# Do Rail Transits Improve Local Air Quality? Take Chengdu-Nanchang for Example

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# Do rail transits improve local air quality? Take Chengdu-Nanchang for example

**Abstract**

Many cities in China have invested the city's rail transit system to reduce urban air pollution and traffic congestion. Earlier studies rarely compare the effects of rail transit on urban air quality in different cities, providing little guidance to urban planners in solving traffic congestion and air quality. By using the rail transit lines in Chengdu and Nanchang as case studies, this paper attempts to examine the effect of rail transit on air pollution. Data were collected from 18 monitoring stations distributed along the chosen rail transit lines in both cities during the period 2014 to 2016 and analyzed using the regression discontinuity design to address the potential endogenous location of subway stations. The results show that subway opening in Nanchang has a better reductions from automobile exhaust than that in Chengdu, specifically, carbon monoxide pollution, one key tailpipe pollutant, experienced a 10.23% greater reduction after Nanchang Metro Line 1 opened. On the contrary, the point estimate for carbon monoxide in Chengdu is 22.42% and statistically significant at the 1% level. Nanchang Metro Line 1 does play an important role in road traffic externalities, but the benefit was not huge enough to change the overall air quality. On the contrary, the opening of the Chengdu Metro Line 4 is unlikely to yield improvements in air quality.

**Keywords**

Urban Rail Transit; Air Pollution; Regression Discontinuity Designs; Chengdu-Nanchang

## 1. Introduction

Traffic is a major contributor to ambient air pollution. Based on the world air quality report published by IQAir AirVisual in 2019, the top 50 most polluted cities are from East and South Asian countries, such as India, Pakistan, Bangladesh, Indonesia, and fourteen of them were located in China, including Hotan, Kashgar, Shangqiu, Anyang, Handan, Shijiazhuang, Xianyang, Xingtai, Puyang, Shihezi, Laiwu, Luoyang, Hebi, Linfen. Ghaziabad, located in India, experienced the highest level of PM2.5 concentration in 2019. PM2.5 is widely regarded as most harmful to human health, originating from a range of sources, for example, vehicle engines, industry, fires and coal burning. Air pollution is responsible for the premature death of 4.2 million people worldwide in 2016, of which 40 percent occurred in China. And the evidence shows that vehicular emissions contribute to around 33% to 57% of ambient air pollution (Chen et al. 2020). The environmental effect of traffic may hardly negligible, traffic congestion and subsequent air pollution present policymakers with pressing challenges.

The most commonly adopted policy measures for improvements in terms of traffic pollution are routinely focusing on limiting transportation demand, such as imposing road pricing (Gibson and Carnovale 2015), parking controls (Melia and Clark 2018), driving restrictions (Melia and Clark 2018；Zhang et al. 2020；Zhang et al. 2017) and traffic calming (Akbari and Haghighi 2020), or increasing transportation supply, including increasing capacities of transportation facilities and investments. This paper focuses on another policy: urban rail transit.

According to data from the China Statistical Yearbook, over the period from 1998 to 2018, GDP per capita increased by nearly 10 times, per capita disposable income of national residents increased by about 7 times, and vehicle ownership increased by 48 times in China. China's reform and opening-up, the rapid growth of its economy has led to plenty of problems (Mbizvo et al. 2019) including urban traffic congestion (Akbari and Haghighi 2020), adverse health consequences (Brook and Rajagopalan 2012；Currie and Neidell 2018；Heinrich and Slama 2007) and air pollution (Ibarra-Espinosa et al. 2020). To reverse the trend of nationwide environmental deterioration, Chinese government made the decision to transform its economic pattern to a new one featured with technology innovation since the Ninth Five-Year Plan by supporting the implement of the Air Pollution Control Action Plan and setting detail emission reduction target for each Five-Year Plan (Wang et al. 2019). Chinese government has also been investing heavily in transportation infrastructure. As of 2019, a total of 46 cities in mainland China have opened urban rail lines, with 5680.84 km in total route length. The rapid subway expansion is still ongoing at the national level: the network consists of another 266 subway lines, serving a total of 3,872 subway stations with a total length of 6282.6 km. The remarkable development of China's transportation infrastructure in the past 10 years has caused the profound changes in the economic structure and the developmental pattern.

Recently major cities in China have been investing heavily in green infrastructure to mitigate air pollution. However, existing studies rarely compare the effects of rail transit on air quality in different cities. This paper examines the impact of rail transit on air quality by leveraging hourly weather data collected from Chengdu and Nanchang during the period of 2014-2016. The literatures in subway infrastructure incorporates two countervailing forces, one possible channel that may affect traffic pollution is the possibility that households near the subway stations may substitute for their driving after the rail transit opened, this traffic diversion effect may relieve traffic congestion and thus alleviate air pollution (Mohring 1972). The other possible channel is the improved traffic conditions may provide some people near the subway stations with more potential choices, and induce additional travel demand using private cars (Vickrey 1969) and the phenomenon of separation of workplace and residence. This traffic creation effect would result in the increase of the traffic volume in the streets and the prolongation of peak-hours and thus aggravate local air pollution.

This analysis is relevant to currently high-profile discussions about whether the opening of rail transit has positive effects on air quality in different cities. Our empirical analysis leverages discontinuity in the concentration of air pollutant to control for possible confounding factors. The data on air quality come from published hourly air quality index from the U.S. National Climatic Data Center. The central empirical challenge in scrutinizing the effects of rail transit on air quality is identification concern. First, in measuring variations in rail transit, confounding with other factors affecting air pollution, have no way to give sound results (Chen and Whalley 2012；Li et al. 2019). For example, subway stations are likely to be located in areas with high population growth, hence induce the demand of travel and deterioration in air pollution. Second, it is a mistake to confound the variation in the demand for public transit with other covariables that affect air quality (Rivers et al. 2017). The demand for public transport is associated with the overall price, income, speed and frequency elasticities (Toro-González et al. 2020). Public transportation is not a sufficiently good alternative for those who travel a lot (Lalive et al. 2018) and the demand for public transport decreases given an increase in per capita income (Toro-González et al. 2020).

Using the regression discontinuity design based on the combinations of weather controls (i.e.

temperature, wind speed, volume, precipitation), air pollution (CO, $NO_2$, $PM_{2.5}$, $SO_2$, $O_3$, $PM_{10}$), time fixed effect and station fixed effect, we find that the opening of rail transit in different cities may have different effects on local air pollutants. The findings of this paper are contrary to much of the existing literature on the relationship between rail transit and air quality. Our first finding shows that carbon monoxide experienced a greater reduction in Nanchang relative to concentrations calculated from the Chengdu monitoring stations after the subway line opened. Second, the opening of Nanchang Metro Line 1 leads to two contradictory results. On the one hand, the expansion of Nanchang's subway network could lead some commuters living near the subway stations to prefer to subways. This traffic diversion effect may be conducive to alleviate people's travel pressure, and thus reduce automobile exhausted gas pollution. On the other hand, a completely new subway line's opening could offer more convenient mobility options and induce additional travel demand, resulting in a traffic creation effect. Third, carbon monoxide pollution led up to 27.01% after Chengdu Metro Line 4 opened, and other forms of air pollution have also risen in varying degree. The opening of the Chengdu Metro Line 4 can provide no benefits in terms of air quality and even deteriorate air pollution. To understand how the concentrations of air pollutant change over time, we divided the sample into two sub-periods and find that the traffic division effect is more obvious in peak hour.

The paper is structured as follows: Section 2 provides the research hypothesis. Section 3 presents the material and methods. Section 4 describes the empirical analysis. Section 5 presents the discussion. Section 6 concludes.

## 2. Research hypothesis

The subway is a good choice as a travel mode in the modern urban green transportation system. The leading environmental effects of subway infrastructure have been practiced in many cities (for example, Taiwan, Changsha, Mexico), however, empirical evidence on its effect on air quality is unclear. Whether properly invested in subway infrastructure can lead some commuters to prefer to travel using subways that to a certain extent may improve air quality (the so-called traffic diversion effect or "Mohring Effect"), or otherwise induce residents to switch to cheaper communities far away from the railway station (the so-called traffic creation effect) has triggered traffic congestion and deteriorated air pollution (Vickrey 1969； Mohring 1972).

According to the earlier literature, the subway network could create two countervailing forces that could affect air quality, i.e. traffic diversion effect and traffic creation effect. We present these effects in the form of mathematical models through an analysis of the associated parameters. On the one hand the traffic diversion effect, it means rapid subway expansion could reduce the trip frequency of travelers using private cars and reduce the daily flow of motor vehicles, then we believe the impact of new subway opening on air quality could appear positive, it may relieve traffic congestion and then improve air quality.

INSERT FIGURE 1

In Fig. 1, the vertical axis is the non-green traffic demand, and the horizontal axis is the green traffic demand, the price of green transportation is $P_G$, the price of non-green transportation is $P_{NG}$, we assume the price of green transportation is lower than that of non-green transportation. Hence, we have $\frac{P_{G2}}{P_{NG2}} < \frac{P_{G1}}{P_{NG1}}$ , then indifference curve $U_1$ gradually shifted outward, it is clear that the new position of maximum utility is at M, where the new budget line is tangent to the indifference curve $U_2$. The dashed line in Fig. 1 has the same slope as the new budget constraint but is drawn to be tangent to initial indifference curve $U_1$, the movement from B to D is a graphic demonstration of the substitution effect of non-green transportation. Because the price of green transportation has decreased, this person has a higher "real" income and can afford a higher utility level ($U_2$). The movement from D to C is a graphic demonstration of the income effect of non-green transportation. Notice in Fig. 1 that the income and substitution effects work in the opposite direction and cut down the demand for non-green transportation in response to an increase in its relative price. In this context, the traffic diversion effect does matter.

On the other hand the traffic creation effect, it means the improved traffic conditions led to an increase in the total number of vehicles in the street as well as a variation in the concentrations of air pollutant.

INSERT FIGURE 2

we assume the price of non-green transportation is relative lower given the high housing cost near metro station, hence, we have $\frac{P_{G2}}{P_{NG2}} > \frac{P_{G1}}{P_{NG1}}$, the movement from C to D is a graphic demonstration of the substitution effect of non-green transportation. The movement from D to B is a graphic demonstration of the income effect of non-green transportation. Notice in Fig. 2 that the income and substitution effects work in the same direction and increase the demand for non-green transportation in response to a reduction in its relative price. In this context, the traffic creation effect does matter.

## 3. Material and methods

3.1. Site description

Chengdu, the capital of southwestern Sichuan Province, is one of the fastest-growing regions in China. Chengdu reshaped its economic growth mode under market economic system in the 1990s, and now it ranked in the top ten richest cities in the second quarter of 2020 in China. The number of passenger vehicles in Chengdu increased dramatically in the past decade, its stock of passenger vehicles increased from about 416,900 units in 2004 to 4.2 million units in 2018. With the rapid development of urban economy and acceleration of motorization process, traffic congestion become more and more serious. Chengdu has made many efforts in the public transportation system, such as, build intelligent transportation systems, traffic restrictions based on the license plate and heavily investing in rail transit. As of December 2018, urban rail lines have been in operation, with 329.8km in total route length and 190 subway stations. The network consists of six lines (numbered 1, 2, 3, 4, 7, 10), serving a total of 156 stations with a total length of 226.017 km. Transportation planners also consider bus routes and their layout based on the characteristics of passenger flow and integrate them with the Chengdu Metro system. The line consists of 5 major transfer points with the other public transport modes: Chengdu Tram Line 2，Chengdu Metro Line 7, Chengdu Metro Line 3, the City Expressway and local buses.

Nanchang is one of the most important regional economic centers in Jiangxi Province in eastern China. It ranked the 42th in one hundred better cities in China and per capita GDP was about 9,825 RMB in 2018. As the end of 2018, Nanchang had a total population of 5.545 million, with a density of approximately 771 people per square kilometer, roughly half of that found in Chengdu. The top 5 areas with the highest population density including Nanchang County, Jinxian County, Xinjian District, Donghu District, Qingshanhu District (Statistics Bureau of Nanchang, 2018).

Our study focuses on two rail transit lines: Chengdu Metro Line 4 and Nanchang Metro Line 1. We chose these two lines because they were opened on the same date. Chengdu Metro Line 4, with its opening on December 26, 2015, runs from Wansheng in the west to Xihe in the east. It is 43.3 km long and serves 30 stations, via some universities (such as Southwestern University of Finance and Economics, Chengdu University), health establishments (such as Chengdu University of TCM & Sichuan Provincial People's Hospital, Chengdu Second People's Hospital) and Chengdu West Railway Station. Nanchang Metro Line 1, with its opening on December 26, 2015, runs from Shuanggang in the north to Yaohu West in the east, serving a total of 52 stations with a total length of 60.31 km. It passes through four administrative regions, including Qingshanhu District (west), Donghu District, Qingshanhu District (east), Nanchang County. Every day 0.38 million people travel on urban rail transit systems in Nanchang. The Nanchang Metro network operates daily from 6:00 am to 23:20 pm, with an interval of 2-4 minutes.

### 3.2. Data

Our research relies on three main datasets, as presented in Table 1. The dependent variables for AQI, CO, SO2, PM2.5, O3, NO2, PM10 are available from the U.S. National Climatic Data Center over the years 2014 and 2016, i.e. the last year before and one year after the opening of the rail transit. The details of the total of 18 monitoring stations distributed along the chosen rail transit lines in these two cities are also collected. To simplify comparison, the concentrations of various air pollutants monitored have been converted to specific values by adopting formula[1].

The second dataset contains the main independent variable. The variable $\text{subway}_t$ is a dummy variable that takes a value of one for all hours after the city's Metro is operational and a value of

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[1] $IAQI_P = \frac{IAQI_{Hi} - IAQI_{Lo}}{BP_{Hi} - BP_{Lo}}(C_P - BP_{L0}) + IAQI_{L0}$, $IAQI_P$ is individual air quality index of pollutant P; $BP_{Hi}$ is the higher value of pollutant concentration limit close to $C_P$; $BP_{L0}$ is the lower value of pollutant concentration limit close to $C_P$; $IAQI_{Hi}$ is individual air quality index corresponding to $BP_{Hi}$; $IAQI_{L0}$ is individual air quality index corresponding to $BP_{L0}$.

zero before the city's Metro is operational. Our data source for the construction of rail transit is the Urban Rail Transit Statistics and Analysis Report.

The third dataset contains the control variables: temperature, pressure, wind speed, and precipitation. The National Meteorological Science Data Center provides daily data for weather monitoring stations. Due to the lack of the original data of climate variables, this chapter is based on the principle of proximity in data processing. Specifically, we use the air quality index at time 0-2 to estimate climate variable at time 0 and the air quality index at time 3-6 to assess climate variable at time 3 and so on.

### 3.3. Methodology

Many documents and papers nowadays have used three approaches to incorporate a sequence of effects of rail transit on air quality. The first method they adopted is Ordinary Least Squares based on the growth of public transportation subsidy to value rail transit infrastructure. This method was used to establish the regression model of rail transit and its results usually showed that the endogenous deviation occurred. A second approach uses the difference-in-difference (DID) to analyze cost-benefit estimates. A classic example of the kind of the approach is Li et al. (2019) who study the effects of the expansion of the Beijing subway system and find a 7.7 percent reduction in air quality within 2 kilometers of the subway station than the monitor within a radius of 20 kilometers 60 days after the opening date of rail transit. A third approach was to make use of Regression Discontinuity designs to estimate the potential effects of rail transit. For example, Rivers et al. (2017) provides a series of studies of 39 cities around the world that opened subways from August 2001 to July 2013, concluding that the opening of a new rail transit line is conducive to the improvement of overall social welfare.

We measure the effect of rail transit on air quality during the period 2014-2016 by using the Sharp Regression Discontinuity design to control for possible confounding factors. To eliminate endogenous problems, we leverage three datasets to study the casual relationship between rail transit and air quality in Chengdu and Nanchang. The key assumption is the only reason for the discontinuous change of air quality on the opening date is the opening of the Metro itself. After the introduction of the dummy variable of $\text{subway}_t$, if we can observe that air quality changes suddenly around the cutoff, and other covariates affecting air quality change smoothly in the neighborhood of the opening date, it is reasonable that the implementation of the dummy variable result in the discontinuity in the concentration of air pollutant. Air quality in the city i is modeled against the following variables: the variable $\mathrm{subway}_t$, air quality index ($\mathrm{Air}_{it}$), daily weather variables including temperature, pressure, wind speed, precipitation, time fixed effects (year, month, week, day of the week, hour and holiday) and monitor fixed effects. Specifically, we use the Regression Discontinuity (RD) designs to estimate the following model:

$$\mathrm{Air}_{it} = \alpha_0 + \alpha_1 \ \mathrm{subway}_t + \alpha_2 T_x + \alpha_3 \mathrm{f}(T_x) + \alpha_4 T_x * \mathrm{f}(T_x) + \beta_0 X_t + \theta_t + \varepsilon_t \qquad (1)$$

where, the variable $\mathrm{Air}_{it}$ is a dependent variable, which denotes air quality in the city i at time t, including air quality index (AQI), CO, NO2, PM2.5, O3, PM10, SO2. The variable $\mathrm{subway}_t$ is a dummy variable that takes a value of one for all hours after the city's Metro is operational and a value of zero before the city's Metro is operational. $T_x$ is forcing variable that indicates the number of days since the opening of the rail transit. It takes a value of zero on the opening day, negative before it and positive after it. The vector $\mathrm{f}(T_x)$ is a polynomial function on $T_x$. We also include interactions between the forcing variable and the polynomial time trend to allow the time trend in air pollution to differ on either side of the opening date. The control variables $X_t$, that include temperature, pressure, wind speed, precipitation. The vector $\theta_t$ indicates year, month, week, day of the week, hour and holiday fixed effects. $\varepsilon_t$ is the error term. The coefficient of interest is $\alpha_1$ which can directly reflect the changes of pollutant concentration and air quality index AQI after the opening of rail transit in each city.

## 4. Empirical analysis

### 4.1. Descriptive statistics analysis

Descriptive statistics of air quality and weather factors are summarized in Table 1. The concentrations of most air pollutants are noticeably higher in the post-Chengdu Metro period than in the pre-Chengdu Metro period. Furthermore, the levels of pollution concentrations of both PM10 and PM2.5 are noticeably higher than other pollutants, suggesting that fine-particle pollutant is in the prominent place among the various pollutants. Then, the concentrations of various air pollutants in Chengdu are higher than those in Nanchang, except for ground-level ozone (O3) and sulfur dioxide (SO2).

INSERT TABLE 1

4.2. Main results: RD estimation

Chengdu Metro Line 4 opened on December 26, 2015. Taking the opening date of rail transit as the cutoff, we analyzed the changing trend of the concentrations of air pollutant within the observation period of 40 days. We first provide graphical presentation of the effect of Chengdu Metro opening on air quality (see Fig. 3).

INSERT FIGURE 3

We can see that sharp jump discontinuity in the concentration of air pollutant within 40 days before and after the opening date and it is easier to see a discontinuous break in air pollution in secondary polynomial fitting graph. Specifically, after the cutoff, the AQI leaps upward and increases sharply and then it decreases slightly, finally it presents the trend of increasing. So the visual analysis method of the data in the narrow window of the Chengdu Metro opening date allows for further statistical analysis. Next, we present the results of models that include controls for weather conditions and time fix effect and station fixed effects in Table 2 to account for variations in air pollution in both cities.

INSERT TABLE 2

The results in Table 2 show a model that controls the relevant variables, indicating that the opening of the Chengdu Metro Line 4 led to a statistically significant increment in most ambient air pollutants at the 1% level, except for O3. The estimates of Chengdu Metro opening reported in Table 2 are consistent with the discontinuities indicated in Fig. 3. In this specification, there is a 22.42 percent increase in CO, which crudely reflect the evidence of pollution. In the scenario, variation in the concentrations of air pollutant increases due to additional travel demand after the opening of the new transit line, resulting in the traffic creation effect.

Then, taking the time when Nanchang Metro Line 1 opened as the cutoff, we consider the graphical presentations of the concentrations of air pollutant near the cutoff in Nanchang using 40 days window of data (see Fig. 4).

INSERT FIGURE 4

As shown in Fig. 4, we found that sharp discontinuity in the concentration of air pollutant around the opening date of the Nanchang Metro Line 1 in secondary polynomial fitting and the changing trend of AQI appears a clear rising trend before the cutoff, and there is a downward trend for AQI after the cutoff. We estimate the results of Nanchang based on control variables when the second-order polynomial was used to fit the time trend in a shorter 40-day window around the Nanchang Metro opening date in Table 2. The negative relationship between subway opening and vehicle emission pollutants across column (2) to (3), while a positive correlation between subway opening and some air pollutants such as O3, PM10, SO2 across column (4), (6) and (7). The contradiction of environmental effects of Nanchang subway opening may boil down to dual influences of traffic creation effect and traffic diversion effect. Overall, our results have confirmed the conjecture of the differential effects of the Metro's opening on the average level of air pollution for both cities.

### 4.3. Robustness test

In this result, we use a two-year data to examine the continuity of the weather variables. There is no jump of the control variables at the cutoff, which also verifies the effective of the regression results. The meteorological conditions, such as temperature, wind speed, precipitation, are the important factors affecting the levels of ambient air pollutant (Lu et al. 2019). We report estimates of the equation (1) with control variables as the outcome. The results in Table 3 show that the coefficients of air pressure and precipitation are insignificant on the opening date in Nanchang and Chengdu. However, temperature does not change smoothly on Nanchang Metro opening date, similarly wind speed on Chengdu Metro opening date does not change smoothly. As the results in this context would have less explanatory power for whole robustness test, we present further estimates to address the potential concern.

INSERT TABLE 3

Second, we examine RD estimates with varying window widths. The bandwidth is adjusted to 15 days, 20 days, 25 days, 30 days, and 35 days respectively, these samples are selected as the bandwidth for regression to be carried out for robustness test. Limiting the sample period to a narrow window is important because it helps disentangle the effect of rail transit from the effect of other time-varying factors that affect air quality (Davis 2008). The results in Table 4 show the main results of five different bandwidths in Chengdu. It can be seen that when the bandwidth is 15, the coefficient of AQI is statistically positive at the 10 percent level. And the opening of rail transit has the positive effect on NO2, O3, PM2.5, SO2 and the results are statistically significant. It can be seen that the regression results in different bandwidths are consistent with the above discussion. Then we can draw a conclusion from the information, that is, the opening of rail transit in Chengdu can deteriorate local air quality.

INSERT TABLE 4

Similarly, the bandwidth is also adjusted to 15 days, 20 days, 25 days, 30 days, and 35 days respectively and Table 5 presents the estimated results of the narrower window before and after the opening date of Nanchang Metro in different bandwidth. We can see the opening of rail transit has negative effect on CO, NO2, PM2.5 at the 1 percent significance level. When the rail transit line is opened, the subway has a negative effect on SO2 but not statistically significant. However, when the bandwidth is 15, the coefficients of PM10 and O3 are statistically positive. It can be seen that the results in five different bandwidths are basically consistent with the above analysis.

INSERT TABLE 5

We may get significant effect on the estimations if we choose the treatment effect at the real cutoff, which could verify that it is the real cutoff, not other cutoffs, at work. A common approach to probe it is to estimate treatment effects at other cutoffs and compare them with the results at the real cutoff. In this subsection, we employ placebo checks for the assumed data in 2014 as the treatment groups to test the treatment effects at other cutoffs. Placebo checks, reported in Table 6 for the main outcomes, document that the Metro opening does not impact the air pollution statistically on 26th December, 2014, that is, the treatment effect at the assumptive cutoff is ineffective in improving air quality.

INSERT TABLE 6

### 4.4. Heterogeneity test

The results thus far have demonstrated the differential effect of the Metro’s opening on local air pollution in Chengdu and Nanchang. In this subsection we examine whether there are any environmental effects of the Metro opening by examining whether local air quality during peak or off-peak hour experiences large or small metro opening effects. To do so, we classify the sub-samples as peak hour and non-peak hour. Peak hour involves morning peak (6: 00-9: 00 am) and evening peak (17: 00-20: 00). We present evidence for heterogeneous results of ambient air pollutant in Table 7 and 8, respectively. The results include all weather covariables, month of the year, day of the week and hour of the day.

INSERT TABLE 7

We see very large differences in the concentrations of ambient air pollutant between peak and off-peak hours in Chengdu and Nanchang. The results in Table 7 indicate that Chengdu Metro Line 4 opening is positive and statistically significant at the 1 percent level for the six pollutants (CO, NO2, O3, PM2.5, PM10, SO2). The opening of Chengdu Metro Line 4 led to traffic creation effect, we can see little adjustments during peak hours. Our analysis of the effects of the opening of the Nanchang Metro Line 1 reveals two findings. First, compared with the regression results in the off-peak hour in Nanchang, the coefficients of air quality index AQI and some air pollutants, such as CO, NO2, PM2.5, PM10, are lower in peak hour. Second, results indicate significantly negative effects on air quality index (AQI) and three for six pollutants (CO, NO2, PM2.5). We find that the opening of the Nanchang Metro significantly reduced nitrogen dioxide from -27.489 (off-peak) to -29.137 (peak). Overall, the traffic creation effect coexists with traffic diversion effect in Nanchang Metro Line 1. This is consistent with the evidence that subway opening encourages some people to take the subway and thus reduce vehicle exhaust emissions and on the same time, the improved traffic conditions induce some people to travel more frequently and increase air pollution to some extent.

INSERT TABLE 8

## 5. Discussion

This paper focuses on the variations in concentrations of various air pollutants of the Chengdu and Nanchang by using the regression discontinuity design. For an easily understandable discussion, the changes in air quality of the Chengdu and Nanchang over the year 2014 to 2016 are depicted in Fig. 3 and Fig. 4, respectively. Consistent with statistical results (shown in Table 2), very different results can be observed in both cities. Furthermore, as presented in Fig. 5, mountain terrain surrounds Chengdu city, many counties and towns lie in the Sichuan Basin, which is unfavorable for pollutant dispersion while facilitating pollution accumulation under stagnant meteorological conditions. As presented in Fig. 6, Nanchang city, mainly to the plains, susceptible to monsoon climate, which are conducive to the diffusion of pollutants.

In this study, we empirically analyzed the influence of the opening of rail transit on CO, NO2, O3, PM2.5, PM10 and SO2 concentrations using urban air quality data from Chengdu and Nanchang over the period 2014 to 2016. We use the estimates of the effect of Metro opening on air quality in Table 3. Dividing these estimates by the corresponding averages one year before Metro opening date from Table 1 and then we can obtain estimates of the effect of rail transit lines opening on air quality. There are quite a few differences in statistical results between Chengdu and Nanchang city. Firstly, the total population in Chengdu has greatly exceeded that of in Nanchang, particularly, the population aged from 15 to 64 makes up almost half of the total, which has become the mainstay in inducing the demand of travel. And this metro line is a vital conduit between the east and the west, via universities (i.e., Southwestern University of Finance and Economics), health establishments (i.e., Chengdu University of TCM & Sichuan Provincial People's Hospital, Chengdu Second People's Hospital) and Chengdu West Railway Station. The high traffic volume usually takes place in relatively dense areas, which induce traffic congestion and thus increase air pollution. Secondly, after the opening of Chengdu Metro Line 4, the concentrations of CO, NO2, PM2.5, O3, PM10, SO2 are increased by 22.42%, 21.63%, 52.63%, -15.19%, 51.93%, 28.80%, respectively.

Compared with Chengdu, both the population density and pollution levels display discernible differences in Nanchang. As the end of 2018, Nanchang had a total population of 5.545 million, with a density of approximately 771 people per square kilometer, roughly half of that found in Chengdu. After the opening of Nanchang Metro Line 1, the average concentrations of CO, NO2, PM2.5, reduced by 10.23%, 0.48%, 22,24%, respectively, but O3, PM10, SO2 increased by 14.79%, 1.56%, 33.70%, respectively. It is worth mentioning that compared with Chengdu Metro Line 4, the opening of Nanchang Metro Line 1 decreased the concentrations of pollutants associated with vehicle exhaust. During the study, the automobile industry in Nanchang rose much more slowly than that in Chengdu. Nanchang's number of civil vehicles increased from 618,086 units in 2014 to 861,045 units in 2016. And Nanchang Metro Line 1 covers the geographical areas with the highest population density. The improved traffic condition works best in densely populated areas where many residents don't own cars. On the one hand, the expansion of subway network in Nanchang could lead some commuters living near the subway stations to prefer to subway. This traffic diversion effect may be conducive to alleviate people's travel pressure, and thus reduce automobile exhausted gas pollution. On the other hand, a completely new subway line's opening could offer more convenient mobility options and induce additional travel demand, resulting in the traffic creation effect. In addition, the evidence of robustness test cannot be ignored, which is discussed in detail below.

INSERT FIGURE 5

Table 3 presents the robustness test of temperature, pressure, wind speed and precipitation to Chengdu and Nanchang from 2014 to 2016. The meteorological conditions, such as temperature, pressure, wind speed and precipitation, are the important factors affecting the variations of concentrations of ambient air pollutant. The unfavorable topographic conditions with lower wind speed in Chengdu, which maybe present another possible factors for interpreting the increase of the levels of ambient air pollutant. Similar scenario take place in Taipei weather control smoothness tests (Chenyihsu and Whalley, 2012;Chen and Whalley, 2012). However, as the results in Table 3 reveals that not all of the control variables are smooth on the opening date we present further estimates to address the potential concern.

INSERT FIGURE 6

The study however has a couple of avail aments. First, we are not able to provide enough evidence for the efficiency of detection based on the limited number of rail transit lines. Thus, future work is needed to explore if transport plan at the city scale is possible for the impacts of rail transit on urban air pollution. Furthermore, air pollution is known to be sensitive to many factors such as the delay time of congestion, space range, amount of gasoline pumped and so on. We cannot confirm the precision of the results of statistical analysis since we find it hard to obtain the above information by official statistics. Lastly, although identification of one specific line could provide useful information to guide policy makers to the local traffic problems, put concrete environment concrete analysis, a single line could not map to the city's transport network and present temporal and spatial variation in traffic patterns.

## 6. Conclusions

Air pollution and traffic congestion are serious threats to health worldwide. Although empirical research was widely used in analysis for air quality, existing studies rarely examine air quality effects of rail transit in different cities. This paper aims to fill the gap by using hourly pollutant concentration data combined with weather controls in Chengdu and Nanchang for the period of 2014-2016.

Based on the regression discontinuity design, our findings reveal the following. The first discovery was that the concentrations of the main pollutant in the automobile exhaust reduced significantly after Nanchang Metro Line 1 opened, more specifically, carbon monoxide experienced a 10.23% greater reduction, but other atmospheric pollutants such as $O_3$，PM10，$SO_2$ may produce adverse environmental effects. The traffic creation effect coexists with traffic diversion effect in Nanchang. Second, carbon monoxide pollution led up to 22.42% after Chengdu Metro Line 4 and other forms of air pollution have also risen in varying degree. The opening of the Chengdu Metro Line 4 can provide no benefits in terms of air quality and even deteriorate air pollution. The traffic creation effect does matter in Chengdu. Nevertheless, our empirical findings suggest that the influence of rail transit relies on population density, climatic and topographical conditions. Future research could examine the impact of subway opening on urban spatial structure, location value and urban planning.

## Data availability

All data generated or analyzed during this study are included in this published article.

## Authorship contributions

Category 1
Conception and design of study:
Xueyuan Wang, Yuping Wang, Zhijian Zhang, Jingwei Li
Category 2
Drafting the manuscript:
Xueyuan Wang, Yuping Wang, Zhijian Zhang, Jingwei Li
Category 3
Approval of the version of the manuscript to be published (the names of all authors must be listed):
Xueyuan Wang, Yuping Wang, Zhijian Zhang, Jingwei Li

## Ethical approval and consent to participate

Not applicable

## Consent to publish

The authors of this manuscript grant the publisher of this manuscript the sole exclusive license of the full copyright, which the publisher hereby accepts.

## Conflict of interest

The authors declare no potential conflicts of interest with respect to the research, authorship and publication of this article.

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# Figures

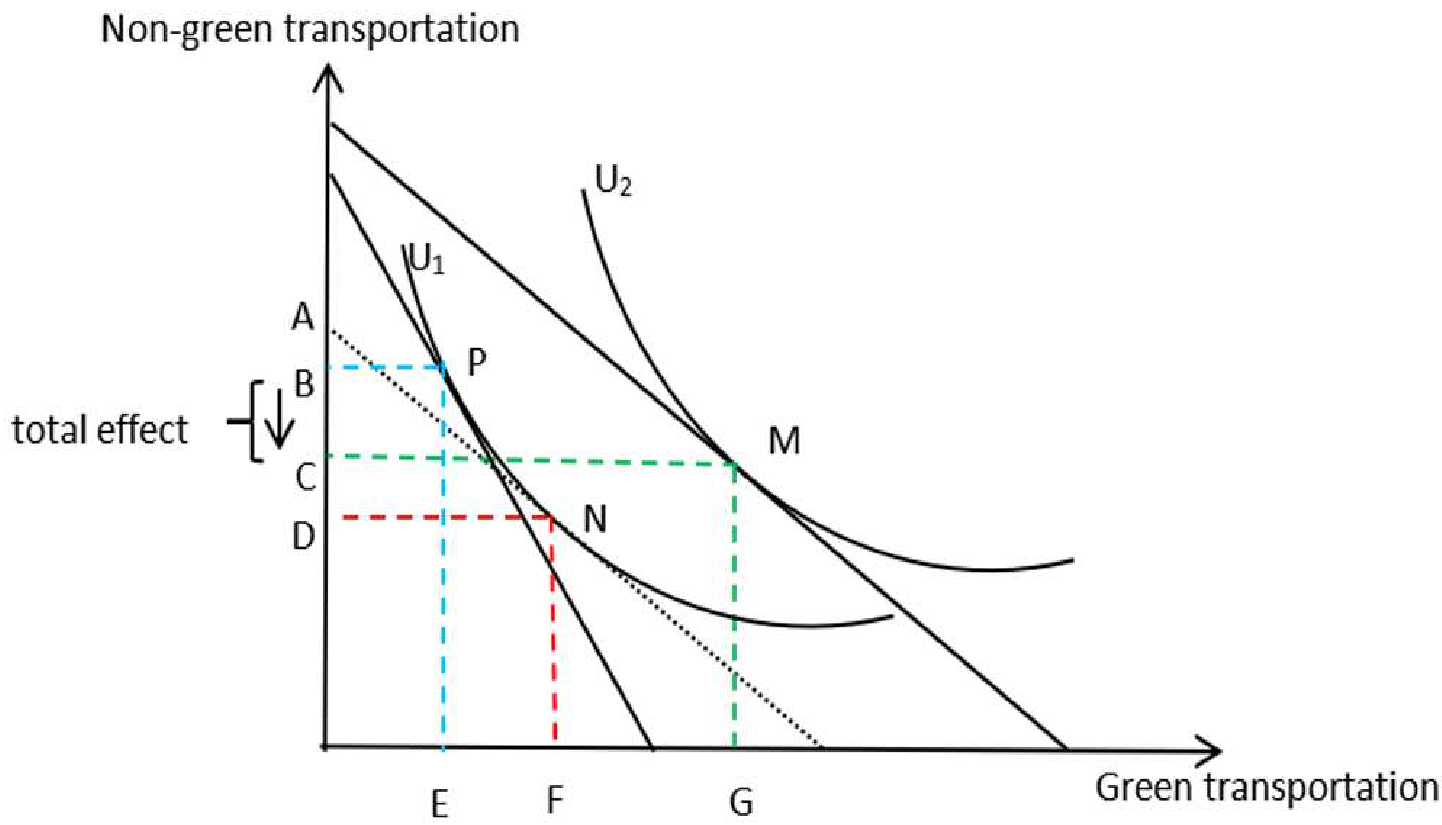


**Figure 1**

Traffic Diversion Effect

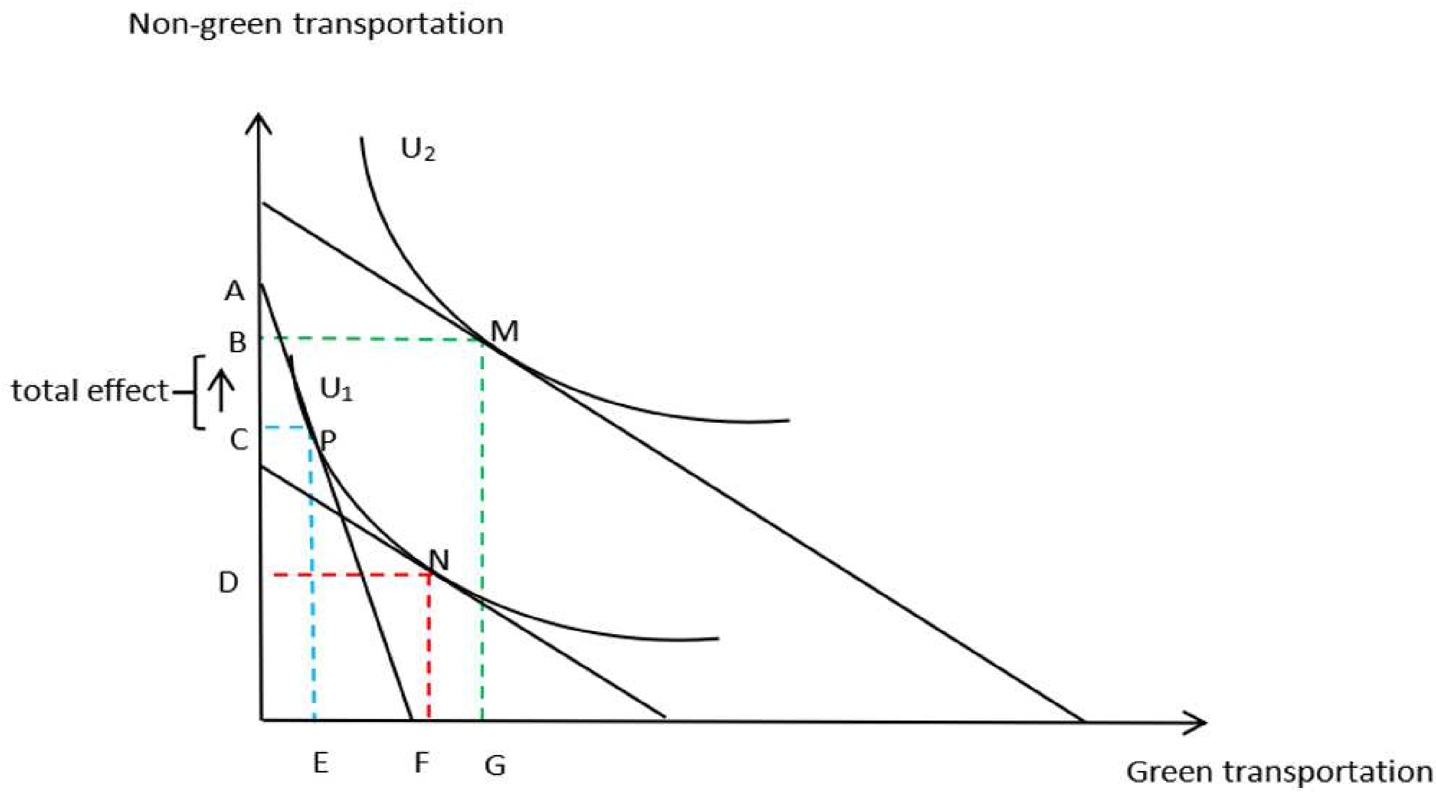


**Figure 2**

Traffic Creation Effect

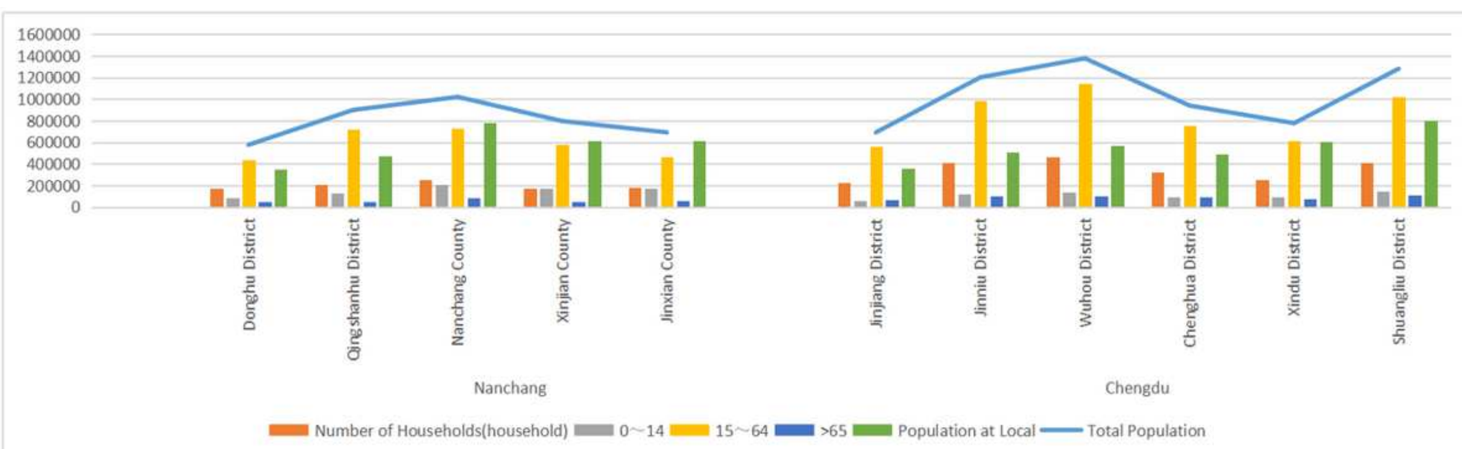


**Figure 3**

Number of households in Nanchang and Chengdu Source: http://www.stats.gov.cn/tjsj/ndsj/renkoupucha/2000jiedao/html/J36.htm

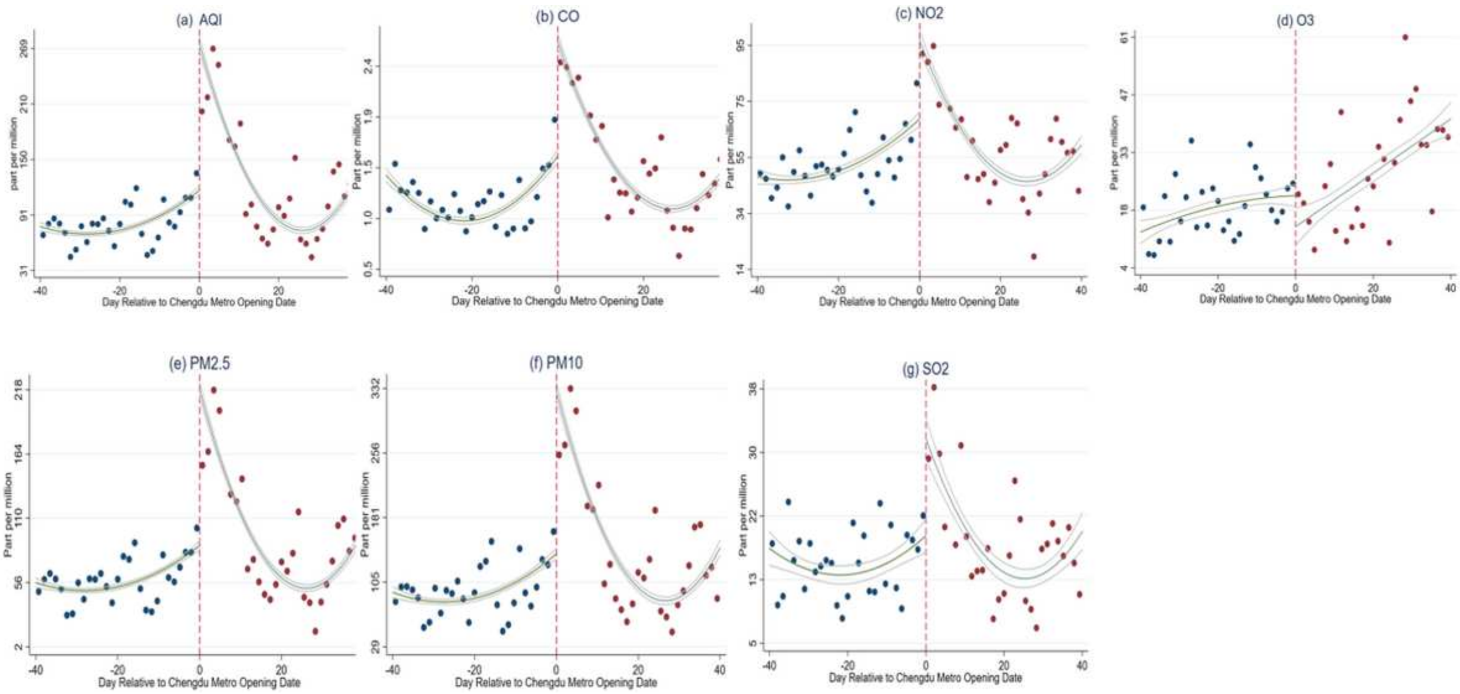


**Figure 4**

Distribution of changes in AQI and contaminants for 40 days relative to Chengdu Metro opening date: second-order polynomial fitting graph

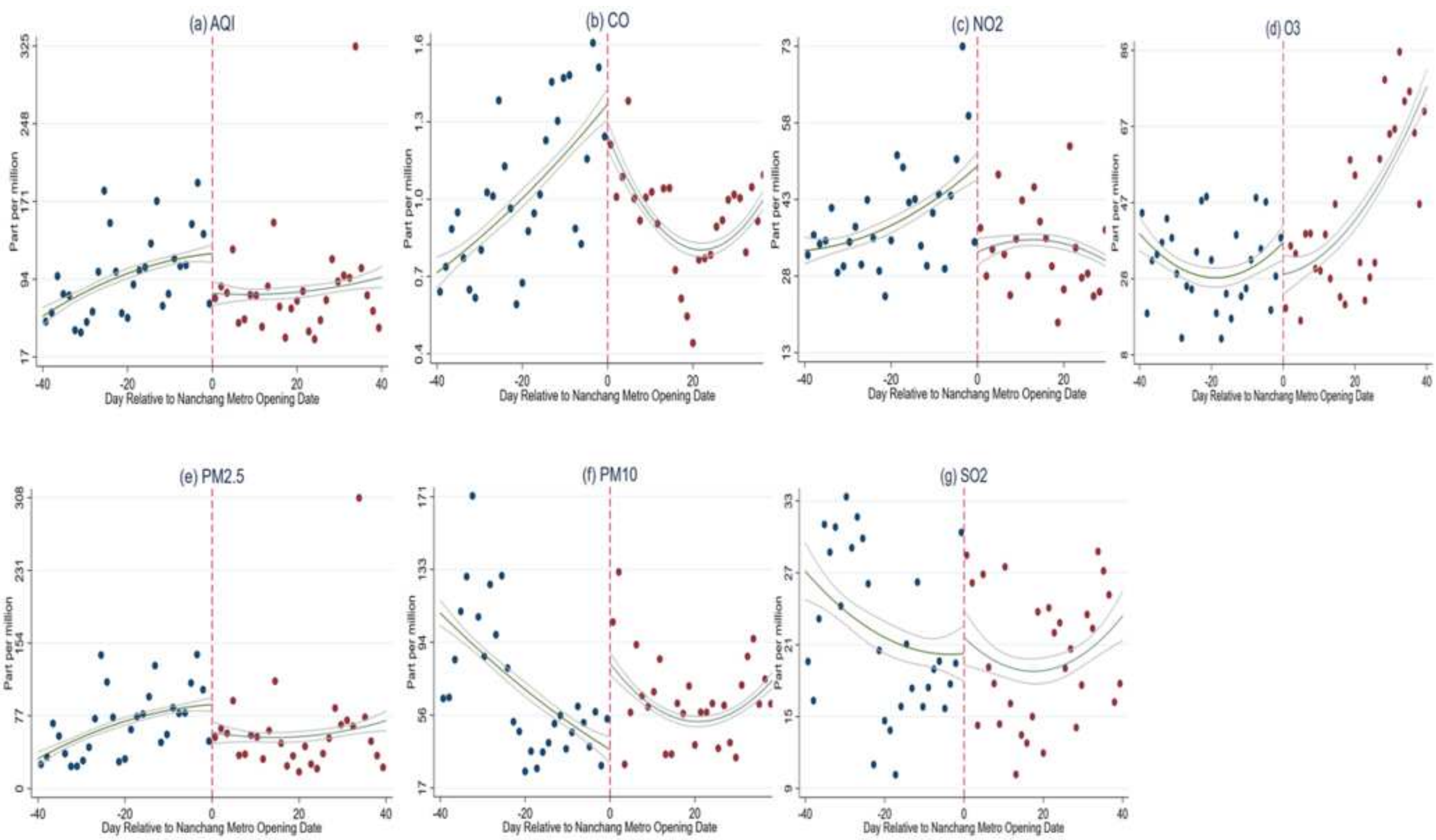


**Figure 5**

Distribution of changes in AQI and contaminants for 40 days relative to Nanchang Metro opening date: second-order polynomial fitting graph

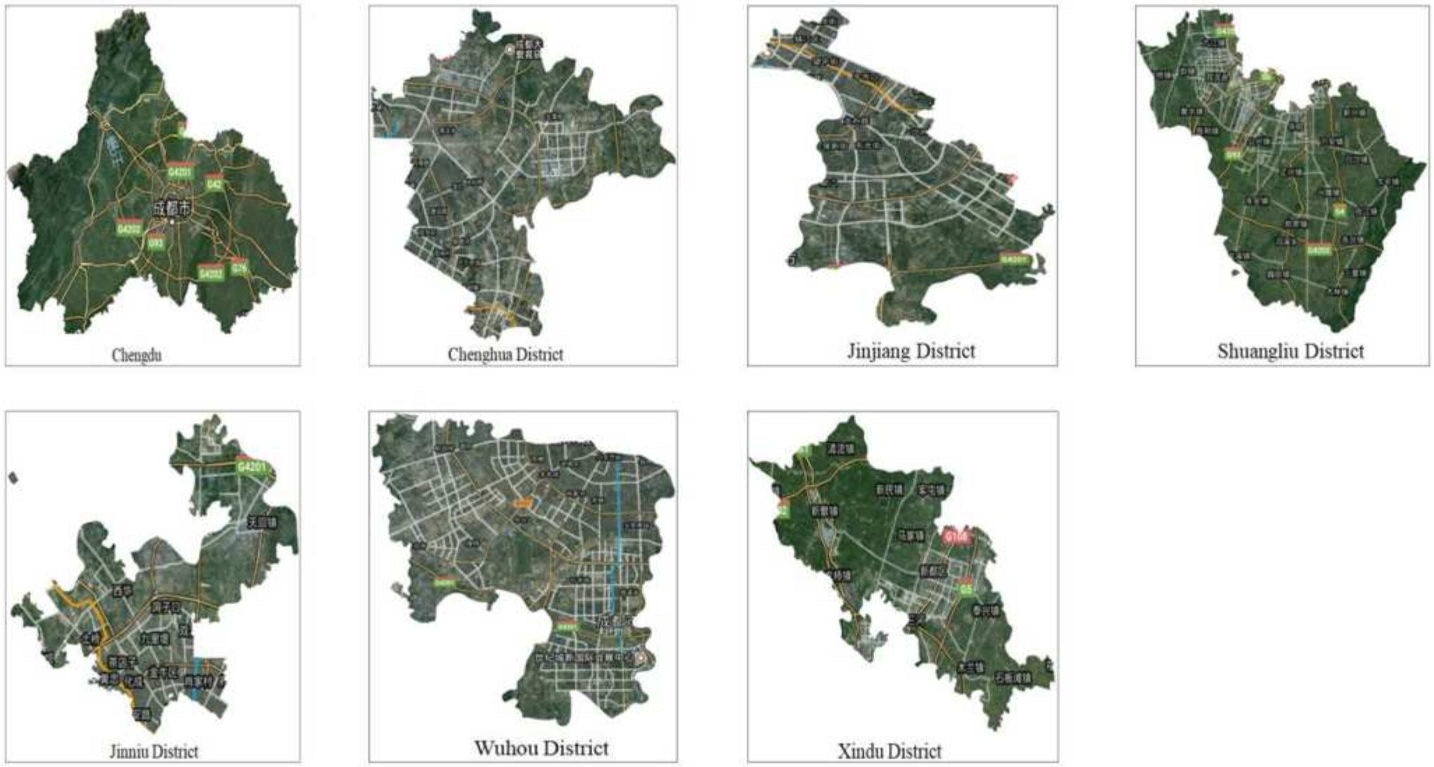


**Figure 6**

Characteristics of topography near Chengdu Metro Line 4 Source: http://www.bigemap.com/source/tree/satel-292.html Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

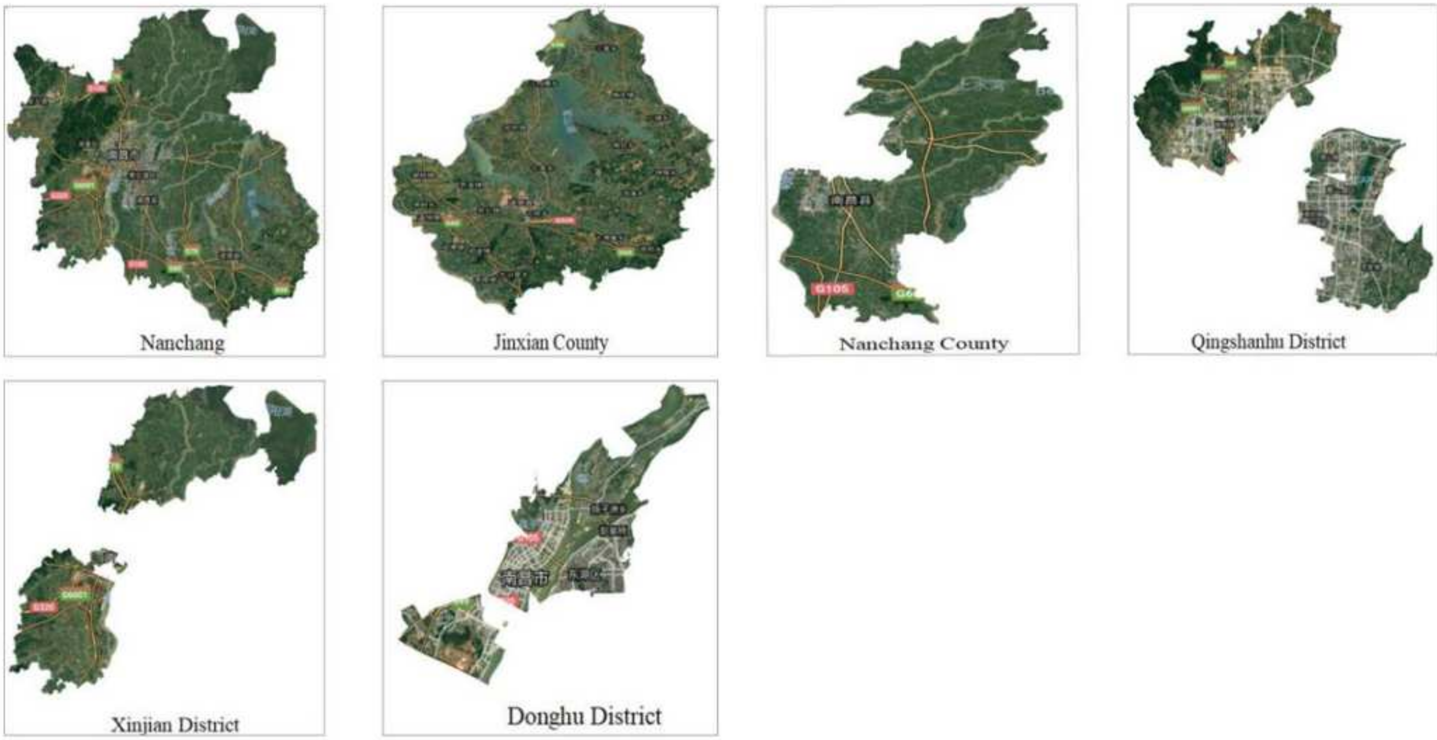


**Figure 7**

Characteristics of topography near Nanchang Metro Line 1 Source: http://www.bigemap.com/source/tree/satel-158.html Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

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