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The Relationship between Urban Density and COVID Spreading, a case study of Wuhan

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by

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Abstract

By 2021, the COVID-19 virus has swept through more than 200 countries worldwide, with enormous impacts on the functioning of cities and the health of people. From the perspective of urban development, the rapid growth of cities over the past 100 years has led to an increase in the density of the world's largest cities, which has resulted in unparalleled economic benefits. The relationship between urban density and the spread of COVID virus is unclear, as high-density cities may become a vector for rapid spread of the virus in an epidemic, but at the same time, higher urban density provides better public services and resources for people's health to stop the rapid spread of the virus. In this paper, we try to construct an OLS model from a quantitative perspective utilizing data from satellite image of ESA and Wuhan Census 2020, taking Wuhan city as an example, and investigate the relationship between urban density and COVID virus transmission from a time series-based panel vector autoregression angle.

Key Words: ***Urban Density, COVID-19, OLS, ESA World Cover Project 2020, Wuhan Census 2020***

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Table of Contents

Introduction

The COVD-19 virus was severely affecting the world's population in 2020 and 2021. Although the vaccines have been developed, the impact of COVID cannot be underestimated. (Shi, Y et al. 2020) The impact of COVID disease on people is multifaceted.

Physiologically, while the infection does not cause serious illness for many people, about 10-20% of those infected require hospital care and about 5% become critically ill (Robert Koch Institute, 2020). Still, COVID has claimed 5.1 million lives (from the first outbreak of COVID in Wuhan in February 2020) (Robert Koch Institute, 2020). Psychologically, the pandemic has also led to unprecedented social consequences and upheaval (Boccaletti, S et al, 2020). As of December 2020, it is estimated that more than 4 billion people (half of all humanity) are subject to enormous restrictions on mobility and social relations.

As a result, COVID also puts an unparalleled strain on medical resources worldwide.
For example, with 22,000 beds for 3.5 million people in Berlin (Berlin.de n.d.), it is clear that 100,000 simultaneous infections requiring 10,000 to 20,000 beds would push the system beyond its limits.

So how can we reduce the spread of COVID? In general, the means to reduce transmission have been repeatedly emphasized by the WHO. The general means of slowing infection are well known: distance and eventually isolation. If an infectious person no longer encounters a susceptible person, then the virus cannot spread further. (Donders, F et al, 2020)

But are there key factors associated with reducing the spread of COVID from a city perspective? Or is it possible to look for influencing factors related to the spread of COVID from a governmental and organizational perspective at the city level? From the existing studies on cities, most of them focus on how cities can take measures to combat COVID, such as (citing several papers). Moreover, there are a few studies on the correlation between urban form and COVID from the cities themselves.

Therefore, this paper attempts to investigate the relationship between urban density and COVID by discussing urban density in the 5Ds of the built environment. (Manville, 2017) However, the urban density explored in this paper is not only the density of urban population in the traditional sense, but also the relationship between the deeper meaning of urban density and COVID under the current New Urbanism advocacy and the popularity of COVID. Therefore, compared with previous studies, this paper will focus on the relationship between the composite concept of urban density and COVID.

Chapter1 Literature Review

Urban Density

From the past literature, urban density is generally defined as following, that urban density is a term used in urban planning and urban design to refer to the number of people inhabiting a given urbanized area. (Williams, K et al, 1996) Therefore, urban density is inevitably closely related to population density, traditionally, higher population density means higher urban density. (Simmel, G, 1950, Wirth, L, 1938)

However, at the same time, in the modern measurement of urban density, more factors other than population density have been considered, such as traffic, pollution, concentration of various resources, and economic behavior. These factors have been increasingly included in the measurement of urban density in recent years. This has also led to a shift in measurement from "population density + distance to city center" (Richard Muth (1961, 1969)， EDWIN S. MILLS, 1970) to various urban indicators nowadays (De Bellefon, M. P. et al, 2021, Copiello, S., 2020). So, is there a combination of both geographic perspective of distance measurement method and indicator measurement method to measure urban density? This paper will also try to start from this aspect.

So, what is the role of high-density cities? And how does this relate to disease control? First, high density cities are more sustainable. It is commonly asserted that higher density cities are more sustainable than low density cities. (Williams, 1996) Much urban planning theory - particularly in North America, the UK, Australia, and New Zealand - has been developed premised on raising urban densities, such as New Urbanism, transit-oriented development, and smart growth. Second, high density cities are more innovative in multiple aspects, such as business, education, and medical resources, which means a higher density city are likely to have a higher concentration of resources.

Therefore, from the perspective of urban density, urban sustainability, innovation, and health care resource concentration have a relatively positive effect. That is, the higher the urban density, the higher the concentration of sustainability, innovation, and health care resources. However, the emergence of COVID seems to shake this view, as it has been shown that many citizens of large cities around the world are fleeing the city centers to prevent COVID infection in the wake of the epidemic, thus making the relationship between urban density and disease control unclear again.

COVID-19

From the perspective of COVID, it is defined as following, coronavirus disease 2019 (COVID-19) is a contagious disease caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). The first known case was identified in Wuhan, China, in December 2019. The disease has since spread worldwide, leading to an ongoing pandemic. (Zimmer, 2021) The rapid spread of COVID was characterized by Qianyue Hao et al. in their study of the transmission characteristics of COVID-19, who noted that the mobility of the population was related to transmission to some extent, i.e., the more mobile the urban population, the more rapidly the virus spreads. However, at the same time, COVID also has an incubation period of 14-28 days, so the combination of these two points makes the control of COVID very difficult. So, the main points in preventing the spread of COVID in society are hand hygiene, social distancing and quarantine, three major parts. (GÜNER et al, 2020; Wei We et al, 2020) And with the increased capacity of COVID testing, the secondary COVID cases can be reduced once the positive patients in the community were detected. (Bakanlığı, S.,2020)

So how is the propagation of COVID measured? What is the metric? Since global pandemic epidemics like COVID are relatively rare, the main measures are proposed and used in this pandemic. Most of the studies used panel data provided by governments, WHO, and university research institutions for analysis, such as David W. et al. used data from JHU and US COVID Atlas for analysis, and DHAVAL DESAI used data from New York Times for qualitative studies. Felipe Carozzi et al. used demographic and infection data from Google, Facebook and the US Census for their analysis. Overall, the main variables included in the calculations of the existing studies include variables such as the number of infections, the number of deaths, and the density of patients with COVID.

Current Research on relationship between COVID-19&Urban Density

The first studies on the relationship between cities and disease date back to the late 1800s, when the cholera outbreak in London led to the first link between the construction of urban facilities and the spread of disease (Johnson, S, 2006; Koch, T. et al, 2005). (Johnson, S, 2006; Koch, T. et al, 2005) Numerous epidemics (e.g. Ebola) have since been studied with a focus on urban construction and the study of prevention and control from an urban perspective (Bashford, A, 2016). In some literature emphasizing the relationship between communities, parks, architectural elements and epidemics, at a time when the root cause of cholera was not correctly identified as contaminated water but blamed on miasma (a nasty gas) , famous architects and urban designers, such as Le Corbusier and Olmsted, believed that the solution to the spread of infectious diseases was through the (Campbell, M, 2005). There are also studies on epidemics and cities that are biased towards the political dimension, such as the use of disease control for colonial rule (Hinchliffe, S et al, 2016).

For urban density specific, from the current studies on urban density and COVID, the relationship between the two is unclear. In general, all studies fall into two main groups, one group believes that there is an association, while the other group believes that there is none.

The school of thought that suggests a relationship between the two focuses on urban density as measured by population density, such as Keyfitz (1966), Hawley (1972), and Galle, Gove & McPherson (1972) in the last century. These studies have mainly deconstructed the relationship between pathology and urban density on the basis of population and social structure as a breakthrough point. Admittedly, such an approach has its merits, but in the 21st century, such an approach appears rather thin. Because the density of modern cities is more complex, including not only population density, but also economic, transportation, and building density characteristics. Modern studies have considered the relationship more comprehensively, such as Haroldo V. Ribeiro et al. (2020) in Brazil, who found that COVID performed more poorly in high-density cities (i.e., large cities) at the beginning of the outbreak, but was more effective in reducing the rate of case growth in the long-term pandemic than in low-density cities; Sachiko Kodera (2020) in a study using Sachiko Kodera, in a panel data study of Japan during the outbreak, showed that cities with high elderly population density had more infections and deaths; Arunava Bhadra (2021), in a linear regression analysis of population density and infections in India, obtained a moderate correlation between the two; DHAVAL DESAI (2020), in a comparison of Indian and Chinese cities under COVID, found that tThe spread of the virus is not only related to socio-demographic structure, but also to policies under high-density cities, such as the Hukou system in China. Such a system directly or indirectly affects the speed and efficiency of COVID transmission. The common feature of these studies is that they are all based on the community level of a single or a small number of cities, i.e., there is the problem of MAUP, while COVID itself is characterized by clustered infection and mortality, and it is not surprising that these studies found a correlation between the two.

The same studies that concluded that there is no significant relationship between the two exist. In a study of provincial land in China, Zhu et al. (2020) analyzed by SAR (Spatial Auto Regression) method obtained no significant correlation between Virus Infections and four urban density indicators of population, transportation volumes, economic activity, air. Felipe Carozzi et al. (2020) used data from Google, Facebook and the US Census at different time points and found that although higher urban density led to earlier outbreaks of COVID, there was no significant correlation between higher population density and the number of infections and deaths. Similarly, an analysis of Covid-19 infection and death rates of 913 urban counties in the USA by scholars from the Johns Hopkins Bloomberg School of Public Health (Hamidi S et al, 2020) found that infection rate is not significantly associated with the number of infections and deaths. The studies that do not consider a relationship focus on multiple cities at the national level and assess the correlation through time, but at the same time, they use a thin system of indicators to measure urban density and lack the in-depth study of urban density attributes by scholars who consider a relationship.

Innovation Point

Based on the above-mentioned research, this paper believes that the following points can be improved: (1) This paper provides a new definition of urban density in the present era, redefining urban density in terms of previous research theories and present-day forms, rather than just the population density of cities. And we optimize the construction of urban density index system.

Try to introduce satellite map analysis into the traditional research structure of "social structure + distance", and consider building density (including the density of residential units), traffic density, economic density and other indicators, and draw advantages from the above two schools; and (2) establishing the use of a single city in Wuhan as the subject of the study. The multi-city model exhibited the problem that the fit was not optimal (Felipe Carozzi, 2020). Therefore, the choice of Wuhan, the city where the initial outbreak of COVID occurred, as the subject of the study is appropriate, while possibly being able to analyze the government's strategy for adjusting urban density during the epidemic.

Chapter 2 Research Design

Based on the characteristics of the propagation-prone nature of COVID and urban density, quantitative studies are better to measure the correlation between the two, which leads to some conclusions. However, when explaining the profound relationship between the two, a qualitative analysis of Wuhan's geographical characteristics, urban development policies and resource layout is needed. Therefore, this study is not comprehensive enough to use only quantitative or qualitative methods, so this study will use a combination of quantitative and qualitative methods to study the relationship between urban density and COVID spreading, and then to analyze the underlying causes.

Quantitative Method

For the quantitative study, this paper will use several sub-indicators to construct a system of indicators to explain the "urban density". Based on previous studies, this paper will adopt a more integrated approach to express the study of the relationship between urban density and COVID. In this paper, urban density is deconstructed into the following major dimensions, population dimension, and built-up area dimension, which are subdivided into several sub-indicators under each major category, as shown in the table 1 below,

Table 1. Urban Density Indicator System

Indicators	***Variables***	***Scale***	***Measure***	***Source***	***Time***
Population	Urban Hukou Population	Community	Percentage	Wuhan Census 2020[1]	
	Population Density	Community	Number	Wuhan Census 2020	
	College Diploma Percentage	Community	Percentage	Wuhan Census 2020	
	Public Transit Percentage	Community	Percentage	The Fourth Wuhan City Residents' Travel Trial Survey	
Built-up area	Density of Residential Patches (DRP)	Community	Number	Wuhan Census 2020	2020
	Shannon's Diversity Index (SHDI)	Community	Number	Calculated by Fragstats3	
	Built-up area per capita	Community	Number	ESA World Cover Project 2020[2]	
	Infectious Disease Hospitals Distance	/	Number	Calculated by ArcGIS 10.8.1	
	Infectious Disease Hospitals Beds per capita	Community	Number	Wuhan Infectious Disease Hospital Official Website	

The selection of the above-mentioned indicators as parameters for this study is a synthesis of the results of previous studies and policies. The two main dimensions (Population, Built-up area) were chosen to better distinguish the degree of change of residential mobility factors from the physical environment, but in general the physical environment changes very slowly compared to a rapid outbreak of a virus like COVID, so this paper will use Data from a single time point are analyzed, and an ecological landscape perspective is invoked to analyze the impact of COVID on the physical environment in Wuhan. In summary, this paper will explain why some of these indicators were selected.

[1] Wuhan Bureau of Statistics http://tjj.wuhan.gov.cn/tjfw/tjfx/
[2] ESA WorldCover project 2020 / Contains modified Copernicus Sentinel data (2020) processed by ESA WorldCover consortium' https://viewer.esa-worldcover.org/worldcover/?language=en&bbox=-225,-72.4487915573067,225,72.44879155730672&overlay=false&bgLayer=MapBox_Satellite&date=2022-03-18&layer=WORLDCOVER_2020_MAP

Urban Hukou Population & College Diploma Percentage

Since 1954, the Chinese government introduced the Hukou system to restrict the flow of people into large cities, i.e., urban residents with Urban-Hukou would have better social security and medical resources than those with non-Urban-Hukou, with the intention of unifying the urban workforce. Although the significance of the Hukou has been greatly diminished (e.g., many studies have proposed separating the Hukou from the social welfare system), it still reflects the distribution of urban resources to some extent. Therefore, how Wuhan responds to the spread of COVID will likely have some connection to the Hukou of its residents.

College Diploma Percentage

Educational attainment has been one of the central directions of urban research. In the study of COVID and urban density, previous studies have shown that higher educated areas will be more likely to strictly comply with regulations such as masking and social distancing, and therefore will have an impact on urban density. (Cantwell, B et al, 2020)

Population Density

Population density has always been an important component of urban density. It has been proven that the urban population and urban land area are both increasing during the urbanization process in China. Since 1978, urban population density has been on the rise despite strong interventions by the Chinese government. It was not until around 2010-2020 that urban population density began to show a slow decline. It is undeniable that the rising population density will have a certain degree of positive impact on air-born transmission virus like COVID.

Public Transit Percentage

The percentage of public transportation trips will directly affect COVID. in a large city like Wuhan, the average percentage of public trips has reached 21.3%, i.e. one out of five people will travel by public transportation (e.g. subway, bus, etc.). This means that in today's Wuhan population of over 12 million people, there will be over 2.4 million people in dangerous social distance. Therefore, it will be important to study the impact of the proportion of public trips on COVID in each community.

Density of Residential Patches (DRP)& Shannon's Diversity Index (SHDI)

This study will also use some concepts of landscape ecology to analyze the Built-up area dimension of Wuhan, and adopt the NP (number of patches) and SHDI (Shannon's Diversity Index). This study will use NP (number of patches) in combination with the residential land in satellite image for analysis. The values of the residential units in the residential land were included in the raster image and then calculated using Fragstats3 to obtain the Density of Residential Patches, which indicates the fragmentation of the residents in each community, i.e., the higher the DPR the higher the fragmentation. This is a good measure of the group, community-based outbreak that was exhibited at the beginning of the COVID outbreak, so it is necessary to include this parameter in the Built-up area.

Second, this study will also incorporate the SHDI (Shannon's Diversity Index) index. SHDI=0 indicates that the entire landscape consists of only one parcel; an increase in SHDI indicates an increase in the number of parcel types or a balanced distribution of parcel types in the landscape. This parameter can indicate the mix of site types in each community, and a higher mix means that there will be a higher probability of stores selling mask drugs, parks and green areas, recreation and sports facilities, and community health care centers within a certain living circle, all of which urban construction may have a suppressive effect on the spread of COVID.

COVID Data

For COVID data, this paper will mainly use GitHub data called ‘AKShare’, whose source is Dingxiangyuan.com. This paper will use python calls and use variables such as geographic location and number of infections for calculation. The data range used in this study was 49,671 cases in Wuhan from April 2020 to December 2020. The specific location of cases was not fully recorded in January, February and March at the beginning of the outbreak due to the problem of rapid transmission, so only cases with location records will be studied in this paper. The COVID data used in this paper are the prevalence rates of each Community.

Methodology

The integrated methodology is shown in the figure below (Figure 1). The data in this study were obtained from three sources, namely, Wuhan Satellite Image, 2020 Census Wuhan, and COVID data from "AKShare", and were cleaned and integrated by Fragstats3, ArcGIS, and Python3.7. All the data were combined and tabulated into IBM SPSS for OLS to calculate the correlation. The final Correlation Results were obtained.

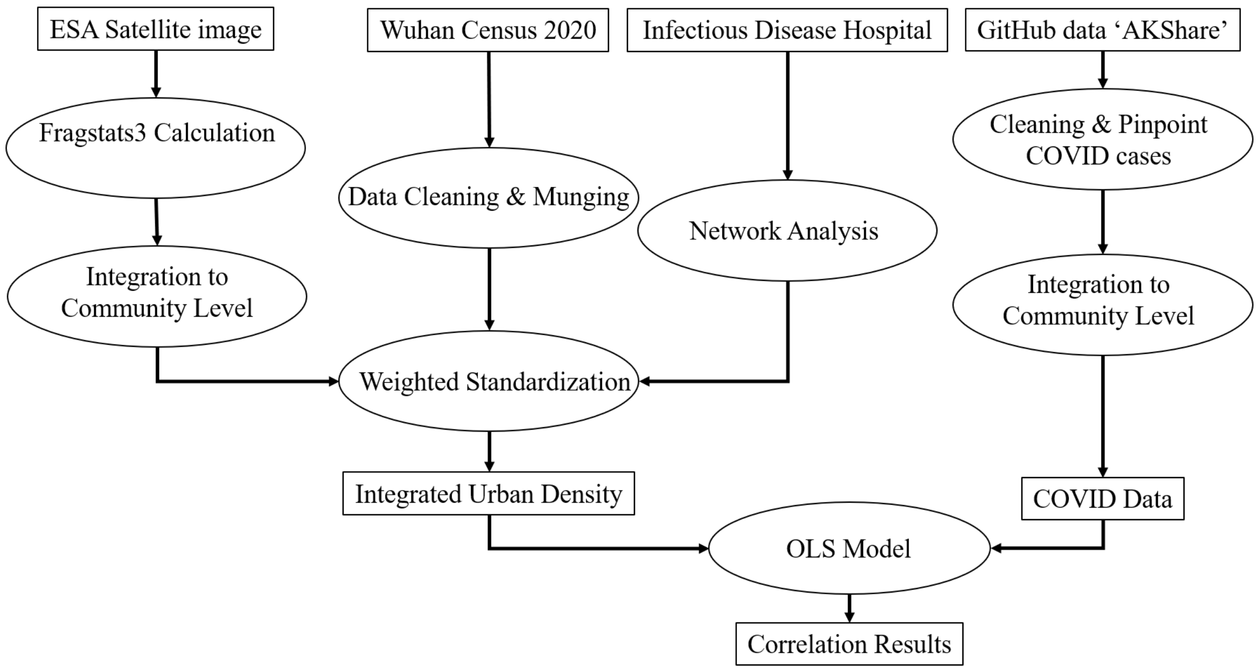

Figure 1. Methodology

OLS Model

Ordinary least squares (OLS) is a type of linear least squares method for estimating the unknown parameters in a linear regression model. OLS chooses the parameters of a linear function of a set of explanatory variables by the principle of least squares: minimizing the sum of the squares of the differences between the observed dependent variable (values of the variable being observed) in the given dataset and those predicted by the linear function of the independent variable. The expression is as follow,

$$y_i = \beta_1 x_{i1} + \beta_2 x_{i2} + \cdots + \beta_p x_{ip} + \varepsilon_i$$

Where x_i, as introduced previously, is a column vector of the i-th observation of all the explanatory variables; β is a $p * 1$ vector of unknown parameters; and the scalar ε_i represents unobserved random variables (errors) of the i-th observation. ε_i accounts for the influences upon the responses y_i (COVID case rate) from sources other than the explanators x_i (Population Density, Transit mode percentage etc.).

Fragstats

Fragstats can use the data of the spatial pattern of the land and calculate the relevant parameters of the tile, which can be used in this paper to calculate the SHDI and RNP parameters. And the RNP at the landscape level is equal to the weighted sum of all tiles in the landscape (including residential lots), i.e. the area ratio of each tile type multiplied by the natural logarithm of its value.

Network Analysis

A network is a structure that represents a group of hospitals and their relationships to all communities. It is also known mathematically as a graph. Using each community as a starting point, a computational radius is divided and the distance to its nearest infectious disease hospital is calculated and recorded. In this paper, ArcGIS 10.8 will be used to calculate the distance value.

Chapter 3 Analysis Result

After the IBM SPSS calculations, the basic results are shown in the following section. This section will analyze the three main parts of the analysis from the covariance test of the variables, the fit of the OLS model and the regression results, of which the basic correlation conclusions are drawn.

Index Collinearity Diagnostics

Pearson Correlation analysis of 9 variables in 2 dimensions shows the correlation between each group of two variables (including the dependent variable COVID_Case_Percentage), and the range of the correlation index value obtained from Pearson Correlation Value is -1 to 1. If the value is closer to 1, it indicates a positive correlation between the two; if it is closer to -1, it indicates a negative correlation between the two; if the value is 0, it indicates that there is no significant correlation between the two. In this study, this value is used to initially investigate whether there is multicollinearity between the variables, and if there is a high Pearson Correlation Value between the variables, it indicates that the selected variables need to be adjusted.

According to Table 2, among all Pearson Correlation Values, there are only three sets of variables that exceed 0.7 (i.e., there may be multicollinearity problems), which are Population_Density vs. Public_Transit_Percentage, Hospital_ The values of 0.79, -0.73, and -0.83 for Distance and Population_Density, and Hospital_Distance and Public_Transit_Percentage, respectively, therefore, we need to perform further multicollinearity tests for all variables.

Table 2. Indicator Correlation

	COVID_Case_Percentage	Hukou_Percentage	Population_Density	College_Diploma_Percentage	Public_Transit_Percentage	RNP	SHDI	Built_up_Area_per10000	Hospital_Distance	Beds_per_capita
COVID_Case_Percentage	1.00	0.03	0.87	0.17	0.84	-0.48	-0.43	-0.44	-0.80	0.82
Hukou_Percentage	0.03	1.00	-0.08	-0.14	-0.07	0.23	0.45	0.00	-0.10	-0.10
Population_Density	0.87	-0.08	1.00	0.20	0.79	-0.53	-0.55	-0.51	-0.73	0.67
College_Diploma_Percentage	0.17	-0.14	0.20	1.00	0.13	-0.49	-0.38	-0.41	-0.27	0.15
Public_Transit_Percentage	0.84	-0.07	0.79	0.13	1.00	-0.60	-0.26	-0.43	-0.83	0.63
RNP	-0.48	0.23	-0.53	-0.49	-0.60	1.00	0.53	0.64	0.30	-0.35
SHDI	-0.43	0.45	-0.55	-0.38	-0.26	0.53	1.00	0.62	0.07	-0.60
Built_up_Area_per10000	-0.44	0.00	-0.51	-0.41	-0.43	0.64	0.62	1.00	0.17	-0.40
Hospital_Distance	-0.80	-0.10	-0.73	-0.27	-0.83	0.30	0.07	0.17	1.00	-0.51
Beds_per_capita	0.82	-0.10	0.67	0.15	0.63	-0.35	-0.60	-0.40	-0.51	1.00

Further Collinearity Diagnostics is performed on all the variables, and it is clear that the main reference for testing whether there is multicollinearity is the Eigenvalue and Condition Index. Index is greater than 10, then there may be a multicollinearity problem.

From the following table (Table 2), only the ninth Eigenvalue is 0 and the Condition Index of the ninth Eigenvalue is greater than 10, which indicates that there is no multicollinearity problem for the variables selected in this paper. Therefore, all the nine variables selected above can be used for regression analysis.

Table 3. Collinearity Diagnostics[a]

	Eigenvalue	Condition Index	Variance Proportions									
			(Constant)	Hukou_Percentage	Population_Density	College_Diploma_Percentage	Public_Transit_Percentage	RNP	SHDI	Built_up_Area_per10000	Hospital_Distance	Beds_per_capita
1	7.88	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	1.76	2.11	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.02
3	0.52	3.89	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.01	0.01	0.04
4	0.32	4.93	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.03	0.10
5	0.20	6.23	0.00	0.11	0.00	0.00	0.00	0.04	0.00	0.13	0.00	0.01
6	0.13	7.67	0.00	0.04	0.19	0.04	0.00	0.01	0.00	0.00	0.02	0.04
7	0.12	8.20	0.00	0.10	0.01	0.08	0.00	0.12	0.00	0.03	0.00	0.01
8	0.05	12.19	0.00	0.12	0.20	0.02	0.02	0.02	0.00	0.16	0.01	0.00
9	0.00	66.29	0.01	0.58	0.07	0.13	0.60	0.33	0.07	0.43	0.19	0.46

a. Dependent Variable: COVID_Case_Percentage

Model Fitness Diagnostics

After confirming that all variables were correct, they were imported into IBM SPSS for OLS regression analysis. Using the stepwise condition in this software, set the relevant parameters as follows: entering value of 0.05 and removing value of 0.1, and add the constant, the OLS regression model for this study was finally obtained.

Table 4. Model Fitness Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.904	.818	0.97	0.01

From Table 4, it can be seen that the model R square used in this study reached 81.8%, which means that the results obtained from this model can explain 81.8% of the variance and passed the F-test with an F-value of 0.2 (according to the F-test table). Therefore, the present model passes the fitness test and the conclusions it exhibits are plausible.

Correlation Result

Statistical Result

The correlation coefficients of the OLS regression model can thus be obtained as shown in Table 5. z-score normalization of the variables leads to the model regression coefficient t. As can be seen from the table below, the range of t-values for a total of nine variables is -5.48 to 3.80. Among them, the t-values of beds_per_capita, SHDI, Population_ Density have positive t-values, Public_Transit_Percentage,, these four variables show positive correlation with the infection rate of COVID; while Hukou_Percentage, Built_up_Area_per10000, College_Diploma_Percentage, and RNP and Hospital_Distance showed a negative correlation with the infection rate of COVID.

Table 5. Coefficient Table

	Standardized Coefficients		
	Beta	t	Sig.
Hukou_Percentage	-0.18	-2.16	0.16
Population_Density	0.42	3.04	0.09
College_Diploma_Percentage	-0.60	-4.94	0.04
Public_Transit_Percentage	1.17	4.18	0.05
RNP	-0.70	-5.09	0.04
SHDI	1.26	3.48	0.07
Built_up_Area_per10000	-0.28	-2.38	0.14
Hospital_Distance	-1.20	-5.48	0.03
Beds_per_capita	0.53	3.80	0.06

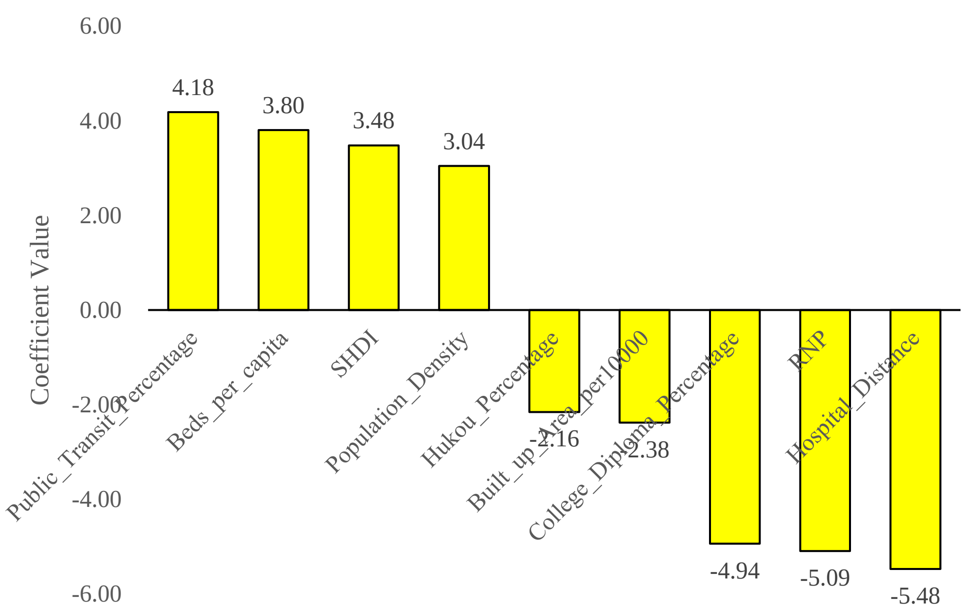

Figure 2. Coefficient Value

Geographical Result

By returning each factor back to each community in Wuhan, we can get what is the most influential (positive or negative) factor in each cell, and the result is shown in the figure below.

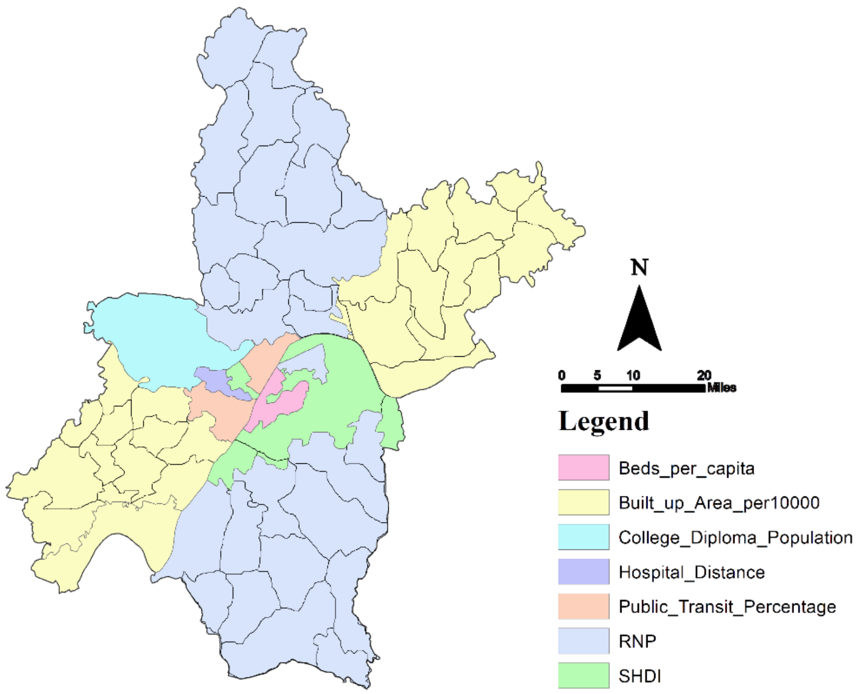

Figure 3. Most Powerful Indicators in Wuhan Communities

From the above figure, it can be seen that different areas of Wuhan city have distinctly different most powerful influencing factors, and they vary with the distance from the city center. The areas located at the edge of the city (northeast and southwest) are more homogeneous in terms of influence factors, with Build-up Area per Capita and RNP becoming the most powerful impression factors, which can be seen to play an important positive or negative role in the spread of COVID in the edge of Wuhan. However, as the area gets closer to the city center, the situation becomes more complicated. As can be seen from the figure, nearly 30 communities located in the urban center are influenced by different factors, namely SHDI, RNP (less), College Diploma

Percentage (favoring suburban areas), Public Transit Percentage and Beds Per 10000 people. These complex factors suggest that urban density is not explained by a single factor, but is the result of a combination of factors that affect the spreading of COVID. Therefore, these factors need to be analyzed according to the specific land type and structure of the Wuhan city.

Chapter 4 Interpretation and Derivation of Regression Results

Urban Density – Population Dimension

For the regression results that appear above, it is possible to look at how urban density affects the propagation of COVID from a demographic perspective. First of all, from Wuhan city itself, the city has grown rapidly in recent years, and with limited growth in the central city area (currently 740 km2), the population has reached 6.4 million (2020), a figure that is close to New York City's 1200 km2 and 8.6 million people. Thus, Wuhan has been under tremendous demographic and policy pressure in recent years, and from a population perspective alone, the city is inherently vulnerable to a major health event (COVID).

The above fact was also shown in the regression results of this paper, where population density showed a strong positive correlation (3.04) with the prevalence of COVID infection. It can be seen that the higher the population density is, the higher the likelihood of COVID infection in the subdivided community of Wuhan city. However, it is noteworthy that population density is not the most important dimension in the population dimension. Instead, public transit percentage showed the highest correlation (4.18) with COVID prevalence among all factors. It can be seen that in the population dimension, the percentage of population traveling by public transit has a higher impact on COVID transmission than population density. This is also consistent with the judgment in epidemiology for COVID that the degree of population mobility is a key factor affecting COVID, a type of airborne virus. Wuhan has a well-developed public transportation system, and the common travel rate in the city center has reached 28%, i.e., 3 out of 10 people travel by public transportation such as subway or bus. In other words, out of 8.6 million people in the city center, more than 2.5 million people travel by public transportation in the near distance without the sound of COVID. Given the large population base of Wuhan and the high basic transmission rate of COVID R0, the high proportion and high density of public travel will be a hotbed of COVID transmission.

In terms of geographical distribution, public transit facilities (subway, buses, shared bikes, etc.) in Wuhan are mainly concentrated in the central urban areas, i.e. Jiang'an, Jianghan, Hanyang, Qiaokou, Qiaokou and other regions. This also explains why the public transit percentage above shows the highest degree of influence in the communities of regions such as Hanyang; meanwhile, the index does not show a high correlation in the peripheral regions of the city where private cars are the main mode of travel (e.g. Xinzhou, Hannan, etc.).

At the same time, the high density of public transportation is usually highly correlated with population density and commuting demand, so it cannot be simply assumed that the ratio of public transportation alone affects the spread of COVID. From the perspective of urban development, as a complex complex, the higher the density (commuting mode density, population distribution density) formed by people as the main body, the more rapidly COVID will spread. Therefore, although public transportation has greatly improved efficiency in economic development, it has become the most important influencing factor in dealing with the propagation of COVID and is the focus of attention for future urban public transportation development.

The Population dimension does not only contain a positive correlation between population density and commuting, but also includes the effects of educational attainment and Hukou system. Both of them show a slight negative correlation with COVID in the above analysis (-

2.16 and -2.38, respectively) and are the least influential (in absolute value) among all the factors. However, we can draw some conclusions from them.

The factor of the proportion of educated population shows a slight negative correlation (-2.38) between the proportion infected with COVID with increasing education in both groups with and without university education. In terms of Wuhan city itself, it is a city with the highest number of colleges and universities in China, with a total of 1.04 million college students currently enrolled and high quality colleges and universities (including famous Chinese universities such as Wuhan University and Huazhong University of Science and Technology). According to the development plan of Wuhan city, many universities and colleges are not located in the central section of the city, but adopt the development of "university satellite cities". Therefore, despite the high density of university students, these areas are not affected by COVID. In addition, the COVID outbreak will occur in January 2020, which is the winter break for college students, and the number of students and teachers is not very high.

On the other hand, Wuhan city government announced the resumption of work and production in April, but the university announced the cancellation of offline classes, which is also out of concern and protection of high density in high education areas. Therefore the conclusion of this paper is also consistent with the timeline of this policy.

The same is true for the Hukou population. The Hukou system was originally intended to compulsorily divide China's large population into two groups based on agricultural production and urban production, and to restrict mobility between the two groups. The Hukou system was originally intended to compulsorily divide China's large population into two groups based on agricultural production and two groups based on urban production, and to restrict mobility between the two groups, giving rise to different social welfare systems. Since 1978, however, the tide of urbanization in China has shown that this system is increasingly unable to resist the economic benefits of high urban agglomeration. As a result, the Hukou system has been infinitely weakened since 2000. This is further elaborated by the findings of this paper that Hukou differentiation was not significantly associated with COVID infection and transmission in a study of nearly 70 communities in Wuhan city.

Urban Density – Built-up Area Dimension

On the other hand, we need to look at the research questions in this paper from the perspective of urban built-up areas. Unlike the Population dimension, the built-up area is not formed overnight; the shape of the city is shaped by policy requirements, human environment, and other factors over a long period of time. Therefore, this part of the analysis is intended to analyze the relevance of the remaining COVID propagation through the density condition of the built-up area.

In this study, some concepts of landscape ecology are introduced, namely the concept of patches. RNP (Residential Number of Patches) is a specialization of NP (Number of Patches). In this paper, the patches of residential areas are extracted and analyzed to obtain the relevant results. Therefore, the statistical significance of RNP is that a higher RNP value means more residential patches, which in a way reflects the higher degree of residential separation. The RNP parameter used in this paper also incorporates the number of residential households in each area, so the index can well reflect the influence of long-term residential density on COVID. From the analysis of the OLS results, a larger RNP showed a significant correlation with a lower COVID infection rate. That is, the more residential areas (households are scattered in each residential area), the lower the COVID infection rate. This is consistent with the results of several reports that have been published so far in Wuhan, where multiple cases of herd-onset disease have been found in large-scale outbreaks of COVID, which are associated with large-scale old neighborhoods and high-density residential buildings in Wuhan, and this result demonstrates that large-scale clustered residential areas are not conducive to COVID prevention.

From the point of view of SHDI (Shannon's Diversity Index), this index is mainly calculated at the landscape level as a negative value equal to the sum of the area ratio of each tessellation type multiplied by the natural logarithm of its value. SHDI=0 indicates that the whole landscape consists of only one tessellation; an increase in SHDI indicates an increase in tessellation types or a balanced distribution of each tessellation type in the landscape. SHDI is a good indicator of the degree of functional mixing advocated by the New Urbanism from the perspective of data analysis. The results of this paper show that when Wuhan city has more balanced land types and higher land mix in a small area (search radius for each community), the higher the possibility of contracting COVID. Therefore, the development of high-mix, high-density forms of new urbanism does not have a suppressive effect on COVID under the current development approach, but rather there is a situation that promotes the spread of the virus.

Another key point of discussion is the distribution of health care resources. It is generally believed that a high-density urban development approach is associated with a higher concentration of health care resources and better accessibility to health care. Especially in the Chinese system, the distribution of healthcare resources in cities is generally characterized by the following, 1) hierarchical distribution, hospitals are divided into three decade[3], according to the size of the hospital, technical skills, and index such as equipment, up to the level of first-class

[3] National Health Commission of the People's Republic of China. http://www.nhc.gov.cn/

hospital, down to the level of community clinics were incorporated into the system, 2) gap between cities and the regional medical resources, high-grade medical resources to the big cities, some rural areas are difficult to reach the high-grade medical resources, 3) different with European and American health care system profit nature, and China's health care system more emphasis on public welfare.[4] 4) during COVID, taking Wuhan as an example, medical resources were classified into Designated hospitals, Mobile cabin hospitals, and Sick Observation Stations due to high density of cases, so as to deal with COVID incidents in an orderly manner.[5] From a quantitative perspective, there is a significant scale relationship between medical resources and population density in China[6], that is, regions with high population density are more likely to have dense and high-quality medical resources.

From the results of this paper, the two variables selected in this paper with respect to medical resources, Beds per capita and Hospital Distance, showed very different results in the regression. Beds per capita in infectious disease hospitals showed a high correlation with COVID (3.8); however, the distance between these cases and infectious disease hospitals showed a negative correlation, i.e., the closer these communities were to the Wuhan infectious disease hospitals, then the probability of infection was lower. From the above two results we can get several basic conclusions, 1) Insufficient number of infectious disease hospitals and inadequate protection, from the factual data, all infectious disease hospitals in all of Wuhan have only 7 hospitals providing a total of 17,430 available infectious disease beds, which is obviously insufficient for an outbreak of COVID cases in all of Wuhan, so the suddenness of the COVID outbreak is a

[4] PENG, Xu-hui, and Qiu-hong MIN. "Scaling Laws between Medical Resources and Population Densities: Evidence from Chinese Cities." Chinese Health Economics 12 (2015): 17.
[5] Wu. ZQ. Smart Planning: Refining the Spatial Anti-epidemic Efforts of our Cities. 7th Urban China Forum (2020)
[6] PENG, Xu-hui, and Qiu-hong MIN. "Scaling Laws between Medical Resources and Population Densities: Evidence from Chinese Cities." Chinese Health Economics 12 (2015): 17.

huge blow to Wuhan city. The distribution of infectious disease hospitals is all located in the urban center of Wuhan, which can be said to take advantage of the high-density development of the city and thus open multiple hospitals; 2) distance to infectious disease hospitals is a more sensitive variable than beds (-5.48 versus 3.8), which shows that for acute infectious diseases like COVID, decentralized infectious disease hospitals, compared to additional large infectious disease hospital beds that may be more effective.

Finally, the analysis of built-up environment indicators is presented. In the past, the built-up area per capita index was mainly used to measure the living environment of residents in urban areas, and the larger the value of this index, the more generous the living environment of citizens; conversely, the smaller the value, the more constrained the living environment of citizens. From the analysis of this paper, the value of the indicator of built-up area per capita shows a negative correlation with the correlation index of COVID (-2.38). This result indicates that the smaller the per capita built-up area is, the more serious the COVID infection is. This result is also consistent with the current urban construction situation in Wuhan, where a large number of crowded residential areas exist (especially in the city center), and many of these residential buildings are less than 5 m apart, thus creating a huge pressure on the ventilation and drainage systems, and most of these facilities lack repair, so it is not surprising that COVID outbreaks are concentrated in these areas. It is worth mentioning that the Wuhan Urban Renewal Center was established in August 2020, and the establishment of this center is further evidence that some areas of Wuhan are in need of the necessary repairs to improve the quality of urban space and prevent COVID, which is consistent with the results presented in this paper.

This paper will also include the renewal of Wuhan's built environment in the discussion and recommendations (especially in the community unit)

Chapter 5 Exploration of the Relationship between Urban Density and COVID

Relationship between Density and COVID?

Based on the above calculation and analysis, it is clear that the definition of urban density is not only population density, and the relationship between urban density and COVID is not simply a positive or negative correlation. Obviously, the definition of urban density has been developed and refined from the widely used population density in the last century to a complex system in the present era, and from the system theory perspective, a dynamic and slow structure has been formed between population and built environment. The demographic factors are constantly influencing the density of the built environment, but the fixed nature of the built environment can in turn influence the density and mobility of the population in the short term, thus constituting a complex relationship between the two. When COVID, a highly contagious virus, enters this complex system like a bomb, the results are equally complex. This paper introduces a number of indicators that measure the two dimensions in order to explain how this complex system is affected and which subdivisions are the most affected.

So we have to discuss how our urban density should change to respond to COVID? In terms of the existing policy timeline, grid, a new form of management, has emerged whose purpose can be seen as a redefinition and management of urban density in the short term. The “grid” working style of community management, actually “grid” working style is first proposed in 2003 in

Shanghai[7], initially designed for improving efficiency of management instead of providing service. However, what makes grid famous is the pandemic in 2020 in Wuhan. The rapid transmission of information, the solid foundation of working staff, the complete cover of community area, make “grid” the most powerful tool against COVID. It is quite clear that this style is going to affect the administration of grassroot level in China.

The purpose of this policy is clear: to re-segment communities and to monitor COVID in real time to prevent its spread (there was no vaccine at the time). From the perspective of urban density in this paper, this is a policy that addresses the population density dimension. The same is true for the famous closure policy (i.e., no one enters or leaves the city of Wuhan). However, it is clear that this policy instrument with a coercive nature does not last long (the city of Wuhan was closed for a total of 76 days, and the grid management approach was slightly longer).

For the other side of the coin, built environment policies are more direct and more effective. Within this category, the most notable policy is the management of the square-cell hospitals and multilevel healthcare system. Beginning in February April 2020, Wuhan began construction of three square-cell hospitals for the reception of patients with minor COVID. A square-compartment hospital outfit typically consists of a series of square-compartment combinations with different medical or technical support functions, with the ability to implement early treatment for lifesaving conditions. It can be adapted to handle emergency medical rescue missions for earthquakes, mudslides, or other sudden disasters due to many advantages such as good mobility, rapid deployment, and environmental adaptability. The construction of these square cabin hospitals can be said to have been made possible by the high concentration of

[7] Mei Liu. et al. “The significance and suggestion of implementing two-way referral between community health service institutions and hospitals” 38-39

medical resources. In addition, the city of Wuhan was able to efficiently screen the population of Wuhan's nearly 6.4 million central city residents with the help of high-density community health stations.

It can be said that the implementation of the policy is also based on the high density of the city in terms of both built environment and population dimensions. Without the extremely high urban density in the central area of Wuhan, there would be no way to achieve an efficient and rapid implementation of the relevant prevention policies.

Chapter 6 Summary & Suggestions

Summary

From the previous analysis, some basic conclusions can be drawn that urban density and COVID transmission cannot be described as a simple positive or negative correlation in the previous literature, but it is a complex and systematic issue. From the nine sub-indicators of urban density selected in this paper, public transit percentage, beds per capita, SHDI and population density show positive correlation with the number of COVID infection, while Hukou population, built-up area per capita, college diploma percentage, and population density show positive correlation with the number of COVID infection. The correlations were negative for Hukou population, built-up area per capita, college diploma percentage, RNP and hospital distance. The correlations of each sub-indicator are based on facts and can be reasonably explained.

It is clear from the policy timeline that the policies are also oriented around population density and built environment, and these policies are focused on the unit of community, which is also the unit of study in Wuhan City. The study of urban density and COVID based on community is reasonable. Therefore, based on the above facts and analysis, this paper also proposes some suggestions.

Given the context above, the solutions against COVID are mainly focused on how built environment, medical resources, and grid construction should play a role based on community.

Reshape of Built Environment

There is no doubt that built environment is affecting the morbidity rate, death rate of COVID. Recently, a study done by Megehed[8] examines the central communities of China and finds that there is a high positive relationship between the age of old buildings and the affection rate, and the key reason is that old ventilation system and narrow corridor are shrinking the space people interacts, thus increases the infection rate.

In general, I think it is necessary to re-shape the built environment in community. First, improve the building quality in community[9], especially those public systems, such as ventilation system, sewage system, heating system, etc. COVID virus is likely to spread in the pipeline of those system, leading to clustered cases in community. Second, horizontally development strategy[10]. Since social distancing measures are essential to the containment effort, some have blamed the density of cities for the rapid spread of the infection and considered decrease building height and space as well. I think lowering the building heights and household per building in the newly built communities can be an effective way of decreasing body contact, thus lower the infection rate etc. However, this strategy will spread out urban population density leading to urban sprawl. This is also a trade-off in horizontal development.

Re-distribution of Medical Resource

Another important part of solution is the redistribution of medical resource. During the pandemic in Wuhan, China, hospitals are running out of goods and doctors to treat patients, even mobile cabin hospitals are built. This phenomenon not only emphasizes the shortage of medical

[8] Megahed, Naglaa A. et al. "Antivirus-built environment: Lessons learned from Covid-19 pandemic." 102350.
[9] Rowe, Peter G.et al. “China's Urban Communities: Concepts, Contexts, and Well-being.”
[10] Megahed, Naglaa A. et al. "Antivirus-built environment: Lessons learned from Covid-19 pandemic." 102350

resource during COVID, but also keeps people wondering where role is community hospital playing in this? If the affected people can be treated in community hospital, the cross-affection rate between patients can be lowered and the travel distance of patient can be shortened. Based on the current <Residential District Planning (GB50180-2018)>, medical service station service should be provided in the range of 5-minute living circle (300m walking distance), community hospital service should be provided in the range of 15-minute living circle (1000m walking distance). But the reality is, people turn to community hospital are much less than city- or province-level hospital. So, the key problem is how to construct the community hospital.

Therefore, I proposed to deeply acting out several policies. First, carry out medical resource decentralization in terms of material goods and doctor resource. For material goods like masks, deliver mode in China is worth learning from. It is basically saying to store medical goods in a network in advance base on community, whenever needed, everyone in this community can get delivered within a short time, instead of travel a long distance to big hospitals. But also, it is going to take a long time building this community network. Second, carry out “two-way trans-treatment”[11] thoroughly, which means to set clear boundary between the function of city-level and community-level hospitals and enable patient transfer between hospitals. Actually, this concept has been proposed since 2004, but problems of unclear medical hierarchy, low-efficiency trans-treatment still remain today. The key barrier is the interest conflict between hospitals. Driven by profit, big hospitals are admitting minor illness that may take the resource (beds) of some critical patients in advance; while community hospital, especially private ones, may purchase some expensive equipment; both of the actions are not necessary. So, I propose to

[11] Mei Liu. et al. “The significance and suggestion of implementing two-way referral between community health service institutions and hospitals” 38-39

introduce the conglomeration of hospitals to integrate medical resource, so no severe interest conflict will take place in transferring patients. In the case of COVID, the high efficiency of trans-treatment is rapidly replacing the patients in a rational way as the planning originally intended to do, and community hospitals work both as treating patients, and mitigate the shortage of city-, province-level medical resource. Still, this proposal may lead to monopoly of hospitals, increasing the price of medicine and doctor fee, so surveillance agencies are extremely needed in this scenario.

Re-deepen role of Grid management

As mentioned previously, "Grid" style of management takes an important place in fighting COVID in Wuhan, like testing temperature, and detect suspected cases by head of each "cell" on the "grid". And what's special about the grid is the double role it is playing during COVID, that not only manages all the residents in the community, but also provides community service like food delivery, message warning etc., which has evolved since the initial version in Shanghai in 2003[12]. Therefore, grid is basically functioning as what community does, in a more specific way though. However, some clarifications have to be made, 1) "gird" is not making changes on the public resource ownership but only redistribute resources in a rational way. 2) Down to the grid level, the forces of market, government, people, company are interreacting more than any other level. 3) The operation of grid is dynamic, which is also the reason why grid has been greatly praised till COVID.

Therefore, I would like to give several advices in re-deepening grid. The word "re-deepen" is used here because grid has already been introduced in the early 21st century, and what I want

[12] Yipeng Tian. "Construction of a system for urban communities to fight against the epidemic from the perspective of governance." 19-27

to iterate is to draw lessons from COVID. First, maintain the grid-community-district-city-province-country hierarchy in goods distribution. Experience from Wuhan is showing that even with the grid management, shortage of mask still happened, indicating that the goods delivery chain is incomplete, especially in grid level. Second, function of grid should be clearly set apart from community. The gird does not have the ability to provide medical service as community or city does, but it supports residents in acting out “community” more accurately. Responding COVID, grid style shows its strength in managing and servicing residents in community, and the mode of grid is going to deepen and popularize across China.

Bibliography

Alirol, Emilie, Laurent Getaz, Beat Stoll, François Chappuis, and Louis Loutan. "Urbanisation and infectious diseases in a globalised world." The Lancet infectious diseases 11, no. 2 (2011): 131-141.

Bakanlığı, S. (2020). Covid-19(SARS-CoV-2 Enfeksiyonu) Rehberi: https://covid19bilgi. saglik. gov. tr/depo/rehberler/COVID-19_Rehberi. pdf? type= file. Erişim Tarihi, 27.

Bashford, A. (Ed.). (2016). Quarantine: local and global histories. Macmillan International Higher Education.

Bhadra, Arunava, Arindam Mukherjee, and Kabita Sarkar. "Impact of population density on Covid-19 infected and mortality rate in India." *Modeling Earth Systems and Environment* 7, no. 1 (2021): 623-629.

Boccaletti, Stefano, William Ditto, Gabriel Mindlin, and Abdon Atangana. "Modeling and forecasting of epidemic spreading: The case of Covid-19 and beyond." *Chaos, solitons, and fractals* 135 (2020): 109794.

Campbell, M. (2005). What tuberculosis did for modernism: the influence of a curative environment on modernist design and architecture. Medical history, 49(4), 463-488.

Cantwell, B and Taylor, B. It's Time for Radical Reorganization The Chronicle of Higher Education (15 April 2020)

Carozzi, Felipe. "Urban density and COVID-19." (2020).

China Real Estate Development Report No. 19. Social Sciences Academic Press, 2019.

Copiello, Sergio, and Carlo Grillenzoni. "The spread of 2019-nCoV in China was primarily driven by population density. Comment on "Association between short-term exposure to air pollution and COVID-19 infection: Evidence from China" by Zhu et al." *Science of The Total Environment* 744 (2020): 141028.

Densities: Evidence from Chinese Cities." Chinese Health Economics 12 (2015): 17.

De Bellefon, Marie-Pierre, Pierre-Philippe Combes, Gilles Duranton, Laurent Gobillon, and Clément Gorin. "Delineating urban areas using building density." *Journal of Urban Economics* 125 (2021): 103226.

Desai, Dhaval. "Urban densities and the Covid-19 pandemic: Upending the sustainability myth of global megacities." *ORF Occasional Paper* 244, no. 4 (2020): 1-4.

Donders, Francesca, Risa Lonnée-Hoffmann, Aristotelis Tsiakalos, Werner Mendling, José Martinez de Oliveira, Philippe Judlin, Fengxia Xue, Gilbert GG Donders, ISIDOG COVID, and Guideline Workgroup. "ISIDOG recommendations concerning COVID-19 and pregnancy." *Diagnostics* 10, no. 4 (2020): 243.

Environmental Research and Public Health 17, no. 20 (2020): 7633.

Ewing, Reid, and Shima Hamidi. "Measuring urban sprawl and validating sprawl measures." Washington, DC: National Institutes of Health and Smart Growth America (2014).

Fang, Wanli, and Sameh Wahba. "Urban density is not an enemy in the coronavirus fight: evidence from China." Sustainable Cities, World Bank. https://blogs.worldbank.org/sustainablecities/urban-density-not-enemy-coronavirus-fight-evidence-china (2020).

Galle, Omer R., Walter R. Gove, and J. Miller McPherson. "Population density and pathology: what are the relations for man?." *Science* 176, no. 4030 (1972): 23-30.

GÜNER, H. R., Hasanoğlu, İ., & Aktaş, F. (2020). COVID-19: Prevention and control measures in community. Turkish Journal of medical sciences, 50(SI-1), 571-577.

Hamidi, Shima, Sadegh Sabouri, and Reid Ewing. "Does density aggravate the COVID-19 pandemic? Early findings and lessons for planners." *Journal of the American Planning Association* 86, no. 4 (2020): 495-509.

Hao, Qianyue, Lin Chen, Fengli Xu, and Yong Li. "Understanding the Urban Pandemic Spreading of COVID-19 with Real World Mobility Data." In *Proceedings of the 26th ACM SIGKDD International Conference on Knowledge Discovery & Data Mining*, pp. 3485-3492. 2020.

Hawley, Amos H. "Population density and the city." *Demography* (1972): 521-529.

Hamidi, Shima, Reid Ewing, and Sadegh Sabouri. "Longitudinal analyses of the relationship between development density and the COVID-19 morbidity and mortality rates: Early evidence from 1,165 metropolitan counties in the United States." Health & place 64 (2020): 102378.

He, Haibin. The change of social management system of urban grassroots: from unit system, street system to community system. Management World,2003

Hinchliffe, S., Bingham, N., Allen, J., & Carter, S. (2016). Pathological lives: Disease, space and biopolitics. John Wiley & Sons.

Holtz-Eakin, Douglas, Whitney Newey, and Harvey S. Rosen. "Estimating vector autoregressions with panel data." *Econometrica: Journal of the econometric society* (1988): 1371-1395.

Johnson, S. (2006). The ghost map: The story of London's most terrifying epidemic--and how it changed science, cities, and the modern world. Penguin.

Kahn, D. "California saw dense housing near transit as its future. What now? Politico." (2020).

Keyfitz, Nathan. "Population density and the style of social life." *Bioscience* 16, no. 12 (1966): 868-873.

Keeling, Matt J., Leon Danon, Matthew C. Vernon, and Thomas A. House. "Individual identity and movement networks for disease metapopulations." Proceedings of the National Academy of Sciences 107, no. 19 (2010): 8866-8870.

Koch, T., & Koch, T. (2005). Cartographies of disease: maps, mapping, and medicine (p. 840). Redlands, CA: Esri Press.

Kodera, Sachiko, Essam A. Rashed, and Akimasa Hirata. "Correlation between COVID-19 morbidity and mortality rates in Japan and local population density, temperature, and absolute humidity." *International journal of environmental research and public health* 17, no. 15 (2020): 5477.

Love, Inessa, and Lea Zicchino. "Financial development and dynamic investment behavior: Evidence from panel VAR." *The Quarterly Review of Economics and Finance* 46, no. 2 (2006): 190-210.

Manville, Michael. "Travel and the built environment: time for change." *Journal of the American Planning Association* 83, no. 1 (2017): 29-32.

Mei Liu, Jinhua Chen, and Xiaoming Peng. “The significance and suggestion of implementing two-way referral between community health service institutions and hospitals” *Chinese General Practice* (2004): 38-39

Megahed, Naglaa A., and Ehab M. Ghoneim. "Antivirus-built environment: Lessons learned from Covid-19 pandemic." *Sustainable Cities and Society* 61 (2020): 102350.

Miller, Tom. “China's urban billion: the story behind the biggest migration in human history”. Zed Books Ltd., 2012. 11-12

Mills, Edwin S. "Urban density functions." *Urban Studies* 7, no. 1 (1970): 5-20.

Muth, Richard F. *Urban residential land and housing markets*. Institute for Urban and Regional Studies, Washington University, 1966.

Muth, Richard F. "The spatial structure of the housing market." In *Papers of the Regional Science Association*, vol. 7, no. 1, pp. 207-220. Springer-Verlag, 1961.

Muth, Richard F. "The spatial structure of the housing market." In *Papers of the Regional Science Association*, vol. 7, no. 1, pp. 207-220. Springer-Verlag, 1961.

PENG, Xu-hui, and Qiu-hong MIN. "Scaling Laws between Medical Resources and Population Densities: Evidence from Chinese Cities." Chinese Health Economics 12 (2015): 17.

Ribeiro, Haroldo V., Andre S. Sunahara, Jack Sutton, Matjaž Perc, and Quentin S. Hanley. "City size and the spreading of COVID-19 in Brazil." *PloS one* 15, no. 9 (2020): e0239699.

Rowe, Peter G., Ann Forsyth, and Har Ye Kan. “China's Urban Communities: Concepts, Contexts, and Well-being.” *Birkhäuser*, 2016.

SARS-CoV, Startseite Infektionskrankheiten AZ Coronavirus. "SARS-CoV-2 Steckbrief zur Coronavirus-Krankheit-2019 (COVID-19)."

Simmel, Georg. *The sociology of georg simmel*. Vol. 92892. Simon and Schuster, 1950.

Sims, Christopher A. "Comparison of interwar and postwar business cycles: Monetarism reconsidered." (1980).

Shi, Yu, Gang Wang, Xiao-peng Cai, Jing-wen Deng, Lin Zheng, Hai-hong Zhu, Min Zheng, Bo Yang, and Zhi Chen. "An overview of COVID-19." *Journal of Zhejiang University-SCIENCE B* 21, no. 5 (2020): 343-360.

Tönnies, Ferdinand. Gemeinschaft und gesellschaft: grundbegriffe der reinen Soziologie. Curtius, 1912.

Wei, W. E., Li, Z., Chiew, C. J., Yong, S. E., Toh, M. P., & Lee, V. J. (2020). Presymptomatic transmission of SARS-CoV-2—Singapore, january 23–march 16, 2020. Morbidity and Mortality Weekly Report, 69(14), 411.

Williams, Katie, Elizabeth Burton, and Mike Jenks. "Achieving the compact city through intensification: An acceptable option." *The compact city: A sustainable urban form* (1996): 83-96.

Winsborough, H. H. 1961. A comparative study of urban population densities. PhD thesis. Univ. Chicago, II. 204 pp

Wirth, Louis. "Urbanism as a Way of Life." *American journal of sociology* 44, no. 1 (1938): 1-24.

Wong, David WS, and Yun Li. "Spreading of COVID-19: Density matters." *Plos one* 15, no. 12 (2020): e0242398.

World Health Organization. (2020). Getting your workplace ready for COVID-19: how COVID-19 spreads, 19 March 2020 (No. WHO/2019-nCov/workplace/2020.2). World Health Organization.

Wu. ZQ. Smart Planning: Refining the Spatial Anti-epidemic Efforts of our Cities. 7th Urban China Forum (2020)

Yashima, K., Sasaki, A., 2014. Epidemic process over the commute network in a metropolitan area. PloS One 9 (6), e98518.

Yipeng Tian. “Construction of a system for urban communities to fight against the epidemic from the perspective of governance.” *Social Science Journal* (2020): 19-27

Zenker, Sebastian, and Florian Kock. "The coronavirus pandemic–A critical discussion of a tourism research agenda." Tourism Management 81 (2020): 104164.

Zimmer, C. "The Secret Life of a Coronavirus–An oily, 100-nanometer-wide bubble of genes has killed more than two million people and reshaped the world. Scientists don't quite know what to make of it." *Scientists don't quite know what to make of it. Retrieved* 28 (2021).

Zhan QM. Pandemic Urbanism: China's Response to COVID-19 and a Post-COVID Future. 7 Urban China Forum (2020)

Zhang, Yuxiao, Peiyu Cao, Jiejie Meng, Jiuyun Qiu, Qiwen Hu, and Lei Cheng. "Exploration of the Evaluation and Optimization of Community Epidemic Prevention in Wuhan Based on a DEA Model." International Journal of

Zhi Rong, and Hao Qin. "The Operational Logic and Practical Enlightenment of Community "Overall Grid" in Covid-19 Based on the View of Social Reorganization" *The Journal of Shanghai Administration Institute* (2020): 21(06)66-77

ZHOU, Ji-biao, Chang-xi MA, Sheng DONG, and Min-jie ZHANG. "Unconventional Prevention Strategies for Urban Public Transport in the COVID-19 Epidemic: Taking Ningbo City as a Case Study" *China Journal of Highway and Transport*. (2020)