

Supplemental materials for: Regional inequalities in excess mortality and its community determinants during the early COVID-19 pandemic in South Korea

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Appendix A. Fitted results of a Seasonal Autoregressive Integrated Moving Average (SARIMA) model by region

To examine the trends in monthly death data, we conducted a thorough analysis involving time decomposition, autocorrelation function (ACF) plots, and the Ljung-Box test to assess the autocorrelations of data residuals. These preliminary tests supported the time-series analysis. Therefore, we fitted a Seasonal Autoregressive Integrated Moving Average (SARIMA) model. For the application of the SARIMA model to predict excess mortality in 2020, we determined optimal parameters using the R function *auto.arima*. Depending on the model parameter settings of SARIMA, the model could take various forms, including SARIMA, ARIMA, ARMA, AR, and MA. We fitted the time-series model to the monthly data for each district, tailoring the model parameters to suit the distinct mortality trends in each community. The distribution of the fitted parameters for the 250 districts is provided in table 1, and a summary of excess mortality across the districts is presented in table 2 and table 3.

Table 1. Distribution of SARIMA model parameter composites for each region in South Korea (2020)

SARIMA model parameter composite: (p,d,q) (P,D,Q) [Frequency]	No. of districts
Administrative regional level 1: national average (South Korea)	
(0,0,1) (0,1,1) [12]	1
Administrative regional level 2: 17 cities and provinces	
(0,0,0) (0,1,1) [12]	3
(0,0,0) (1,1,0) [12]	1
(0,0,1) (0,1,1) [12]	4
(0,0,1) (1,1,0) [12]	2
(1,0,0) (0,1,1) [12]	3
(1,0,0) (1,0,0) [12]	1
(1,0,0) (1,1,0) [12]	2
(1,1,1) (1,0,0) [12]	1
Administrative regional level 3: 250 districts	
(0,0,0)	72
(0,0,0) (0,0,1) [12]	14
(0,0,0) (0,1,1) [12]	4
(0,0,0) (1,0,0) [12]	35
(0,0,0) (1,0,1) [12]	1
(0,0,0) (1,1,0) [12]	1
(0,0,1)	4
(0,0,1) (0,0,1) [12]	2
(0,0,1) (1,0,0) [12]	3

(0,1,0)	2
(0,1,1)	19
(0,1,1) (0,0,1) [12]	5
(0,1,1) (1,0,0) [12]	29
(0,1,2)	1
(0,1,2) (1,0,0) [12]	1
(0,1,2) (1,0,1) [12]	1
(1,0,0)	20
(1,0,0) (0,0,1) [12]	4
(1,0,0) (1,0,0) [12]	8
(1,0,0) (1,0,1) [12]	1
(1,0,1)	3
(1,0,1) (1,0,0) [12]	2
(1,1,1)	4
(1,1,1) (0,0,1) [12]	3
(1,1,1) (1,0,0) [12]	4
(1,1,2) (1,0,0) [12]	1
(2,0,0)	2
(2,0,2) (1,0,0) [12]	1
(2,1,1)	2
(3,1,0) (1,0,1) [12]	1

Table 2. Summary of excess deaths per 100,000 individuals across 250 districts in South Korea (2020)

N	Min.	1st quartile	Median	Mean	3rd quartile	Max.
250	-326.3	10.8	27.7	37.4	62.7	276.0

Table 3. Estimates of excess deaths per 100,000 individuals for 250 districts in South Korea (2020)

Name of cities and provinces	Name of districts	Observed mortality (O)	Predicted(expected) mortality		Excess mortality (O-P)
			(P)*	(95% PI)	
Seoul	Jongno-gu	576.7	549.7	(503.6, 594.7)	27.0
Seoul	Jung-gu	574.2	543.2	(494.8, 591.4)	31.0
Seoul	Yongsan-gu	498.6	486.5	(453.1, 519.2)	12.1
Seoul	Seongdong-gu	458.9	443.9	(415.1, 473.4)	15.0
Seoul	Gwangjin-gu	425.6	394.7	(366.8, 422.8)	30.9
Seoul	Dongdaemun-gu	554	524.6	(495.3, 554.1)	29.3
Seoul	Jungnang-gu	567.8	508.1	(482.5, 533.2)	59.6
Seoul	Seongbuk-gu	513.9	483.8	(447.7, 520.0)	30.1
Seoul	Gangbuk-gu	632.5	587.8	(548.3, 626.4)	44.7
Seoul	Dobong-gu	583.6	543.3	(490.1, 596.8)	40.2
Seoul	Nowon-gu	511.3	492.5	(466.0, 518.3)	18.8
Seoul	Eunpyeong-gu	546.7	490	(462.6, 516.0)	56.7
Seoul	Seodaemun-gu	536.6	497.7	(461.3, 533.5)	38.9
Seoul	Mapo-gu	442.3	419	(391.9, 446.4)	23.3
Seoul	Yangcheon-gu	420.6	393.9	(371.8, 415.9)	26.7
Seoul	Gangseo-gu	459.7	446.8	(419.6, 474.0)	12.8
Seoul	Guro-gu	466.6	464.9	(364.9, 563.8)	1.8
Seoul	Geumcheon-gu	535.9	503.6	(477.3, 530.0)	32.3
Seoul	Yeongdeungpo-gu	466.8	450.3	(425.2, 475.6)	16.5
Seoul	Dongjak-gu	449.1	421.2	(399.9, 442.3)	27.8
Seoul	Gwanak-gu	443.1	416.7	(392.2, 441.1)	26.4
Seoul	Seocho-gu	334.6	325.8	(307.5, 344.5)	8.8
Seoul	Gangnam-gu	344.5	340.9	(310.3, 371.4)	3.6
Seoul	Songpa-gu	342.4	339.2	(309.9, 368.2)	3.2
Seoul	Gangdong-gu	417.9	448.3	(414.9, 482.1)	-30.4
Busan	Jung-gu	919.4	855.5	(747.1, 963.5)	63.9
Busan	Seo-gu	969.4	891.4	(818.0, 965.2)	78.0
Busan	Dong-gu	935.8	961.4	(860.8, 1060.7)	-25.6
Busan	Yeongdo-gu	1056	1001.4	(927.6, 1075.4)	54.5
Busan	Busanjin-gu	707.4	678.9	(626.4, 731.8)	28.5
Busan	Dongnae-gu	571.9	585.3	(504.4, 665.7)	-13.4
Busan	Nam-gu	662.1	608.5	(555.0, 661.2)	53.6

Busan	Buk-gu	596.1	600.9	(547.7,	653.6)	-4.8
Busan	Haeundae-gu	566	562.9	(484.5,	640.3)	3.1
Busan	Saha-gu	712.2	649.3	(597.1,	701.5)	63.0
Busan	Geumjeong-gu	700.6	683.2	(615.0,	753.1)	17.4
Busan	Gangseo-gu	452.2	456.9	(302.8,	611.0)	-4.7
Busan	Yeonje-gu	620.6	567.9	(516.7,	619.7)	52.7
Busan	Suyeong-gu	701.6	626.1	(566.2,	686.3)	75.5
Busan	Sasang-gu	698	651.4	(583.3,	719.3)	46.6
Busan	Gijang-gun	610.2	586.4	(535.6,	638.5)	23.8
Daegu	Jung-gu	774.1	734.8	(649.6,	819.0)	39.3
Daegu	Dong-gu	684.7	640.4	(595.6,	683.9)	44.3
Daegu	Seo-gu	821.2	749.9	(664.5,	835.6)	71.2
Daegu	Nam-gu	924.7	783.8	(691.6,	874.6)	140.9
Daegu	Buk-gu	526.3	509	(469.4,	548.3)	17.4
Daegu	Suseong-gu	516.1	490.5	(452.7,	528.8)	25.6
Daegu	Dalseo-gu	520.4	480.2	(442.1,	518.0)	40.2
Daegu	Dalseong-gun	497.1	494.5	(435.0,	555.2)	2.6
Incheon	Jung-gu	539	574.8	(517.4,	632.4)	-35.8
Incheon	Dong-gu	836.3	768.2	(655.7,	881.9)	68.0
Incheon	Yeonsu-gu	378.6	367.6	(343.4,	391.8)	10.9
Incheon	Namdong-gu	515.2	514.9	(450.9,	578.8)	0.3
Incheon	Bupyeong-gu	562.8	548.6	(498.9,	597.4)	14.2
Incheon	Gyeyang-gu	518.6	507.9	(455.9,	558.7)	10.7
Incheon	Seo-gu	418.3	402.3	(371.1,	433.1)	16.0
Incheon	Michuhol-gu	618.9	609.8	(568.4,	651.7)	9.1
Incheon	Ganghwa-gun	1308.5	1120	(1027.2,	1212.6)	188.5
Incheon	Ongjin-gun	954.3	879.3	(772.7,	986.2)	75.0
Gwangju	Dong-gu	763.8	780.9	(698.8,	862.8)	-17.1
Gwangju	Seo-gu	514.1	491.2	(462.9,	520.0)	22.9
Gwangju	Nam-gu	622.3	585.1	(532.6,	636.9)	37.2
Gwangju	Buk-gu	576.1	561.9	(504.5,	620.0)	14.2
Gwangju	Gwangsan-gu	405.2	406.2	(381.2,	431.6)	-1.0
Daejeon	Dong-gu	725.3	734.6	(661.9,	807.3)	-9.3
Daejeon	Jung-gu	682.9	689.6	(656.6,	722.4)	-6.7
Daejeon	Seo-gu	443.4	413	(385.9,	440.4)	30.4
Daejeon	Yuseong-gu	338.4	325.2	(303.2,	346.8)	13.2
Daejeon	Daedeok-gu	569	612.7	(551.6,	674.6)	-43.7
Ulsan	Jung-gu	519.7	503.8	(451.0,	556.6)	15.9
Ulsan	Nam-gu	446.2	418.7	(373.9,	463.8)	27.5
Ulsan	Dong-gu	420.4	402.3	(363.9,	439.0)	18.1

Ulsan	Buk-gu	332.6	344.8	(300.0,	389.6)	-12.3
Ulsan	Ulju-gun	596.7	575.2	(532.4,	618.0)	21.5
Sejong	Sejong	379.2	338.5	(310.6,	367.0)	40.7
GG	Jangan-gu	500.8	488.8	(429.9,	546.7)	12.0
GG	Gwonseon-gu	435.3	404.2	(359.9,	448.9)	31.1
GG	Paldal-gu	567.3	601.6	(537.2,	665.6)	-34.3
GG	Yeongtong-gu	250.7	270.9	(242.4,	298.8)	-20.2
GG	Sujeong-gu	530.5	524.5	(493.2,	555.7)	6.0
GG	Jungwon-gu	549	530.9	(500.4,	562.0)	18.0
GG	Bundang-gu	373.4	358.3	(331.9,	384.7)	15.1
GG	Uijeongbu-si	548.8	548.7	(495.8,	601.2)	0.1
GG	Manan-gu	544.1	473.9	(443.0,	505.0)	70.2
GG	Dongan-gu	362.6	357.7	(325.0,	390.7)	4.9
GG	Bucheon-si	477.4	452.4	(408.4,	496.1)	25.0
GG	Gwangmyeong-si	455.2	436.8	(393.5,	479.2)	18.4
GG	Pyeongtaek-si	488.7	494.2	(465.9,	522.3)	-5.4
GG	Dongducheon-si	833.5	863.3	(723.9,	1001.8)	-29.8
GG	Sangnok-gu	494.6	483.1	(435.7,	530.9)	11.4
GG	Danwon-gu	442.6	420.7	(371.8,	468.9)	21.9
GG	Deogyang-gu	501.6	485.6	(457.3,	513.3)	16.0
GG	Ilsandong-gu	468.2	433.3	(401.2,	465.2)	34.9
GG	Ilsanseo-gu	443.9	402.6	(372.9,	431.9)	41.3
GG	Gwacheon-si	403.6	418.7	(355.4,	482.4)	-15.1
GG	Guri-si	457.3	435.9	(384.1,	488.7)	21.4
GG	Namyangju-si	477.7	500.5	(435.8,	564.6)	-22.7
GG	Osan-si	368.9	345.8	(316.7,	374.7)	23.1
GG	Siheung-si	381.8	368.3	(349.4,	387.1)	13.5
GG	Gunpo-si	455.7	496.1	(299.5,	690.6)	-40.4
GG	Uiwang-si	447	422.9	(387.9,	458.2)	24.2
GG	Hanam-si	397.2	394.9	(323.5,	464.7)	2.4
GG	Cheoin-gu	572.9	554.4	(516.7,	592.9)	18.5
GG	Giheung-gu	374.3	356.6	(324.7,	389.1)	17.8
GG	Suji-gu	312.1	321.6	(299.6,	344.0)	-9.5
GG	Paju-si	547.7	518.8	(492.8,	544.9)	28.9
GG	Icheon-si	554.2	540.3	(504.3,	577.7)	13.9
GG	Anseong-si	701.6	655.1	(606.5,	704.6)	46.5
GG	Gimpo-si	391.3	405.5	(381.4,	430.2)	-14.2
GG	Hwaseong-si	334.2	329.9	(303.3,	356.5)	4.3
GG	Gwangju-si	452.4	422.4	(396.8,	448.5)	30.0
GG	Yangju-si	631.3	634.2	(553.3,	713.6)	-2.9

GG	Pocheon-si	873.4	766.9	(692.4,	841.9)	106.6
GG	Yeoju-si	838.7	816.2	(758.3,	875.1)	22.5
GG	Yeoncheon-gun	1078.1	999.7	(933.9,	1065.8)	78.4
GG	Gapyeong-gun	1046.9	1019.3	(883.7,	1154.2)	27.5
GG	Yangpyeong-gun	884.3	867.2	(796.1,	938.7)	17.1
GW	Chuncheon-si	667	654	(602.1,	707.7)	13.0
GW	Wonju-si	605.3	584.6	(553.3,	617.0)	20.6
GW	Gangneung-si	802	816.6	(744.4,	888.1)	-14.6
GW	Donghae-si	776.2	712.8	(641.2,	784.6)	63.4
GW	Taebaek-si	831.7	806.4	(725.8,	889.0)	25.4
GW	Sokcho-si	745.2	706.1	(640.2,	773.0)	39.1
GW	Samcheok-si	961.4	904.4	(816.3,	990.1)	57.0
GW	Hongcheon-gun	1085.5	979.2	(895.8,	1060.9)	106.3
GW	Hoengseong-gun	1112.1	1137	(981.3,	1296.3)	-25.0
GW	Yeongwol-gun	1040.9	1053.5	(944.3,	1165.0)	-12.6
GW	Pyeongchang-gun	986.3	940.4	(830.8,	1050.5)	45.9
GW	Jeongseon-gun	1007.9	1007	(896.2,	1117.1)	0.9
GW	Cheorwon-gun	960.6	857.1	(761.4,	954.2)	103.5
GW	Hwacheon-gun	827.6	767	(662.4,	874.5)	60.5
GW	Yanggu-gun	864	763.7	(662.1,	865.0)	100.2
GW	Inje-gun	748	822.2	(725.2,	916.2)	-74.2
GW	Goseong-gun	1222.4	1078.8	(970.8,	1186.9)	143.6
GW	Yangyang-gun	1096.1	1044.2	(914.6,	1177.2)	51.9
CB	Chungju-si	799.7	781.9	(705.6,	858.4)	17.8
CB	Jecheon-si	848.7	808.8	(740.0,	879.3)	39.8
CB	Sangdang-gu	631.6	614.2	(572.1,	657.5)	17.3
CB	Seowon-gu	558.5	544.4	(484.0,	605.4)	14.1
CB	Heungdeok-gu	432.1	440.4	(402.1,	477.5)	-8.2
CB	Cheongwon-gu	513.1	488.4	(454.6,	522.3)	24.6
CB	Boeun-gun	1627.8	1351.8	(1226.8,	1481.1)	276.0
CB	Okcheon-gun	1197.6	1116.1	(988.3,	1242.3)	81.5
CB	Yeongdong-gun	1428.9	1235.4	(1128,	1343.9)	193.5
CB	Jincheon-gun	651.7	716.5	(649.4,	784.4)	-64.8
CB	Goesan-gun	1314.3	1299.2	(1136.7,	1458.0)	15.0
CB	Eumseong-gun	943	868	(805.4,	929.7)	75.0
CB	Danyang-gun	1123.7	1165.5	(1044.3,	1287.1)	-41.9
CB	Jeungpyeong-gun	774.7	664	(557.2,	769.6)	110.7
CN	Dongnam-gu	571.1	547.4	(513.0,	581.0)	23.7
CN	Sebuk-gu	366.1	364.3	(337.7,	390.3)	1.8
CN	Gongju-si	1083.5	1041.6	(921.1,	1155.7)	41.9

CN	Boryeong-si	990.5	921.3	(856.4,	987.4)	69.2
CN	Asan-si	528.1	542.5	(490.6,	595.0)	-14.5
CN	Seosan-si	687.2	641	(571.2,	710.7)	46.2
CN	Nonsan-si	1118.6	1078.2	(864.1,	1285.3)	40.4
CN	Gyeryong-si	430.4	408.9	(346.3,	471.4)	21.5
CN	Dangjin-si	752	716.2	(653.8,	778.6)	35.9
CN	Geumsan-gun	1319.2	1190	(1061.9,	1314.6)	129.2
CN	Buyeo-gun	1364.8	1271.4	(1180.7,	1362.2)	93.4
CN	Seocheon-gun	1374.6	1349.4	(1235.9,	1464.2)	25.2
CN	Cheongyang-gun	1532.8	1422.1	(1268.0,	1575.7)	110.7
CN	Hongseong-gun	906.7	937.7	(866.6,	1007.2)	-31.0
CN	Yesan-gun	1256.2	1171.7	(1017.9,	1322.2)	84.5
CN	Taeon-gun	1070	1045.3	(925.2,	1166.0)	24.7
JB	Wansan-gu	549.6	546.1	(502.0,	590.2)	3.5
JB	Deokjin-gu	485.5	488.5	(467.0,	510.0)	-3.0
JB	Gunsan-si	688	715.8	(646.3,	786.4)	-27.7
JB	Iksan-si	728.5	698.6	(647.3,	748.8)	29.9
JB	Jeongeup-si	1168.3	1021.4	(901.5,	1140.2)	146.9
JB	Namwon-si	1226.4	1041.4	(954.5,	1127.3)	185.0
JB	Gimje-si	1315.4	1182.9	(1079.0,	1290.0)	132.5
JB	Wanju-gun	875.3	851.7	(780.1,	921.6)	23.6
JB	Jinan-gun	1231.1	1335.7	(1195.0,	1478.5)	-104.7
JB	Muju-gun	1456.7	1398.4	(1138.6,	1663.3)	58.3
JB	Jangsu-gun	1238.2	1247.2	(1111.4,	1388.5)	-9.0
JB	Imsil-gun	1533.4	1439.6	(1270.3,	1606.4)	93.8
JB	Sunchang-gun	1406.2	1364.7	(1233.7,	1494.7)	41.5
JB	Gochang-gun	1344	1237.4	(1127.3,	1347.2)	106.7
JB	Buan-gun	1335.6	1248.4	(1145.7,	1354.2)	87.3
JN	Mokpo-si	687	649.4	(595.6,	703.1)	37.7
JN	Yeosu-si	731.7	689.5	(652.4,	727.1)	42.2
JN	Suncheon-si	618	591.1	(538.9,	644.0)	26.9
JN	Naju-si	895.6	903.2	(821.6,	986.6)	-7.6
JN	Gwangyang-si	537.5	518	(465.4,	570.5)	19.6
JN	Damyang-gun	1198.8	1525	(597.2,	2475.7)	-326.2
JN	Gokseong-gun	1542	1297.1	(1162,	1431.9)	244.9
JN	Gurye-gun	1366.9	1206.9	(1068.3,	1345.5)	160.0
JN	Goheung-gun	1627.8	1584.8	(1451.9,	1718.2)	43.0
JN	Boseong-gun	1493.3	1378.4	(1248.7,	1509.9)	114.9
JN	Hwasun-gun	1041.9	945.6	(861.4,	1028.2)	96.3
JN	Jangheung-gun	1339	1268.2	(1145.2,	1390.5)	70.8

JN	Gangjin-gun	1309.2	1274.8	(1148.8,	1401.3)	34.3
JN	Haenam-gun	1400.5	1384	(1240.6,	1526.3)	16.5
JN	Yeongam-gun	1127.1	1061.6	(894.5,	1232.4)	65.4
JN	Muan-gun	893	881.1	(784.1,	978.7)	11.9
JN	Hampyeong-gun	1525.4	1356.5	(1204.7,	1506.3)	168.9
JN	Yeonggwang-gun	1227.3	1141.8	(1046,	1236.7)	85.5
JN	Jangseong-gun	1173.8	1100.9	(987.7,	1217.6)	72.9
JN	Wando-gun	1283.9	1204.7	(1099.3,	1311.0)	79.2
JN	Jindo-gun	1286.4	1402.4	(1264.7,	1540.2)	-116.0
JN	Sinan-gun	1455.4	1382.4	(1205.2,	1559.9)	73.0
GB	Nam-gu	613.7	577.2	(540.2,	613.5)	36.5
GB	Buk-gu	627.6	578.8	(537.6,	619.2)	48.8
GB	Gyeongju-si	863.5	829	(754.8,	904.2)	34.5
GB	Gimcheon-si	963.1	905	(837.4,	974.8)	58.0
GB	Andong-si	977.7	929.5	(871.4,	988.9)	48.2
GB	Gumi-si	426.5	398.1	(358.5,	437.7)	28.4
GB	Yeongju-si	1018.3	1030.5	(937.7,	1124.2)	-12.2
GB	Yeongcheon-si	1179.9	1073.2	(977.8,	1169.7)	106.7
GB	Sangju-si	1251.9	1186.5	(1110.8,	1259.1)	65.5
GB	Mungyeong-si	1199.3	1137.8	(1037.2,	1239.5)	61.5
GB	Gyeongsan-si	646.8	584.9	(548.7,	621.0)	61.9
GB	Gunwi-gun	1499.6	1471.3	(1287.3,	1655.5)	28.3
GB	Uiseong-gun	1788.7	1646.7	(1494.4,	1796.2)	142.0
GB	Cheongsong-gun	1558	1451.1	(1226.2,	1676.7)	106.9
GB	Yeongyang-gun	1573.4	1439.1	(1242.2,	1636.2)	134.3
GB	Yeongdeok-gun	1524.1	1401.9	(1277.7,	1526.2)	122.2
GB	Cheongdo-gun	1543	1351.4	(1233.6,	1468.1)	191.6
GB	Goryeong-gun	1314.3	1072.9	(894.6,	1250.7)	241.3
GB	Seongju-gun	1271.2	1235.6	(1123.6,	1347.8)	35.6
GB	Chilgok-gun	686.7	607.4	(545.1,	669.1)	79.3
GB	Yecheon-gun	1230.6	1259.7	(1060.4,	1457.9)	-29.1
GB	Bonghwa-gun	1526.1	1348.4	(1128.2,	1563.3)	177.7
GB	Uljin-gun	1186.8	1091.7	(988.4,	1196.2)	95.1
GB	Ulleung-gun	690.5	695.6	(546.6,	846.7)	-5.1
GN	Jinju-si	649.7	616.3	(575.9,	658.6)	33.4
GN	Tongyeong-si	809.2	744	(669.6,	819.3)	65.2
GN	Sacheon-si	900.3	830.9	(763.5,	898.0)	69.4
GN	Gimhae-si	463.5	466.9	(448.2,	485.3)	-3.4
GN	Miryang-si	1122.7	1075.2	(951.9,	1198.4)	47.4
GN	Geoje-si	453.4	434	(389.1,	479.1)	19.4

GN	Yongsan-si	504.8	471.9	(422.0,	523.2)	32.8
GN	Uichang-gu	507	494.1	(443.8,	544.7)	12.9
GN	seongsan-gu	342.6	315.4	(287.9,	341.5)	27.1
GN	Masanhappo-gu	804.8	735.7	(687.0,	784.3)	69.0
GN	Masanhoewon-gu	569.1	585.8	(511.9,	657.7)	-16.7
GN	Jinhae-gu	542.7	511.5	(474.3,	548.7)	31.1
GN	Uiryong-gun	1514.4	1530.6	(1360.1,	1702.0)	-16.2
GN	Haman-gun	1000	944.6	(866.0,	1023.6)	55.4
GN	Changnyeong-gun	1294.4	1243.5	(1126.9,	1360.9)	50.9
GN	Goseong-gun	1236.7	1213.4	(1109.3,	1318.1)	23.2
GN	Namhae-gun	1646	1605.9	(1471.7,	1741.5)	40.1
GN	Hadong-gun	1372.9	1304.3	(1201.8,	1404.4)	68.6
GN	Sancheong-gun	1484.1	1383.8	(1256.4,	1511.4)	100.2
GN	Hamyang-gun	1420.4	1341.2	(1129.2,	1558.7)	79.1
GN	Geochang-gun	1156.5	1076.5	(955.1,	1196.2)	80.0
GN	Hapcheon-gun	1652.1	1549.8	(1406.4,	1692.5)	102.3
JJ	Jeju-si	553.4	570.2	(544.0,	596.5)	-16.8
JJ	Seogwipo-si	681.8	690.4	(642.1,	738.9)	-8.6

Abbreviation: GG, Gyeonggi-do; GW, Gangwon-do; CB, Chungcheongbuk-do; CN, Chungcheongnam-do; JB, Jeollabuk-do; JN, Jellanam-do; GB, Gyeongsangbuk-do; GN, Gyeongsangnam-do; JJ, Jeju-do; PI, prediction interval

Notes: *Average of 10,000 iterations for annual predicted deaths using the SARIMA model. Table was arranged according to the order of the administrative regional code.

Appendix B. Correlation between excess mortality rates and COVID-19 confirmed death rates by administrative units

We investigated the correlation between excess mortality rates and COVID-19-confirmed death rates using non-linear plots and linear relationship-specific statistics.

Figure 1 presents a smoothed curve for each administrative regional unit: (A) at the city and province level and (B) at the district level of South Korea. Among the 17 cities and provinces, one city, Daegu, was excluded because of the extreme pattern observed in each rate. Among the 250 districts, eight were excluded based on the results of leverage and influence tests. These eight observations exhibited both high leverage and influence on the association between excess mortality and COVID-19 mortality rates. Leverages were identified when their hat values exceeded twice the mean of hat values [hat value > (2 × mean of hat values)]. Influences were defined as Cook's distance exceeding 4 divided by the sample sizes [Cook's distance > (4/250)]. The loess method was applied to depict a smoothed curve, and the optimal spans were estimated based on the lowest AICc for each regional unit. The spans were 0.699 for 16 cities and provinces and 0.724 for 242 districts.

Table 4 presents the correlation coefficients assuming a linear relationship. At the city and province level, the correlation was not statistically significant, whereas at the district level, a significantly positive relationship between excess mortality and COVID-19-confirmed death rates was observed (p-value = 0.032).

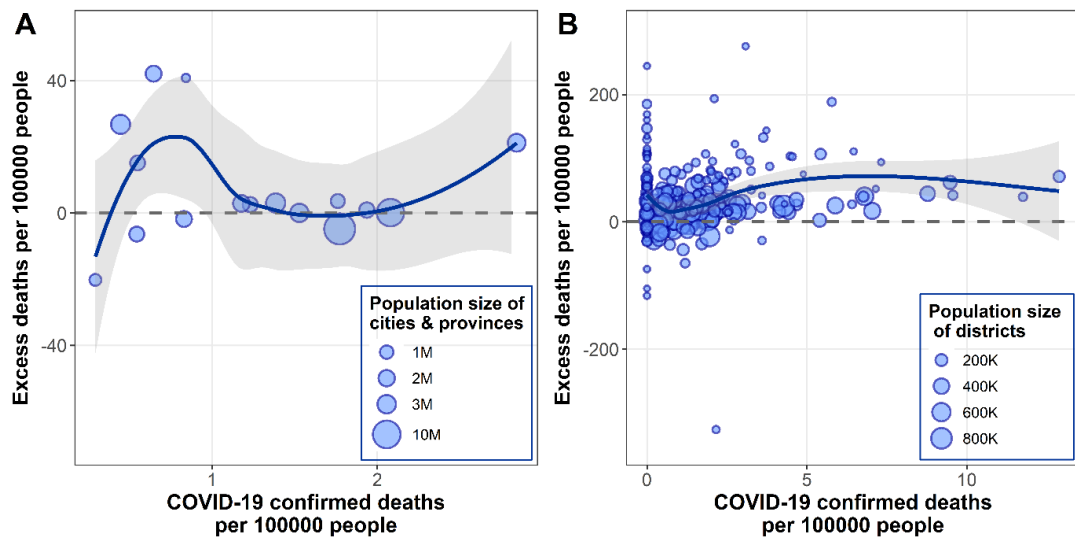


Figure 1. Smoothed curves illustrating the relationship between excess mortality rates and COVID-19 confirmed death rates for (A) cities and provinces and (B) districts of South Korea in 2020

Table 4. Correlation coefficients for excess mortality rates and COVID-19 confirmed death rates for cities and districts of South Korea in 2020

	16 cities and provinces	242 districts
Correlation coefficient (r)	-0.080	0.138
P-value	0.769	0.032

Appendix C. Data sources and descriptive results of community determinants

Table 5. Data sources and definitions of community characteristics

Variables		Definition	Unit	Region unit	Year	Data sources	Publisher	Data repository	Reference
-	Population size	Number of registered residents by district	Number of	250	2015.01. – 2020.12.	Population Statistics Based on Resident Registration	MOIS	KOSIS	(1)
-	All-cause mortality*	Monthly all-cause deaths by district	Number of, per 100,000	250	2015.01. – 2020.12.	Vital Statistics (Death)	Statistics Korea	KOSIS	(2)
-	COVID-19 confirmed cases*	COVID-19 confirmed cases by city and province	Number of, per 100,000	17	2020.12. 31.	KDCA press releases	KDCA	KDCA website	(3)
-	COVID-19 confirmed deaths*	COVID-19 confirmed deaths by district	Number of, per 100,000	17 & 250	2020	Cause-of-death Statistics	Statistics Korea	MDIS	(4)
A. Health status									
A1	Hypertension	Diagnosed hypertension among individuals aged ≥ 30 years	%	255	2019	Community Health Survey	KDCA	CHS website	(5)
A2	Diabetes	Diagnosed diabetes among individuals aged ≥ 30 years	%	255	2019	Community Health Survey	KDCA	CHS website	(5)
A3	Depression	Sadness or hopelessness that interfered with daily life for > 2 consecutive weeks in the past year	%	255	2019	Community Health Survey	KDCA	CHS website	(5)
A4	Unmet medical needs	Inability to receive the necessary medical services in the past year	%	255	2019	Community Health Survey	KDCA	CHS website	(5)
B. Healthcare resources									
B1	Doctors*	Physicians, Korean oriental medicine doctors, and dentists	Number of, per 100,000	250	2019 4/4	National Health Insurance Statistical Yearbook	NHIS, HIRA	KOSIS	(6)
B2	Essential medical clinics*	Internal medicine, surgery, pediatrics, or obstetrics and gynecology	Number of, per 100,000	250	2019 4/4	National Health Insurance Statistical Yearbook	NHIS, HIRA	KOSIS	(7)
B3	Tertiary hospitals*	Tertiary and general hospitals	Number of, per 100,000	250	2019 4/4	National Health Insurance Statistical Yearbook	NHIS, HIRA	KOSIS	(8)
B4	Nursing hospitals*	Nursing hospitals	Number of, per 100,000	250	2019 4/4	National Health Insurance Statistical Yearbook	NHIS, HIRA	KOSIS	(8)
B5	Social welfare facilities*	Social welfare facilities (e.g., nursing homes for the elderly or disabled,	Number of, per 100,000	250	2019	Census on Establishments	Statistics Korea	MDIS	(9)

		residential welfare facilities for mental and substance abuse disorders)							
C. Built environment & social restriction policies									
C1	Social distancing policy level	Daily average level of social distancing policy (level 1–3) during 307 days in 2020 by regions	Index (1.26–1.56)	62	2020.02.29. – 2020.12.31. (307 days)	COVID-19 Regular Briefing of the Central Disaster and Safety Countermeasure Headquarters	MOHW	MOHW website	(10)
C2	Risky facilities to the COVID-19 spread*	Facilities with a high risk of viral spread, designated by the South Korean government during the COVID-19 pandemic (e.g., bars, singing rooms, bathhouse, performance halls, door-to-door sales businesses, restaurants, and cafés)	Number of, per 100,000	250	2019	Census on Establishments	Statistics Korea	MDIS	(9)
C3	Healthy facilities to enhance healthy behaviors*	Sports service establishments (e.g., stadiums, golf courses, ski resorts, multi-sports facilities, fitness centers, swimming pools, bowling alleys, billiard halls, (golf) driving ranges)	Number of, per 100,000	250	2019	Census on Establishments	Statistics Korea	MDIS	(9)
		Culture infrastructure (e.g., libraries, museums, art museums, art centers, and cultural centers)	Number of, per 100,000	229	2019	National General Report of Cultural Infrastructure	MCST	KOSIS	(11)
C4	Parks*	Nature parks, children’s parks, neighborhood parks, history parks, cultural parks, waterfront parks, and so forth	Number of, per 100,000	232	2019	Statistics of Urban Planning	LX	KOSIS	(12)
C5	Road	Sum of the road area (m ²) within the total administrative area (m ²)	%	229	2019.12.	Statistics of Urban Planning	LX	KOSIS	(13)
						Cadastral Statistics	MOLIT	KOSIS	(14)
D. Social capital									
D1	Trust	Percentage of response “My neighbors can be trusted.”	%	255	2019	Community Health Survey	KDCA	CHS website	(5)
D2	Social network	Social networking with family, friends, or neighbors regularly (more than once a week)	%	255	2019	Community Health Survey	KDCA	CHS website	(5)
D3	Social participation	Regular (more than once a month) social participation in religious, voluntary, friendship, or leisure activities	%	255	2019	Community Health Survey	KDCA	CHS website	(5)

E. Socioeconomic characteristics									
E1	Aging index	Aged-child ratio (65+/ $<$ 15 years)	Index	250	2019	Population Statistics Based on Resident Registration	MOIS	KOSIS	(15)
E2	Single-person households	Percentage of single-person households in the region	%	229	2019	Population Census	Statistics Korea	KOSIS	(16)
E3	Employment rate	Percentage of employed individuals among those aged \geq 15 years	%	154	2019	Local Area Labour Force Survey	Statistics Korea	KOSIS	(17)
				75 (8 cities)	2019 (Adjusted)	Economically Active Population Survey	Statistics Korea	KOSIS	(18)
E4	GRDP per capita	Gross Regional Domestic Product (GRDP) per capita (the exchange rate in 2019 corresponded to 1,156.4 KRW for 1 USD)	1000 USD	205	2019	Regional Indicators	Statistics Korea	KOSIS	(19)
				23	2018 (Adjusted)	Gyeongsangbuk-do GRDP	Gyeongsangbuk-do	KOSIS	(20)
				1 (Sejong)	2019	Regional Income	Statistics Korea	KOSIS	(21)
E5	Urbanization rate of city	Percentage of individuals living in urban areas out of the total population in the region	%	229	2019	Statistics of Urban Planning	LX	KOSIS	(22)
E6	Population density	Number of residents per km ²	Number of, per km ²	229	2019.12.	Population Statistics Based on Resident Registration	MOIS	KOSIS	(1)
						Cadastral Statistics	MOLIT	KOSIS	(14)

Abbreviation: GRDP, Gross Regional Domestic Product; CHS, Community Health Survey; MOIS, Ministry of the Interior and Safety; KDCA, Korea Disease Control and Prevention Agency; NHIS, National Health Insurance Service; HIRA, Health Insurance Review and Assessment Service; MDIS, MicroData Integrated Service; MOHW, Ministry of Health and Welfare; MCST, Ministry of Culture, Sports and Tourism; LX, Korea Land and Geospatial InformatiX Corporation; MOLIT, Minister of Land, Infrastructure and Transport

Data repository: KOSIS (<https://kosis.kr>); MDIS (<https://mdis.kostat.go.kr>); KDCA website (<https://www.kdca.go.kr>); CHS website (<https://chs.kdca.go.kr>); MOHW website (<http://ncov.mohw.go.kr>)

Note: *Variables indexed as “per 100,000 people” were calculated using a “population size (2019.12.)” variable; the labels A1 to E6 correspond to those in figure 3 in the manuscript.

Table 6. Descriptive results of community characteristics in South Korea (2019)

	N	Mean (Weighted percent*)	SD (Standard error of percent*)
Health status			
Hypertension (aged \geq 30 years) (%)	205668	(24.83)	(0.13)
Diabetes (aged \geq 30 years) (%)	205676	(10.26)	(0.09)
Depression (%)	229009	(6.25)	(0.07)
Unmet medical needs (%)	212713	(6.00)	(0.08)
Healthcare resources			
Doctors (No. of, per 100,000)	250	277.65	223.22
Essential medical clinics (No. of, per 100,000)	250	15.61	7.43
Tertiary Hospitals (No. of, per 100,000)	250	3.77	2.41
Nursing hospitals (No. of, per 100,000)	250	3.67	2.98
Social welfare facilities (No. of, per 100,000)	250	21.11	13.61
Built environment & social restriction policies			
Social distancing policy level (index)	250	1.39	0.11
Risky facilities to the COVID-19 spread (No. of, per 100,000)	250	1671.39	613.17
Healthy facilities to enhance healthy behaviors (No. of, per 100,000)	250	87.58	23.06
Parks (No. of, per 100,000)	250	51.94	33.24
Road (%)	250	4.56	5.23
Social capital			
Trust (%)	212257	(62.82)	(0.17)
Social networks with ANY (+1 a week) (%) : family/ neighbors/ friends	228730	(82.00)	(0.12)
Social participation in ANY (+1 a month) (%) : religious/ voluntary/ leisure/ friendship activities	229053	(70.72)	(0.14)
Socioeconomic characteristics			
Aged-child ratio (index)	250	2.11	1.38
Single-person households (%)	250	31.77	4.93
Employment rate (%)	250	62.50	5.34
GRDP per capita (1000 USD)	250	33.30	29.07
Urbanization rate of city (%)	250	76.72	26.53
Population density (No. of people/km ²)	250	3921.33	5911.55

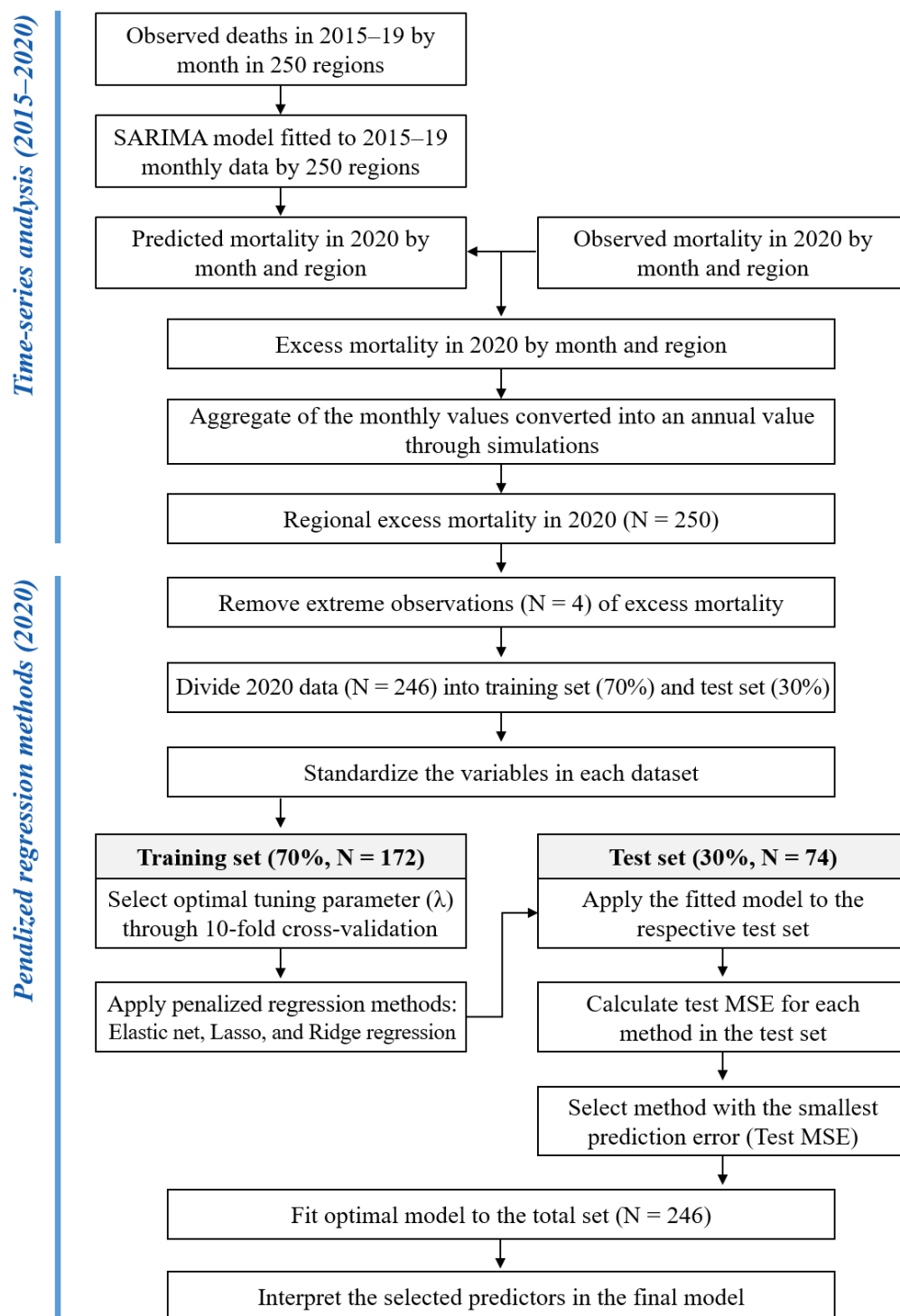
Note: * Values were derived from survey data with a complex sampling design; Number of Strata = 5586; Number of Clusters = 21763; Total number of respondents = 229099; Sum of weights = 43038864.

Appendix D. Data preparation and overall analysis process

We used CHS data concerning the complex sampling design, such as strata and clusters, and sampling weights when aggregating the individual responses to the community average. Public data were based on different administrative regional units, e.g., CHS provides data from 255 nationwide healthcare centers, while KOSIS statistics provides data for 250 or 229 area units. Therefore, the data were rearranged into 250 administrative districts.

Before applying the penalized regression methods, we deleted four extreme outliers that exceeded lower ($Q1 - 3 \times IQR$; interquartile range) and upper ($Q3 + 3 \times IQR$) bounds of excess mortality rates among the dataset of 250 districts.

GRDP per capita and population density were log-transformed. The number of doctors, clinics, hospitals, facilities, and parks per 100,000 residents were modified such that the outliers exceeding the upper bound ($Q3 + 3 \times IQR$) were replaced with the bound's value. Each variable was standardized.



*MSE: Mean squared error

Figure 2. The flow of selecting predictors of excess mortality using time-series analysis and penalized regression methods

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