19-39	4,267	1_1_19-39	47	629.36	4825692
4	Apgujeong-dong	1	M	19-39	4,014	1_1_19-39	47	629.36	4825692
5	Cheongdam-dong	1	M	19-39	5,060	1_1_19-39	47	629.36	4825692
6	Samsung 1-dong	1	M	19-39	2,577	1_1_19-39	47	629.36	4825692
7	Samsung 2-dong	1	M	19-39	5,224	1_1_19-39	47	629.36	4825692
8	Shinsa-dong	1	M	40-59	2,841	1_1_40-59	48	470.96	2914779
9	Nonhyeon 1-dong	1	M	40-59	3,476	1_1_40-59	48	470.96	2914779
10	Nonhyeon 2-dong	1	M	40-59	3,061	1_1_40-59	48	470.96	2914779
11	Apgujeong-dong	1	M	40-59	4,153	1_1_40-59	48	470.96	2914779
12	Cheongdam-dong	1	M	40-59	4,659	1_1_40-59	48	470.96	2914779
13	Samsung 1-dong	1	M	40-59	2,427	1_1_40-59	48	470.96	2914779
14	Samsung 2-dong	1	M	40-59	4,852	1_1_40-59	48	470.96	2914779
15	Shinsa-dong	1	M	≥60	1,527	1_1_≥60	27	414.07	898420.2
16	Nonhyeon 1-dong	1	M	≥60	1,540	1_1_≥60	27	414.07	898420.2
17	Nonhyeon 2-dong	1	M	≥60	1,613	1_1_≥60	27	414.07	898420.2
18	Apgujeong-dong	1	M	≥60	2,462	1_1_≥60	27	414.07	898420.2
19	Cheongdam-dong	1	M	≥60	2,179	1_1_≥60	27	414.07	898420.2

wt, weight; wj, weight; yj, observed value; rj, smoking rate; M, male.

Table 6. Variance calculation of synthetic estimates by dong and group

Observation	Eup/myeon/dong	Corrected cluster	Sex	Age	Population	Group1	n	Mean	sum_wj_yj_rj_Sum	Sum	Zjk	Var
1	Gaepo 1-dong	3	M	19-39	3,677	3_1_19-39	54	615.277	5180109	19069	0.193	0.000178
2	Gaepo 1-dong	3	M	40-59	3,677	3_1_40-59	58	461.391	3071663	19069	0.193	0.000162
3	Gaepo 1-dong	3	M	≥60	1,659	3_1_≥60	29	406.868	1009267	19069	0.087	5.68E-05
4	Gaepo 1-dong	3	F	19-39	3,601	3_2_19-39	64	583.223	2031942	19069	0.189	5.28E-05
5	Gaepo 1-dong	3	F	40-59	4,455	3_2_40-59	78	419.521	0	19069	0.233	0.00
6	Gaepo 1-dong	3	F	≥60	2,000	3_2_≥60	37	411.813	728625.3	19069	0.105	3.55E-05
7	Gaepo 2-dong	3	M	19-39	5,720	3_1_19-39	54	615.267	5180109	27359	0.209	0.000209
8	Gaepo 2-dong	3	M	40-59	5,590	3_1_40-59	58	461.391	3071663	27359	0.204	0.000182
9	Gaepo 2-dong	3	M	≥60	1,656	3_1_≥60	29	406.868	1009267	27359	0.060	2.75E-05
10	Gaepo 2-dong	3	F	19-39	5,760	3_2_19-39	64	583.223	2031942	27359	0.210	6.57E-05
11	Gaepo 2-dong	3	F	40-59	6,368	3_2_40-59	78	419.521	0	27359	0.233	0.00
12	Gaepo 2-dong	3	F	≥60	2,265	3_2_≥60	37	411.813	728625.3	27359	0.083	2.21E-05

wj, weight; yj, observed value; rj, smoking rate; Zjk, proportion of registered population of category k; Var, variance; M, male; F, female.

$$\alpha_{i(opt)} = \frac{MSE(\hat{Y}_S^i)}{MSE(\hat{Y}_S^i) + V(\hat{Y}_D^i)} \quad (7)$$

The estimated value of the optimal weight $\alpha_{i(opt)}$ is calculated as follows:

$$\hat{\alpha}_{i(opt)} = \frac{MSE(\hat{Y}_S^i)}{(\hat{Y}_S^i - \hat{Y}_D^i)^2} \quad (8)$$

The weight minimizing the mean MSE ($\hat{Y}_S^i$) using the initial common weight α as an approach to giving the common weight to all small areas is obtained as follows:

$$\hat{\alpha}(opt) = 1 - \frac{\sum_i V(\hat{Y}_D^i)}{\sum_i (\hat{Y}_S^i - \hat{Y}_D^i)^2} \quad (9)$$

The weight dependent on the sample size assigned to each small area is calculated as follows:

$$\alpha_i(\delta) = \begin{cases} 1, & \bar{N}_i \geq \delta N_i \\ \frac{\bar{N}_i}{\delta N_i}, & (an \ so \ on) \end{cases} \quad (10)$$

where N_i is the size of small area i , $\bar{N}_i = N(\frac{n_i}{n})$. $\bar{N}_i$ is the direct estimator, and δ is the value adjusting the synthetic estimator's contribution, thus a subjectively determined value. The Canadian Labor Force Survey, for example, uses $\delta=2/3$, which is also applied to this calculation [8].

After calculating the composite estimators of the dong-level smoking rates with each of the three types of weight presented above, an optimal estimation method is selected. The composite estimates are calculated in the following procedure.

① Data set generation by integrating the direct estimates (Y_d) and synthetic estimates (Y_s) calculated for the 22 dongs
/Integration of direct and synthetic estimators (estimates and variance)*/
data abc.seoul_gangnam_estimators;
merge abc.seoul_gangnam_estimator_direct abc.seoul_gangnam_estimator_com;

by eup/myeon/dong;

run;

Table 7 contains the direct and synthetic estimates.

② Calculation of composite estimates using the first weight (Y_c1)

/*Composite estimator_1*/

```
data abc.seoul_gangnam_estimator_c1;
    set abc.seoul_gangnam_estimators;
    alpha1=Var_Y_s/(Var_Y_d+Var_Y_s);
    Y_c1=(alpha1*Y_d)+((1-alpha1)*Y_s);
    Var_Y_c1=((alpha1*alpha1)*Var_Y_d)+(((1-alpha1)*(1-alpha1))*var_Y_s);
    sumvar_Ys_Yd=(var_Y_s+var_Y_d);
run;
```

/*Direct estimator variance by corrected cluster and direct estimator variance + composite estimator*/

```
proc surveymeans data=abc.seoul_gangnam_estimator_c1 sum;
    domain corrected cluster;
    var Var_Y_d;
    ods output domain=abc1;
run;
data abc1;
    set abc1;
    rename sum=sum1;
run;
proc surveymeans data=abc.seoul_gangnam_estimator_c1 sum;
    domain corrected cluster;
```

Table 7. Direct estimator and synthetic estimator calculation results for current smoking rates by dong

Observation	Eup/myeon/dong	n	Y_d	Var_Y_d	Corrected cluster	Y_s	var_Y_s
1	Gaepo 1-dong	51	0.149	0.003	3	0.185	0.000485
2	Gaepo 2-dong	52	0.163	0.004	3	0.188	0.000506
3	Gaepo 4-dong	24	0.155	0.006	3	0.190	0.000511
4	Nonhyeon 1-dong	41	0.383	0.007	1	0.265	0.000828
5	Nonhyeon 2-dong	28	0.444	0.010	1	0.258	0.000742
6	Daechi 1-dong	30	0.186	0.006	2	0.211	0.000528
7	Daechi 2-dong	53	0.070	0.001	2	0.214	0.000541
8	Daechi 4-dong	31	0.357	0.008	2	0.213	0.000595
9	Dogok 1-dong	44	0.185	0.003	2	0.210	0.000548
10	Dogok 2-dong	54	0.075	0.001	2	0.205	0.000506
11	Samsung 1-dong	35	0.212	0.005	1	0.260	0.000694
12	Samsung 2-dong	51	0.241	0.004	1	0.261	0.000737
13	Segok-dong	25	0.108	0.003	3	0.190	0.000522
14	Sooseo-dong	40	0.259	0.005	3	0.187	0.000516
15	Shinsa-dong	36	0.218	0.005	1	0.251	0.000682
16	Apgujeong-dong	36	0.156	0.005	1	0.245	0.000639
17	Yeoksam 1-dong	58	0.365	0.004	2	0.219	0.000717
18	Yeoksam 2-dong	55	0.267	0.005	2	0.211	0.000562
19	Ilwon 1-dong	38	0.218	0.005	3	0.190	0.000513
20	Ilwon 2-dong	44	0.167	0.003	3	0.188	0.000500
21	Ilwonbon-dong	46	0.242	0.004	3	0.184	0.000490
22	Cheongdam-dong	49	0.135	0.002	1	0.256	0.000692

Y_d, direct estimate; Var_Y_d, variance of Y_d; Y_s, synthetic estimate; var_Y_s, variance of Y_s.

```

var sumvar_Ys_Yd;
ods output domain=abc2;
run;
data abc3;
merge abc1 abc2;
by corrected cluster;
alpha2=1-(sum1/sum);
keep corrected cluster alpha2;
run;
proc sort data=abc.seoul_gangnam_estimator_
c1; by corrected cluster; run;

```

③ Calculation of composite estimates using the second weight (Y_c2)

```

/*Composite estimator_2*/
data abc.seoul_gangnam_estimator_c2;
merge abc.seoul_gangnam_estimator_c1
abc3;
by corrected cluster;
Y_c2= (alpha2*Y_d)+((1-alpha2)*Y_s);
Var_Y_c2= ((alpha2*alpha2)*Var_y_
d)+((1-alpha2)*(1-alpha2))*var_Y_s);
run;

proc surveymeans data=abc.seoul_gangnam_pop
sum; domain eup/myeon/dong; var population;

```

```

ods output domain=abc4; run;
proc surveymeans data=abc.seoul_gangnam_pop
sum; domain corrected cluster; var population;
ods output domain=abc5; run;
proc surveymeans data=abc.seoul_gangnam_es-
timator_c2 sum; domain corrected cluster; var
N; ods output domain=abc6; run;
proc sort data=abc4; by eup/myeon/dong; run;
data abc5; set abc5; rename Sum=cluster popu-
lation; run;
proc sort data=abc5; by corrected cluster;
run;
data abc6; set abc6; rename Sum=cluster sam-
ple size; run;
proc sort data=abc6; by corrected cluster;
run;
proc sort data=abc.seoul_gangnam_estimator_
c2; by eup/myeon/dong; run;
data abc.seoul_gangnam_estimator_c3_1;
merge abc.seoul_gangnam_estimator_c2
abc4;
by eup/myeon/dong;
drop DomainLabel VarName VarLabel StdDev;
rename sum=registered number of population;
run;
proc sort data=abc.seoul_gangnam_estimator_

```



```

c3_1; by corrected cluster; run;
data abc.seoul_gangnam_estimator_c3_2;
    merge abc.seoul_gangnam_estimator_c3_1
abc5 abc6;
    by corrected cluster;
    drop DomainLabel VarName VarLabel StdDev;
run;

```

④ Calculation of composite estimates using the third weight (Y_{c3})

```

/*Composite estimator_3*/
data abc.seoul_gangnam_estimator_c3;
    set abc.seoul_gangnam_estimator_c3_2;
    hat_N_i=cluster population*(N/cluster
sample size);
    if hat_N_i>=((2/3)*number of regis-
tered population) then
        alpha3=1
    else alpha3=hat_N_i/((2/3)*number of
registered population);
    Y_c3= (alpha3*Y_d)+((1-alpha3)*Y_s);
    Var_Y_c3= ((alpha3*alpha3)*Var_y_
d)+((1-alpha3)*(1-alpha3))*var_Y_s);
run;

```

⑤ Calculation of the composite estimates using the average weight of the first and third weights (Y_{c4})

```

/*Composite estimator_4*/
data abc.seoul_gangnam_estimator_c4;
    set abc.seoul_gangnam_estimator_c3;
    alpha4= (alpha1+alpha3)/2
    Y_c4= (alpha4*Y_d)+((1-alpha4)*Y_s);
    Var_Y_c4= ((alpha4*alpha4)*Var_y_
d)+((1-alpha4)*(1-alpha4))*var_Y_s);
run;

/*Direct estimator_synthetic estimator_com-
posite estimator*/
data abc.estimator_total;
    set abc.seoul_gangnam_estimator_c4;
    keep eup/myeon/dong Y_d Var_Y_d Y_s
var_y_s alpha1 Y_c1 var_Y_c1 alpha3 Y_c3 var_
y_c3 Y_c4 var_y_c4;
run;
proc print data=abc.estimator_total; run;

```

Table 8 outlines the results of calculating the current smoking rates of each of the 22 dong applying the four types of composite estimates. While variances are found to be lower compared

Table 8. Results of estimating the current smoking rates by dong applying four types of composite estimate

Eup/myeon/dong	n	Y _d	V _d	Y _{c1}	V _{c1}	Y _{c2}	V _{c2}	Y _{c3}	V _{c3}	Y _{c4}	V _{c4}
Nonhyeon 1-dong	41	0.3832	0.0063	0.2787	0.0007	0.2787	0.0007	0.3832	0.0063	0.3310	0.0021
Nonhyeon 1-dong	28	0.4439	0.0096	0.2718	0.0007	0.2802	0.0007	0.4439	0.0096	0.3579	0.0029
Samsung 1-dong	35	0.2118	0.0052	0.2542	0.0006	0.2542	0.0006	0.2119	0.0052	0.2330	0.0018
Samsung 2-dong	51	0.2407	0.0042	0.2584	0.0006	0.2591	0.0006	0.2407	0.0042	0.2495	0.0015
Shinsa-dong	36	0.2180	0.0052	0.2476	0.0006	0.2475	0.0006	0.2180	0.0052	0.2328	0.0018
Apkujeong-dong	36	0.1564	0.0051	0.2352	0.0006	0.2347	0.0006	0.1564	0.0051	0.1958	0.0017
Cheongdam-dong	49	0.1351	0.0024	0.2288	0.0005	0.2421	0.0006	0.1351	0.0024	0.1820	0.0010
Daechi 1-dong	30	0.1862	0.0059	0.2088	0.0005	0.2079	0.0005	0.1862	0.0059	0.1975	0.0018
Daechi 2-dong	53	0.0703	0.0010	0.1642	0.0004	0.1965	0.0004	0.0703	0.0010	0.1173	0.0005
Daechi 4-dong	31	0.3576	0.0077	0.2232	0.0006	0.2303	0.0006	0.3576	0.0077	0.2904	0.0023
Dogok 1-dong	44	0.1855	0.0034	0.2064	0.0005	0.2068	0.0005	0.1855	0.0034	0.1960	0.0012
Dogok 2-dong	54	0.0752	0.0011	0.1650	0.0003	0.1894	0.0004	0.0752	0.0011	0.1201	0.0005
Yeoksam 1-dong	58	0.3655	0.0046	0.2390	0.0006	0.2369	0.0006	0.3655	0.0046	0.3023	0.0016
Yeoksam 2-dong	55	0.2670	0.0053	0.2162	0.0005	0.2175	0.0005	0.2670	0.0053	0.2416	0.0017
Gaepo 1-dong	51	0.1494	0.0030	0.1803	0.0004	0.1816	0.0004	0.1494	0.0030	0.1648	0.0011
Gaepo 2-dong	52	0.1632	0.0041	0.1857	0.0005	0.1859	0.0005	0.1632	0.0041	0.1744	0.0014
Gaepo 4-dong	24	0.1552	0.0069	0.1874	0.0005	0.1863	0.0005	0.1610	0.0048	0.1742	0.0016
Segok-dong	25	0.1082	0.0036	0.1800	0.0005	0.1822	0.0005	0.1083	0.0036	0.1441	0.0012
Soosea-dong	40	0.2596	0.0051	0.1933	0.0005	0.1940	0.0005	0.2596	0.0051	0.2264	0.0016
Ilwon 1-dong	38	0.2184	0.0053	0.1930	0.0005	0.1934	0.0005	0.2184	0.0053	0.2057	0.0017
Ilwon 2-dong	44	0.1670	0.0035	0.1860	0.0004	0.1865	0.0004	0.1670	0.0035	0.1765	0.0012
Ilwonbon-dong	46	0.2416	0.0045	0.1894	0.0004	0.1895	0.0004	0.2416	0.0045	0.2155	0.0015

Y_d, direct estimate; V_d, variance of Y_d; Y_{c1}, first weight composite estimate; V_{c1}, variance of Y_{c1}; Y_{c2}, second weight composite estimate; V_{c2}, variance of Y_{c2}; Y_{c3}, third weight composite estimate; V_{c3}, variance of Y_{c3}; Y_{c4}, composite estimate using average weight of first and third weights; V_{c4}, variance of Y_{c4}.

with direct estimates, the current smoking rate estimates vary widely depending on dong sample sizes, reflecting the estimate-stabilizing feature of composite estimation. Viewed from the aspect of reducing the variance of direct estimates and correcting the bias of synthetic estimates, the fourth composite estimator is considered most effective in stabilizing the dong-level estimates.

CONCLUSION

This paper explained the procedure for producing health indicators at dong/eup/myeon-level (smaller than the designed domain) from the CHS data with the aim of producing health indicators at the level of health center district (designed domain), by applying small-area estimation to an example case of numerical estimation. The calculation procedures were presented using SAS codes, a method that is expected to be useful in cases in which statistics for smaller or detailed areas are to be produced from a survey conducted with the objective of producing statistics at a larger domain level.

ACKNOWLEDGEMENTS

This work was supported by the Research Program funded by the Korea Centers for Disease Control and Prevention (fund code 2014-P33001-00).

CONFLICT OF INTEREST

The authors have no conflicts of interest to declare for this study.

SUPPLEMENTARY MATERIAL

Supplementary material is available at <http://www.e-epih.org/>.

REFERENCES

1. Korea Centers for Disease Control and Prevention. Sample design for 2013 National Community Health Survey and monitoring sample survey. Cheongju: Korea Centers for Disease Control and Prevention; 2013, p. 9-11 (Korean).
2. Ghosh M, Rao JN. Small area estimation: an appraisal. *Stat Sci* 1994; 9:55-93.
3. Lee KO, Chung YS. Small-area estimation: research report. Daejeon: Statistics Korea; 2001, p. 70-76 (Korean).
4. Gonzalez Jr JF, Placek PJ, Scott C. Synthetic estimation in follow-back surveys at the National Center for Health Statistics. New York: Springer; 1996, p. 16-27.
5. Lee KO. Application of small-area estimation for estimating the number of the unemployed by si/gun/gu unit. *Korean J Appl Stat* 2000; 13:275-285 (Korean).
6. Korea Centers for Disease Control and Prevention. The study program (algorithm) to compute dong/eub/meon's statistics in Community Health Survey. Cheongju: Korea Centers for Disease Control and Prevention; 2014, p. 24-43 (Korean).
7. Korea Centers for Disease Control and Prevention. Community Health Survey raw data use guidelines. Cheongju: Korea Centers for Disease Control and Prevention; 2012, p. 28-35 (Korean).
8. Singh MP, Gambino J, Mantel HJ. Issues and strategies for small-area data. *Surv Methodol* 1994;20:3-22.