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# Population density index and its use for distribution of Covid-19: A case study using Turkish data

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## ABSTRACT

Since March 2020, many countries around the world have been experiencing a large outbreak of a novel coronavirus (2019-nCoV). Because there is a higher rate of contact between humans in cities with higher population weighted densities, Covid-19 spreads faster in these areas. In this study, we examined the relationship between population weighted density and the spread of Covid-19. Using data from Turkey, we calculated the elasticity of Covid-19 spread with respect to population weighted density to be 0.67 after controlling for other factors. In addition to the density, the proportion of people over 65, the per capita GDP, and the number of total health care workers in each city positively contributed to the case numbers, while education level and temperature had a negative effect. We suggested a policy measure on how to transfer health care workers from different areas to the areas with a possibility of wide spread.

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## 1. Introduction

An ongoing outbreak of a novel coronavirus (2019-nCoV) was identified only a few days after the World Health Organization (WHO) was alerted about a cluster of pneumonia of unknown aetiology in the city of Wuhan, China on 31 December 2019 [1]. The outbreak appears to have started from a single zoonotic transmission event or multiple zoonotic transmission events at a wet market in Wuhan where game animals and meat were sold [2] and is quickly approaching 25 million confirmed cases worldwide [3].

The start date for the epidemic, total cases, and fatalities were different for each country. The country with the highest number of cases as of August 28, 2020 is the United States, with more than 6 million confirmed cases, followed by Brazil and India. There were more than 3.5 million confirmed cases in Europe. In all of these regions, crowded cities are the epicenters for the disease [4]. What sets these cities apart from rural areas are their high population densities. Population weighted density can be described as a weighted average of density across the tracts, where tracts are not weighted by land area but by population [5].

Density is one of the most fundamental characteristics of an urban area [6]. However, raw population density, simply population divided by count, is not a good measure of the density at which the population lives [5]. Los Angeles is actually denser than New York, but it is hemmed in by mountains, limiting how far the commuting zone can reach. However, according to population weighted density, an average New Yorker lives in a census tract with more than 12,400 people within a kilometer square. That is three times more than the density of Los Angeles County [7]. The population weighted density of several of European cities, such as Barcelona (24,600), Madrid (18,600), Valencia (17,300) and Paris (13,300) are much higher than New York City. The population weighted density of Rome (8,900), Berlin (8,200) and London (8,000) is also relatively high [8].

Especially in pandemics such as coronavirus, where human contact is the main reason for spread, population-weighted densities are better measure than conventional densities, because the variation in density across the subareas matters more than the density in total area. Before New York City placed restrictions on its residents in order to combat disease spread, the number of cases in New York City was close to 20 times the number of cases in Los Angeles County [4].

The aim for this paper was first to derive population weighted density for the cities in Turkey and the districts for its major three cities in 2020. Then using the data points in April 2020, we analyzed the relationship with the density and the spread of coronavirus in

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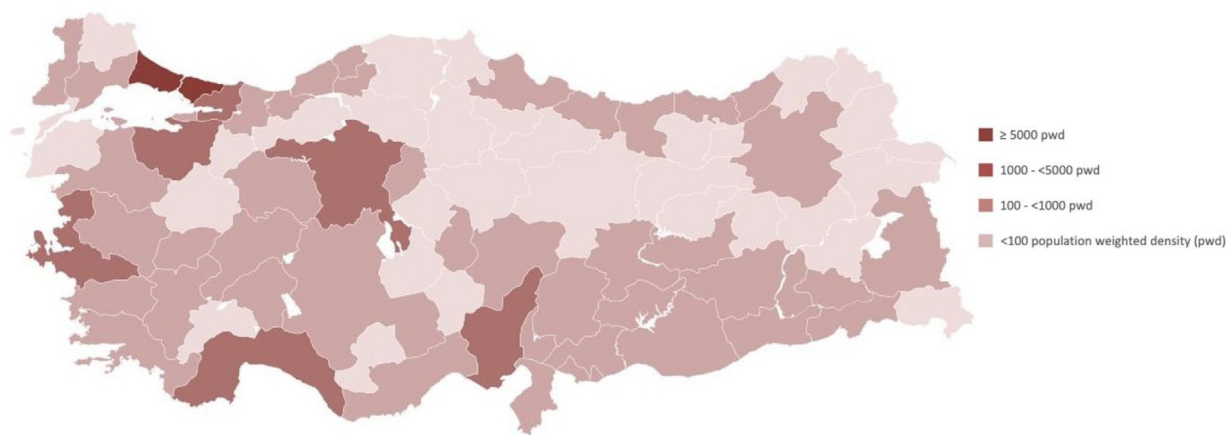


Fig. 1. Population Weighted Density Map for Turkey.

those cities controlling for cities’ education level, wealth, health care force, temperature, and demographics. We suggest that, in conjunction with information about a cities’ number of health care workers and fatality statistics in August 2020, population weighted density can also inform us on how to mobilize each region health care force from low spread risk areas to high spread risk areas.

### 2. Population weighted density in Turkey

Let  $D$  be the density of the urban area, which is the total population,  $P$  divided by the total area  $A$ :

$$D = \frac{P}{A}$$

Let  $p_i$  is the population and  $a_i$  is the area of subareas, by definition  $P = \sum p_i$  and  $A = \sum a_i$ . Therefore the density for each areas is  $d_i = \frac{p_i}{a_i}$ . Population-weighted density  $D_p$  is the mean of the subareas densities weighted by the population of the subareas:

$$D_p = \frac{1}{P} \sum p_i d_i.$$

Ottensmann [9] showed that the difference between population-weighted density and conventional density is a simple function of the variance in density across the census subareas and conventional density. Craig [5] suggested the amount of differences will depend on the variation in density across the subareas. We would expect similar results for the areas that have been defined in such a ways that they do not include sparsely settled territory. In the USA, this measure has been part of the national statistics since 2010, but it has not been used yet in Turkey.

By using population values from the Turkish Statistical Institution and area values from several websites that use Google Earth, we calculated population weighted density for each city in Turkey [10].

Istanbul, with a population of more than 15 million, was ranked as the first city according to population weighted density. On average, residents in Istanbul live with 16, 757 people around their 1 km<sup>2</sup>. Istanbul population weighted density is lower than Barcelona, Madrid and Valencia. However, it is higher than Paris population density and almost double that of London. Fig. 1 shows a map of Turkey with respect to the population weighted density of each of its regions.

Izmir was the second dense population in Turkey according to population weighted index, although it is in third place when it comes to population and raw density. Ankara was the third dense population, although according to raw density it was as eighth

(Table A1). For the three major cities, we also calculated population density of the each district (Tables A2–A4) as well as their corresponding population weighted density maps. For our knowledge, this was the first time the population weighted densities are calculated for Turkey and these three cities (Fig. A1).

### 3. Method

Turkey’s Health Ministry has released only limited data on the spread of the virus and announced the number of Covid-19 cases in individual cities on two occasions, on April 1 st and April 4th [11]. As of August 28, 2020, there were more than 265,000 cases in Turkey and Istanbul accounted for almost 60 percent of confirmed cases of Covid-19. Izmir and Ankara have been declared growing hot spots, as was predicted by population weighted density.

For each city, we calculated the difference in the case numbers to proxy for the spread of the disease in each city. There was a strong positive relationship between population weighted density and the spread of the disease (Fig. 2). Correlation coefficient was calculated as 0.97 with  $p$  – value < 0.0001.

Risk factors including education and wealth of each city, number of health care workers, proportion of male population to female population, and proportion of people over 65 years old were available from the Turkish Statistical Institution. For each city we calculated the average temperature in Celcius since 1941 and use it as an additional regressor to control for the effect of temperature on spread of the disease [12].

To determine the relationship between these variables and our outcome variable, corona spread, we consider the following model:

$$y_j = \beta_0 + \beta_1 x_{1j} \dots + \beta_k x_{kj} + u_j,$$

where  $j$  indexes  $m$  cities. All of our variables are at the city level. The spread, our outcomes variable, defined as log of differences in case numbers in a given city measured two different time period. However, note that estimating the model on individuals and clustering standard errors by city would yield the same coefficients and standard errors as estimating city means using analytic weights and standard errors robust to heteroskedasticity.

The coefficient  $[(k + 1) \times 1]$  matrix  $\beta$  can be obtained

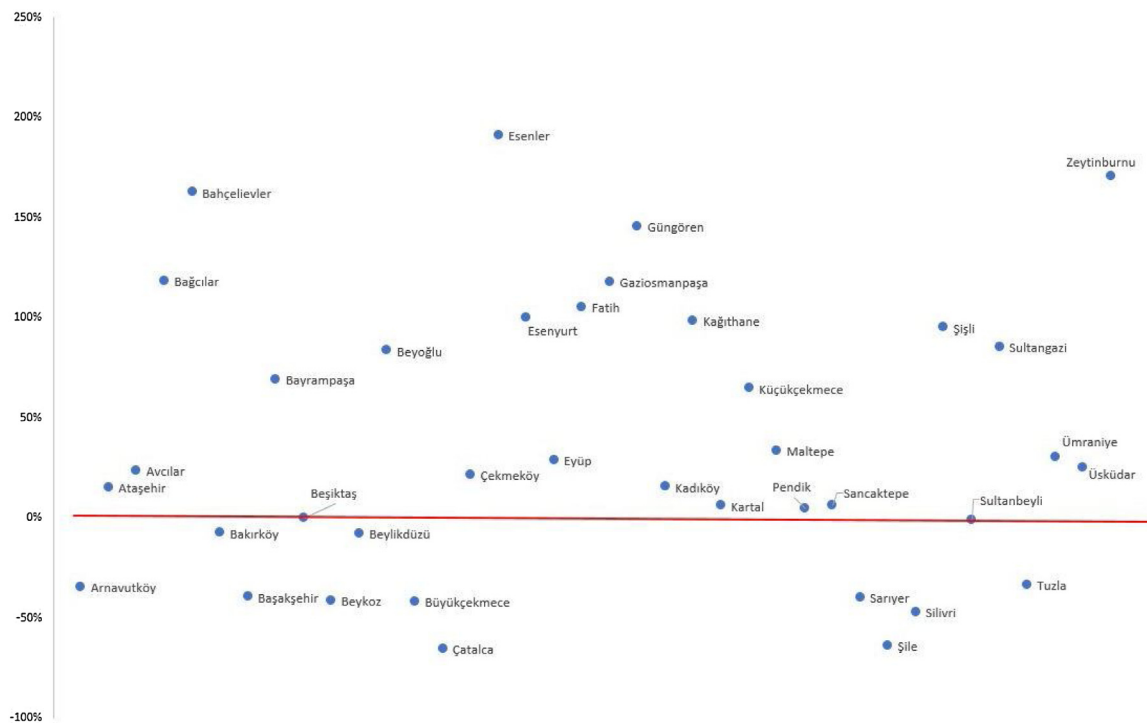
$$\hat{\beta} = (\tilde{X} \tilde{X})^{-1} \tilde{X} \tilde{y},$$

where  $\tilde{X}$  and  $\tilde{y}$  obtained by multiplying each row of  $[n \times (k + 1)]$  matrix  $X$  and row of  $[n \times 1]$  matrix  $y$  by  $\sqrt{w_j}$ ,  $w_j$  being the number



**Table 1**  
City Characteristics.

Demographics	N	Mean	STD	Weighted Mean	Weighted STD
Number of Cities	81				
Population-Weighted-Density		543	1918	3868	6327
Education Level (years)		6.96	.71	7.42	0.96
Temperature(Celcius)		6.70	3.53	7.82	3.02
Doctors		1877	4200	9347	12252
Nurses		2340	4269	9994	12477
Other Health Care Workers		2197	3506	8415	9840
65 and over age		% 10.53	3.58	9.12	3.02
Per capita Income		\$7,249	\$2,570	\$9,745	\$4,210
Proportion of Male to Female		1.02	.037	1.01	.02



**Fig. 3.** The Expected Percentage increase in district cases in Istanbul relative to Istanbul average.

**Table 2**  
Weighted Regression to Explain Log of Differences in Cases.

Variables	Coefficient	Std. Err.	P> t
Log (Population-Weighted-Density)	0.67	0.15	0.001
Education	-0.45	0.16	0.007
Log (Total Health Care Workers)	0.85	0.18	0.001
Temperature	-0.16	0.03	0.001
65 and over age	.11	.04	0.005
Log (per capita GDP)	1.12	0.45	0.02
Proportion of Male to Female	4.86	4.08	0.238

The proportion of male population to female population was not associated with growth rate of the cases. Although the coefficient was positive, i.e. the cities with higher male to female population had higher cases, the variable was not significant. ( $p = 0.238$ ) (Table 2). A recent study has shown that men and women have the same prevalence for Covid-19, although men who have tested positive for Covid-19 are more at risk for worse outcomes and death, independent of age [21].

Newly published research on the rate of Covid-19 spread in the US has also provided insight on which factors affect disease spread. The researchers examined data from January 20, 2020 through May 25, 2020 from 913 different metropolitan US counties. They used a regression model and took into account factors such as popu-

lation size, education level, and demographic variables including age, race, and health care infrastructure (e.g. ICU bed capacity). In so doing, the authors of the study concluded that a higher county population, a higher proportion of people aged 60 and above, a lower proportion of college educated individuals, and a higher proportion of African Americans were all associated with a greater infection rate of Covid-19 [18].

### 5. Discussion

In epidemiological terms, flattening the curve refers to the implementation of measures that slow the rate at which people are infected by the virus, thus lessening the burden on medical professionals and the health care system. The curve refers to the projected number of people who will come into contact with COVID-19 over a period of time. As more people contract the virus, the infection curve rises. If it rises too quickly, then the health care system risks becoming overloaded, which can lead to hospitals running out of the supplies they need to help infected people recover.

How many people a given patient is likely to infect is defined by the reproductive number. Decreasing this number is the ultimate goal in fighting the pandemic. If it is less than one, then group of infected people would be generating less infection, the curve



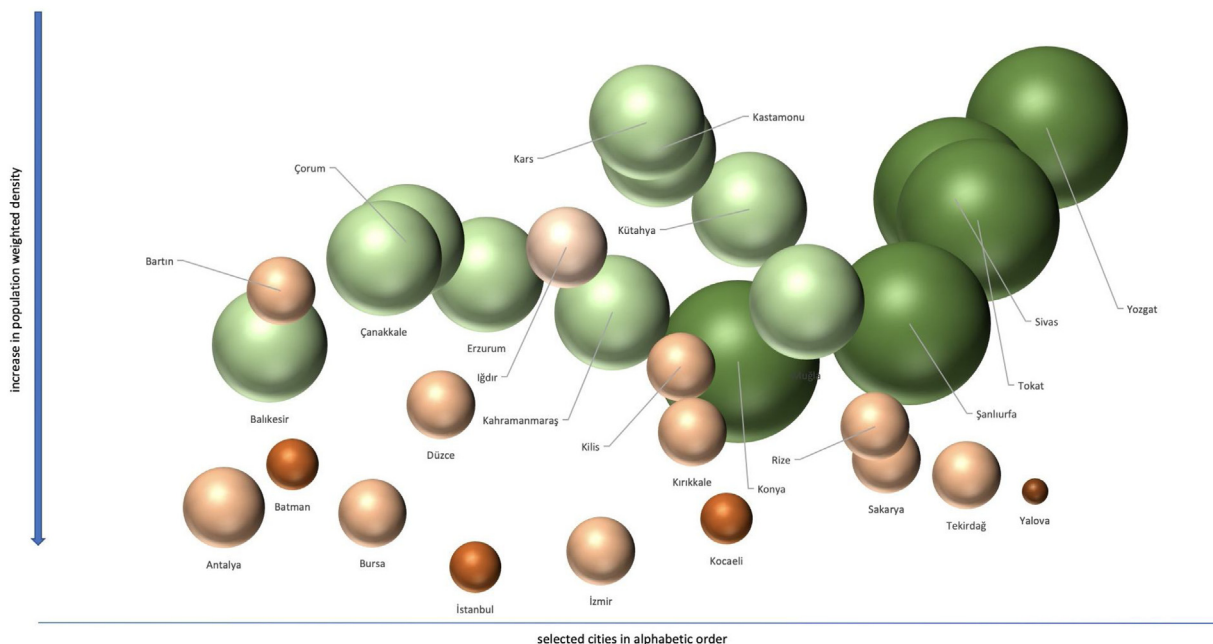


Fig. 4. Possible Health Care Workers Transfer Among the Cities during the outbreak. Size of each bubble is proportional to the ratio of health care workers divided by population weighted density.

would flatten, and eventually die down. The reproductive number has four components: *duration*, *opportunity*, *transmission probability* and *susceptibility* [22]. The multiplication of each component gives the reproductive number. *Duration* here refers to the duration of infectivity, not duration of symptoms, as some patients may remain symptomatic even after viral recovery [23]. *Opportunity* is a measure of how many people you come into contact with for every day you're infections. *Transmission probability* is a measure of the chance the infection will get across during an interaction and *susceptibility* is a measure of the chance the person at the other end of the interaction will pick up the infection and became infectious themselves.

Population Weighted Density increases the *opportunity* component of reproductive number and increases the probability of speeding up the curve. The faster the infection curve rises, the quicker the local health care system gets overloaded beyond its capacity to treat people. More and more new patients may be forced to go without ICU beds, and more and more hospitals may run out of the basic supplies they need to respond to the outbreak.

From a policy-planning perspective, population weighted density can give a very clear objective: paying attention to the areas with highest population weighted density. In 2009, the H1N1 pandemic persisted for relatively longer periods of time in areas of Taiwan that had higher population densities [24]. There was a positive and significant relationship between the death rate from the 1918 influenza pandemic and the state-level population density in the United States [25].

Many countries have initially implemented measures in the hope of slowing the Covid-19 spread. These measures include social distancing, placing restrictions on domestic travel, and implementing a curfew. Although these measures were initially successful, June saw the beginning of quarantine fatigue caused by the profound burden of extreme social distancing and economic hardship as well as forced reopening of shuttered business, resulting in an increase spread. Governments around the world fear that the combination of the coming influenza season and Covid-19 will flood hospitals with patients. Many countries are responding to this imminent issue by augmenting hospital capacity, including

constructing temporary hospitals within large spaces such as convention centers. The most effective of these temporary measures would be constructed near the areas with highest population weighted densities.

For any health care system to perform well it depends on the availability of a sufficient number of skilled health care workers. Furthermore, it is crucial that these health workers be mobile, since urban areas are first to experience spikes in Covid-19 cases. For example, in the first months of the Covid-19 epidemic, health care workers flew from San Francisco to New York City, where there was a higher need for services [26]. If such mobility is available, we suggest that attention to population weighted density can direct how this transfer might be done. We graphed the cities in Turkey with low risk spread (proxied by low population density) with a high number of health care workers (Fig. 4). The big green cities like Yozgat, Sivas, Tokat are the cities with low population weighted density with relatively high number of health care workers, and the brown small cities like İstanbul, Batman, Kocaeli and Yalova are the ones with high population weighted density with relatively low number health care workers. Possible transfer of health care workers can be done from cities marked by big green bubbles to cities marked by small brown bubbles. Note that healthcare workers are one major resource in the health systems, but for treating patients with Covid it would not be enough to shift workers without providing/shifting other care resources such as beds, reanimation equipment.

Population weighted density can also be used as a tool to evaluate the success of fighting with pandemic. We compiled the death data from 8 different cities in Turkey. These were the only 8 cities that make the death data available on a daily basis online [27]. We graphed the series of daily death since March 25, 2020 (two weeks after the first corona virus case) until August 30, 2020 for last three years (Fig. A2). The total deaths are directly linked with the coronavirus as well as those from other causes such as stroke, heart disease, and cancer. Turkey's total count of coronavirus cases only includes cases that have been confirmed with a positive test result and does not include cases that have been clinically diagnosed with no test. The total number of deaths indicate fatalities

**Table 3**

Ascending Ranking of Increase in Death between March 15 to August 30, 2020 relative to average of last three years, controlling for population weighted density.

Cities	Population Weighted Density (Ranking) (A)	Excess Death (B)	B/A	Population Density (C)	B/C
Kocaeli	1916(4)	237	0.12	541	0.44
Istanbul	16757 (1)	4771	0.28	2987	1.60
Bursa	1903 (5)	757	0.40	293	2.58
Denizli	433(19)	213	0.49	89	2.39
Malatya	260 (26)	221	0.85	68	3.25
Sakarya	535 (15)	1116	2.08	213	5.24
Kahramanmaraş	129 (42)	363	2.81	80	4.54
Konya	165 (33)	795	4.81	57	13.95

that have coincided with the onset of the outbreak, though they are not necessarily attributed solely to the coronavirus.

For eight cities we selected, we calculated the increase amount of death relative to average of last three years. We then divided this number with population weighted density to determine, controlling for the density, the proportion death per density measure (Table 3). Consistent with previous research, cities with higher population densities tend to have lower death rates, possibly they enjoyed a higher level of development including better health care systems. The recent analysis found that after controlling for factors such as metropolitan size, education, race and age, doubling the activity density was associated with an 11.3 percent lower death rate [18].

## 6. Conclusions

The impact of population density on the rate of spread of emerging highly contagious infectious diseases has rarely been studied. The current Covid-19 pandemic allows us to investigate these relationships. Our study uses a regression model to study the impact of population weighted density on Covid-19 spread in Turkey while controlling for key compounding. We found that population weighted density is one of the most significant predictors of infection rates. However, counties with higher densities have significantly lower virus-related mortality rates, possibly due to superior health care systems.

Most of the data is preliminary during the outbreak and the data that we can use in Turkey is limited. We were able to update our analysis for the death statistics by August 30th. However, the Turkish ministry of health has not published case numbers by cities after April 2, 2020. Because of this, the results in Table 2 have not been updated beyond April 2, 2020. However, our results were consistent with the previous research [14,16–21]. Additionally, we are unable to measure the number of patients with underlying conditions in each city, which would decrease the survival rate of each of these regions. We have seen death toll raise in a cities like Zonguldak where most of the population suffers from chronic lung diseases due to work conditions in the minings located in the city. We have used the death statistics to measure the success of dealing with the outbreak, but any death statistics in the midst of pandemic are tricky to pin down and must be considered preliminary. We have seen most of the countries are improving their death statistics, which they now acknowledge incomplete.

In order to control and manage the outbreak, our analysis suggests that population weighted density can be a useful tool. According to previous research, there are many advantages of compact development. It is associated with with open space preservation, higher innovation and overall economic productivity, greater social capital, less likelihood of obesity and related chronic diseases and increased overall life expectancy [28–32]. However, compact development can be big enemyin the coronavirus fight [15]. High density means that people in those areas live very differently from other people. Those who live or work in or near the city

shop and commute differently: they are far more likely to walk or take public transit than the rest of the people. The disease spreads faster in the areas with high population weighted areas then elsewhere simply because there is so much human contact.

At this stage, particular attention should be given to the prevention of spreading in the highest dense areas directed by population weighted density. The concept of flattening the curve ultimately assumes that the same number of people will contract the coronavirus whether or not the curve is steep or flattened. If the curve is flattened, however, there is less stress placed upon the health care system, which results in better health care access for those who are sick.

## Declaration of Competing Interest

The authors report no declarations of interest.

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