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REGRESSION ANALYSIS OF THE DEVELOPMENT AREA OF UNDERGROUND SPACE IN SHANGHAI

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Abstract: This article is based on the development history and current status of underground space in Shanghai. Using the annual development area of underground space in Shanghai as the dependent variable, SPSS analysis methods were employed to select data from 2016 to 2022. Independent variables such as population density, gross regional domestic product, average sales price of residential housing, and metro passenger volume were analyzed using linear regression. The main conclusions indicate that while population density, GRDP, and metro passenger volume jointly influence the development area of urban underground space, there is basically no interaction between them. However, GRDP and the average sales price of residential housing can significantly affect the development area of urban underground space.

Keywords: regression analysis; development area of underground Space; Shanghai

1. INTRODUCTION

Underground space is part of land resources, and its development and utilization strategies are related to urbanization processes, industrial structures, population policies, regional economies, and more. In September 2024, the Ministry of Natural Resources issued the Guiding Opinions on Exploring and Promoting the Rational Development and Utilization of Urban Underground Space, which mentions the need to "coordinate efforts to promote the reasonable development and utilization of urban underground space and fully tap into the potential of underground resources."

For many years, demand forecasting in quantitative methods for the development and use of urban underground space has been a challenge and focal point in both urban planning and underground space utilization WU Li-xin, JIANG Yun, LIANG Yue, XU Lei, CHEN Xue-xi, ZHU Wen-jun. (2004). Fundamental Research on Capacity Assessment of Development and Utilization of Urban Underground Space. Geography and Geo-Information Science, (04) , 44-47., especially with difficulties in data collection Nikolai Bobylev.(2010).Underground space in the Alexanderplatz area, Berlin: Research into the quantification of urban underground space use. Tunnelling and Underground Space Technology incorporating Trenchless Technology Research,25(5),495-507.. Therefore, analyzing relevant factors to predict the demands and trends in urban underground space development can aid in accurate planning and provide spatial support for high-quality economic and social development.

As China's economic and financial center, a global first-tier City and an international metropolis, Shanghai began the utilization of urban underground space resources in the mid-19th century, having gone through three stages: the germinal stage, a focus on civil defense, and a combination of peace and war considerations. Currently, it is transitioning from a high-speed development phase to a slower one.

By the end of 2023, there were a total of 43,639 underground projects completed citywide, with a total construction area reaching 155 million m², an average development intensity of 24,400 m² per km², and a per capita

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scale of 6.23 m². Since 2017, the annual newly added development scale of Shanghai's underground space has fluctuated between 4.44 million and 10.24 million m².

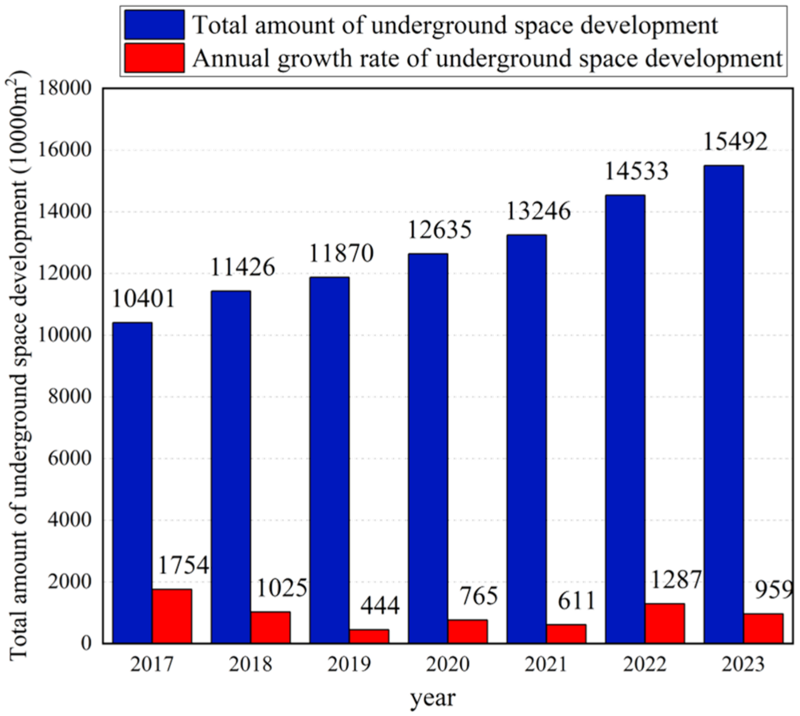

Figure 1. *Annual Development Volume and Yearly Growth of Shanghai's Underground Space from 2017 to Present*

In recent years, Shanghai has faced numerous changes in its urban planning and construction domains: urbanization development has shifted toward optimizing existing stock, the city has continued to grapple with severe imbalances in population age structure, macroeconomic growth has slowed down, and fluctuations persisted in the real estate market. Furthermore, the proportion of underground space used for rail transit has reached 7.8%, while the overall connectivity rate of underground spaces with surrounding areas stands at 36.7% MA Chen-xiao. (2023). Evaluation methods of spatial performance and planning optimization of urban underground space in the context of inventory land redevelopment. [Doctoral dissertation, Tongji University].. In terms of layout demands for underground space, based on the requirements outlined in the Shanghai Urban Master Plan (2017–2035), the city aims to further refine its overall underground space framework by leveraging rail transit networks and various public centers, with a focus on main urban districts, new towns, transfer hubs, and public activity centers ZHANG De-ying, LIAO Yuan-qin, ZHENG Geng-he. (2025). Analysis of population import status of five new towns in Shanghai from the spatio-temporal behavior perspective. Shanghai Land & Resources, 46(01):1113-1120..

2. RESEARCH METHODS

By reviewing related literatures HE Lei, DAI Shen-zhi, WANG Dai-xia, et al. (2018). Empirical study on forecasting the demand for the scale of urban underground space in Shanghai. Urban Planning, 42(03),30-40+58., it is concluded that a socioeconomic system generally includes three elements: gross domestic product, population, and real estate prices. In this analysis, Shanghai serves as the research subject, with the development area of urban underground space acting as the dependent variable. Factors such as population density, regional gross domestic product (GRDP), and average sales price of residential commodity housing are considered for selection as independent variables. Data analysis will identify appropriate independent variables using SPSS software to perform single-factor and multiple-factor linear regression based on the least squares method. This approach analyzes the relationships between the dependent variable and each independent variable. The conclusions drawn from these analyses will be used to predict future demands for urban underground spaces, thereby guiding their development and utilization.

2.1. Population density

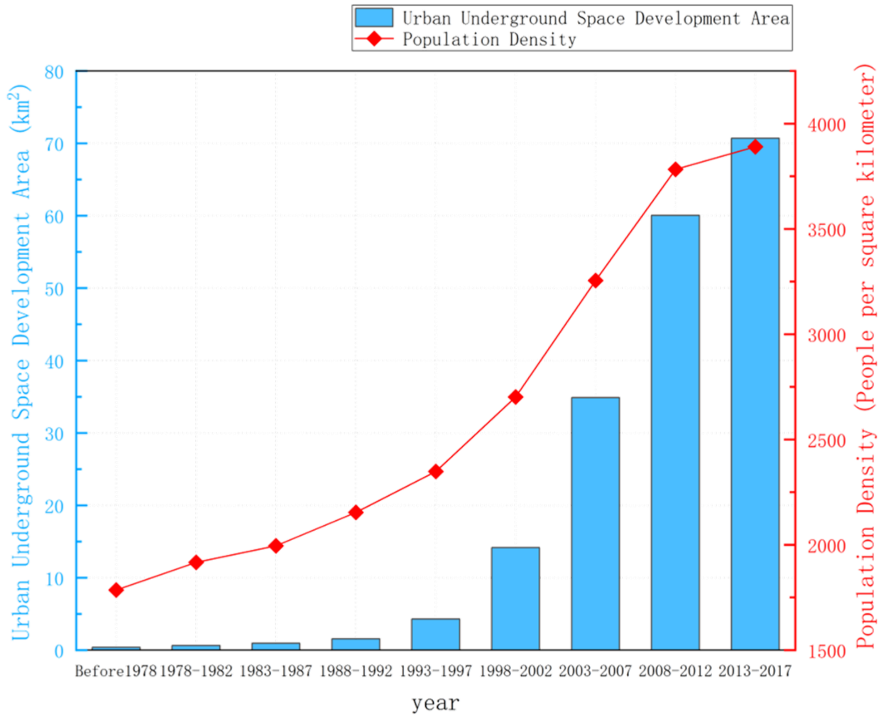

Figure 2. *Relationship Curve between Shanghai's Population Density and Urban Underground Space Development Area (1978–2017)*

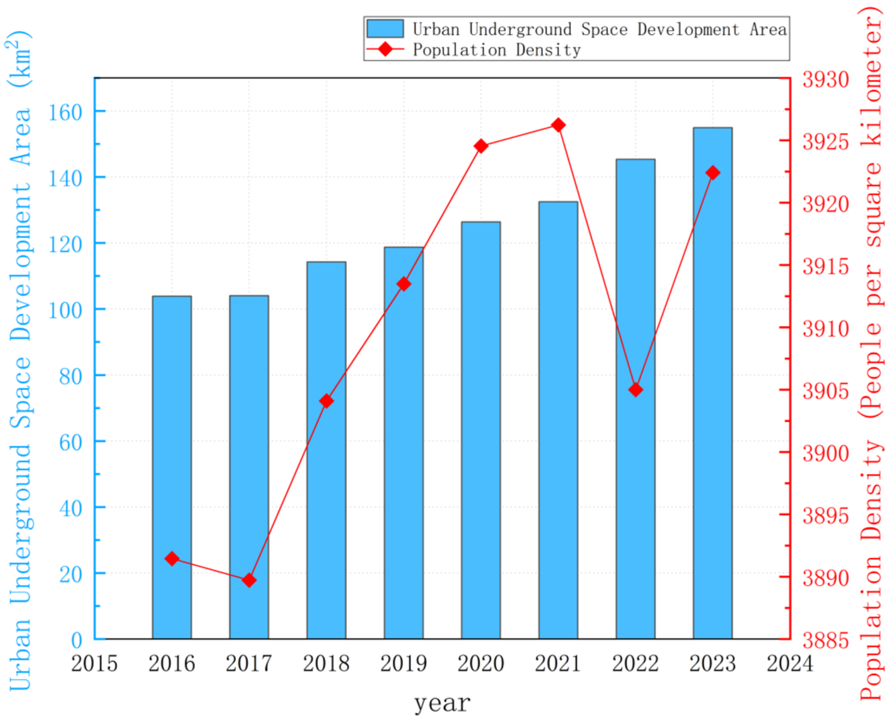

Figure 3. *Relationship Curve between Shanghai's Population Density and Urban Underground Space Development Area (2016–2023)*

Based on the above chart, it is evident that between 1978 and 2017, both the population density of Shanghai City and the development area of underground spaces were in a phase of rapid growth. Additionally, their growth trends are quite similar, suggesting there exists a certain influential relationship between them, which is relatively close to being linearly correlated.

Between 2016 and 2023, the development of underground spaces in Shanghai also experienced a growth phase. However, unlike previous periods, the rate of increase was relatively slow. While population density continued to grow, it showed some fluctuations in certain years, which preliminary analysis suggests may be due to factors like the pandemic. These anomalies could significantly impact subsequent regression analyses.

2.2. Regional gross domestic product

In light of the need to conduct a multivariate regression analysis on the development area of Shanghai's urban underground space and its various influencing factors, measures should be taken to avoid issues of multicollinearity that could lead to inaccurate results. Therefore, for economic factors, it selects Shanghai's GRDP rather than per capita GDP.

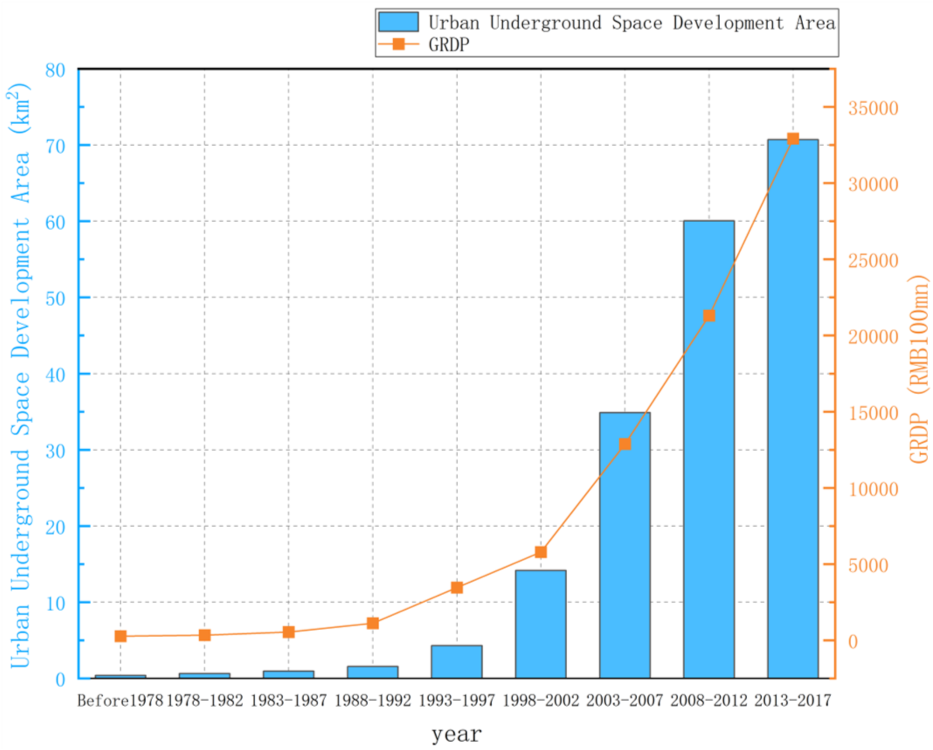

Figure 4. *Relationship Curve between Shanghai's GRDP and Urban Underground Space Development Area (1978–2017)*

Based on the above chart, it is evident that from 1978 to 2017, Shanghai's GRDP was also in a phase of rapid growth, similar to its population density. It can be preliminarily judged that there exists a relationship akin to linear correlation between the region's gross domestic product and the development area of underground space.

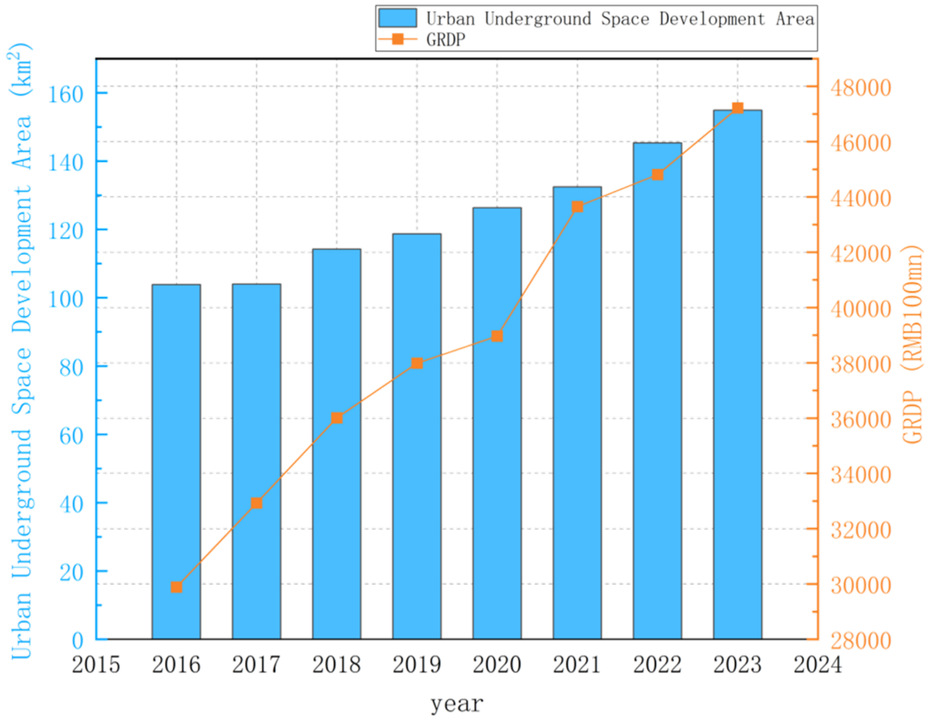

Figure 5. *Relationship Curve between Shanghai's GRDP and Urban Underground Space Development Area (2016–2023)*

Between 2016 and 2023, both the GRDP of Shanghai and the development area of underground spaces experienced growth phase. However, the trend for the expansion of underground space development gradually slowed down.

2.3. Average sales price of residential commodity housing

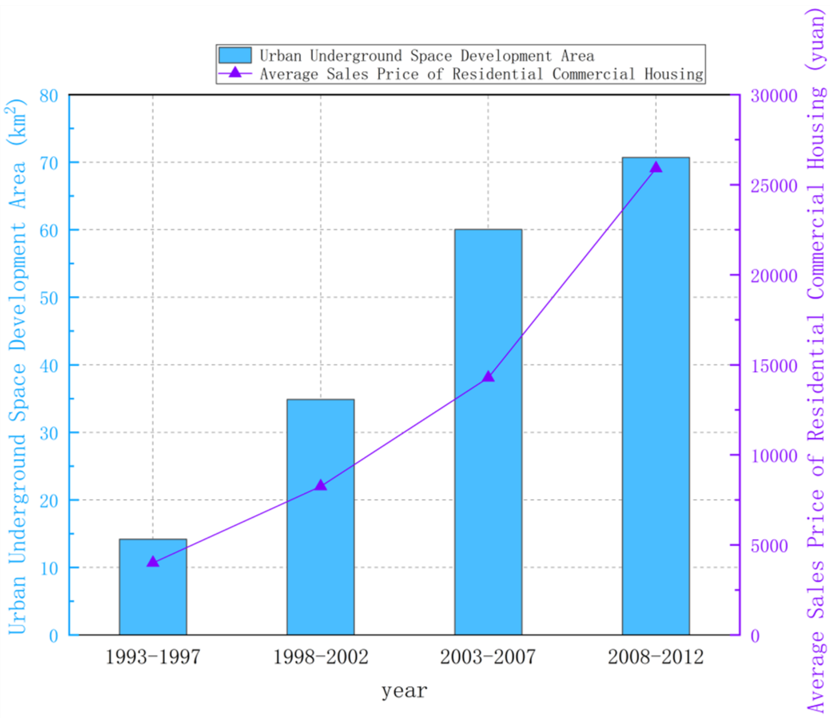

Figure 6. *Relationship Curve between the Average Sales Price of Residential Commodity Housing in Shanghai and Urban Underground Space Development Area (1993–2012)*

Based on the above chart, it can be observed that from 1978 to 2012, the average sales price of residential commodity housing in Shanghai was also in a rapid growth phase. It is preliminarily judged that the average sales price of residential commodity housing is one of the factors influencing the development area of underground spaces.

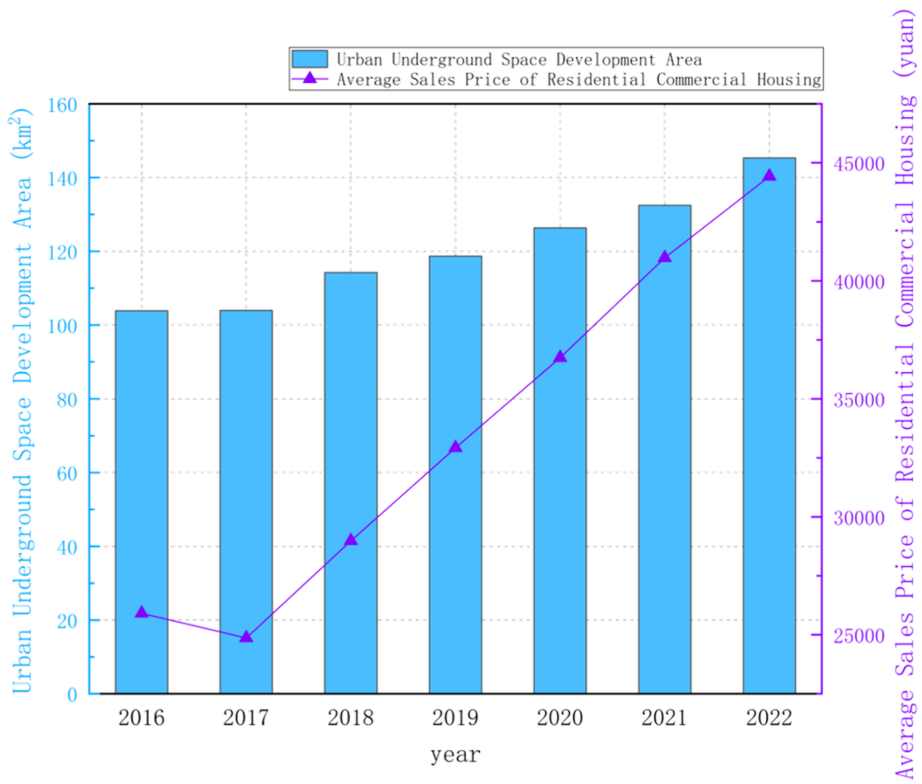

Figure 7. *Relationship Curve between the Average Sales Price of Residential Commodity Housing in Shanghai and Urban Underground Space Development Area (2016–2022)*

From 2016 to 2022, with the exception of a few years that saw slight declines, the overall average sales price for residential commodity housing in Shanghai remained in a phase of rapid growth.

2.4. Rail transit passenger volume

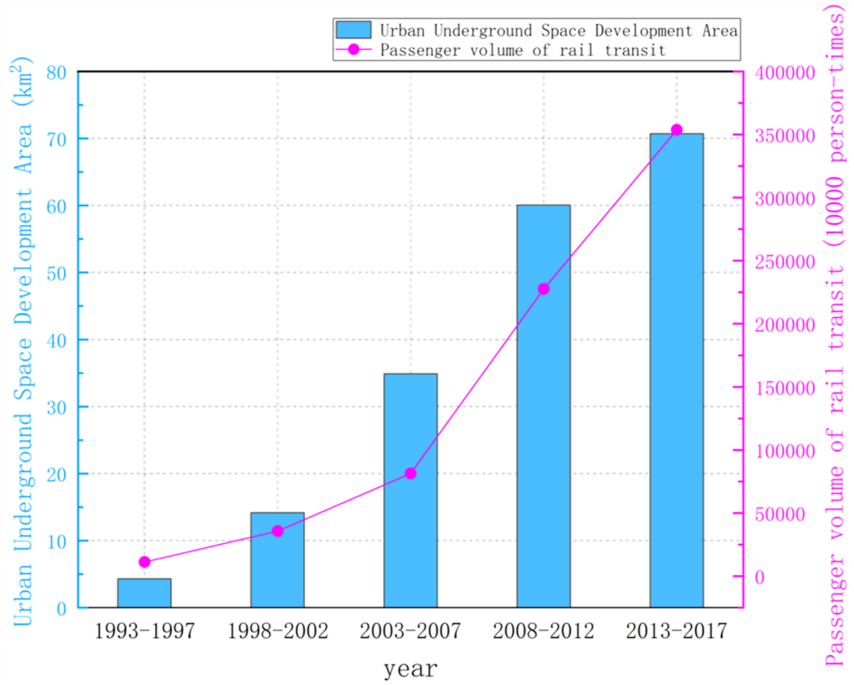

Figure 8. *Relationship Curve between Subway Passenger Volume in Shanghai and Urban Underground Space Development Area (1993–2017)*

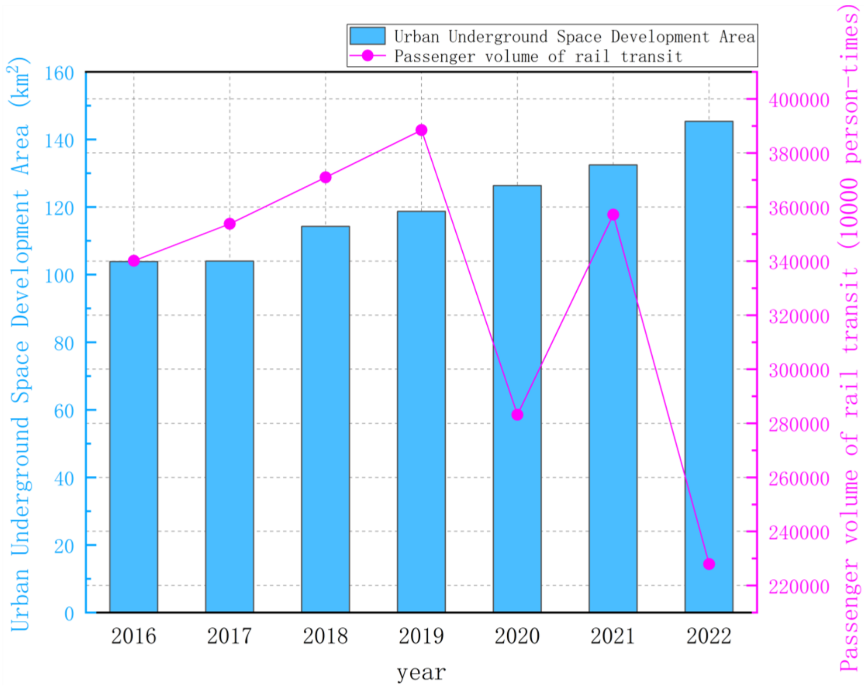

Figure 9. *Relationship Curve between Subway Passenger Volume in Shanghai and Urban Underground Space Development Area (2016–2022)*

According to the above two pictures, it can be seen that from 1993 to 2017, passenger volume of Shanghai's rail transit also experienced rapid growth. Similarly, passenger volume of rail transit should be considered as one of the factors influencing the development area of underground spaces.

Between 2016 and 2022, the passenger volume of Shanghai's rail transit system exhibited trends similar to those of population density. During certain years, there was noticeable volatility, with an overall decline observed. This volatility primarily occurred between 2019 and 2022, suggesting that factors such as the pandemic likely played a significant role in these fluctuations.

2.5. Operating mileage of rail transit

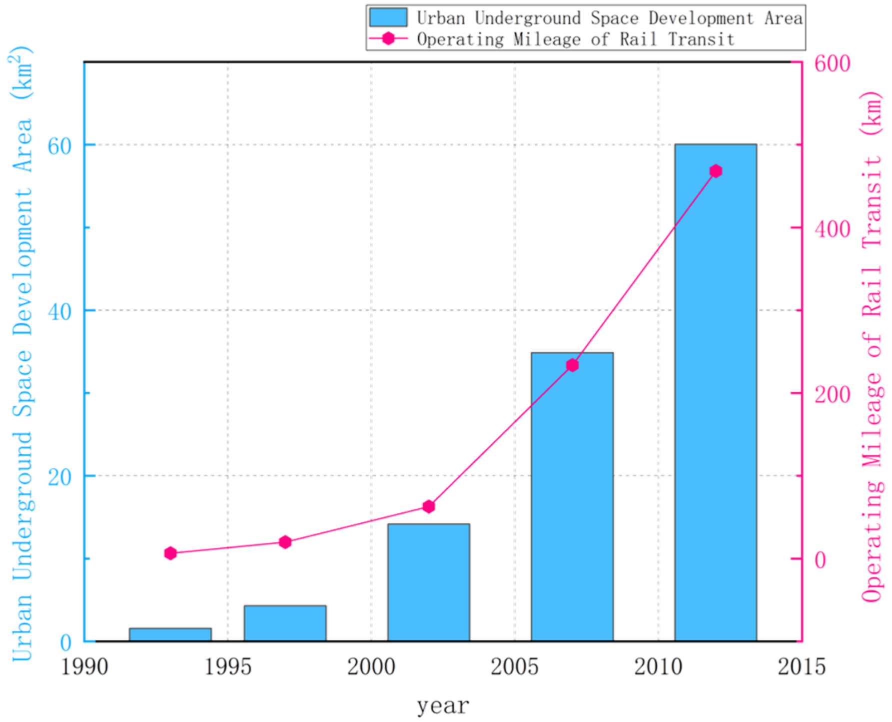

Figure 10. *Relationship Curve between Operating mileage of rail transit in Shanghai and Urban Underground Space Development Area (1993–2012)*

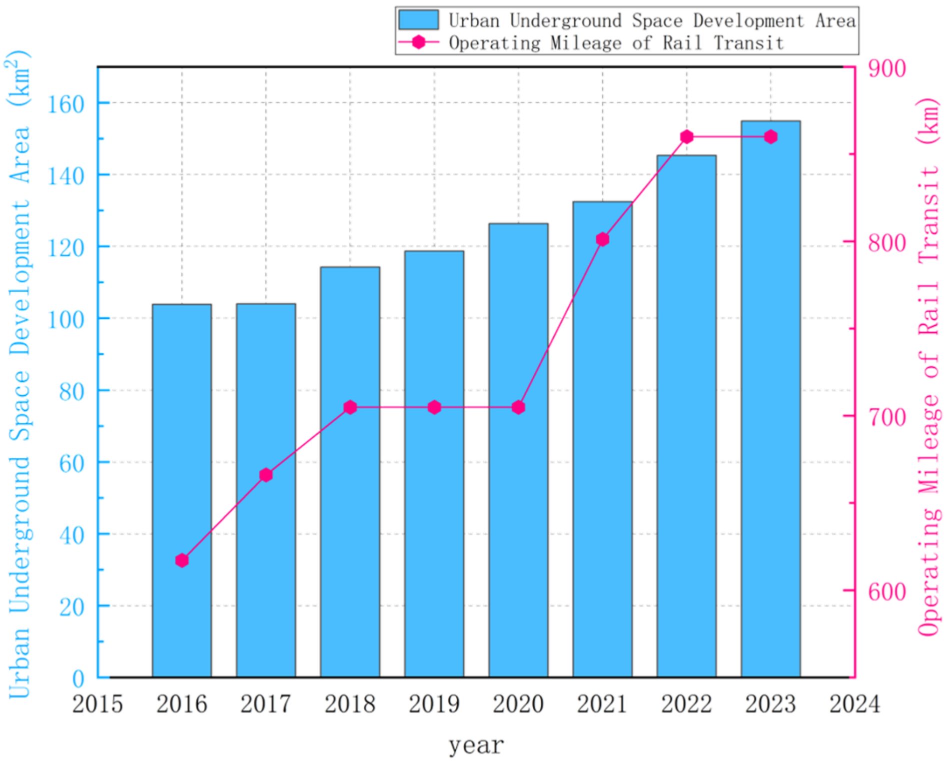

Figure 11. *Relationship Curve between Operating mileage of rail transit in Shanghai and Urban Underground Space Development Area (2016–2023)*

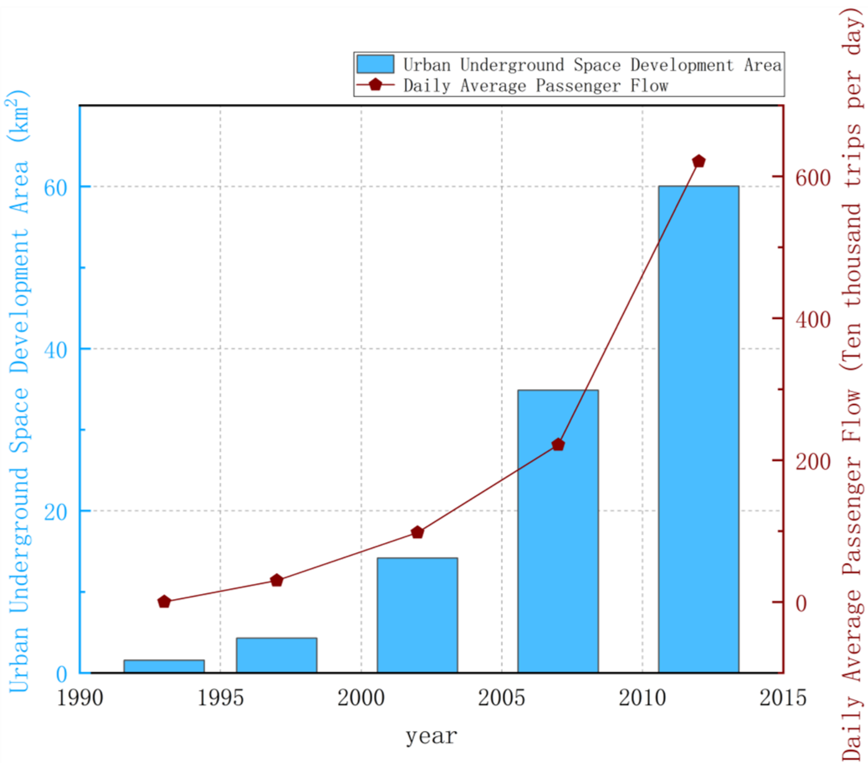

Figure 12. *Relationship Curve between Daily Average Subway Ridership in Shanghai and Urban Underground Space Development Area (1993–2012)*

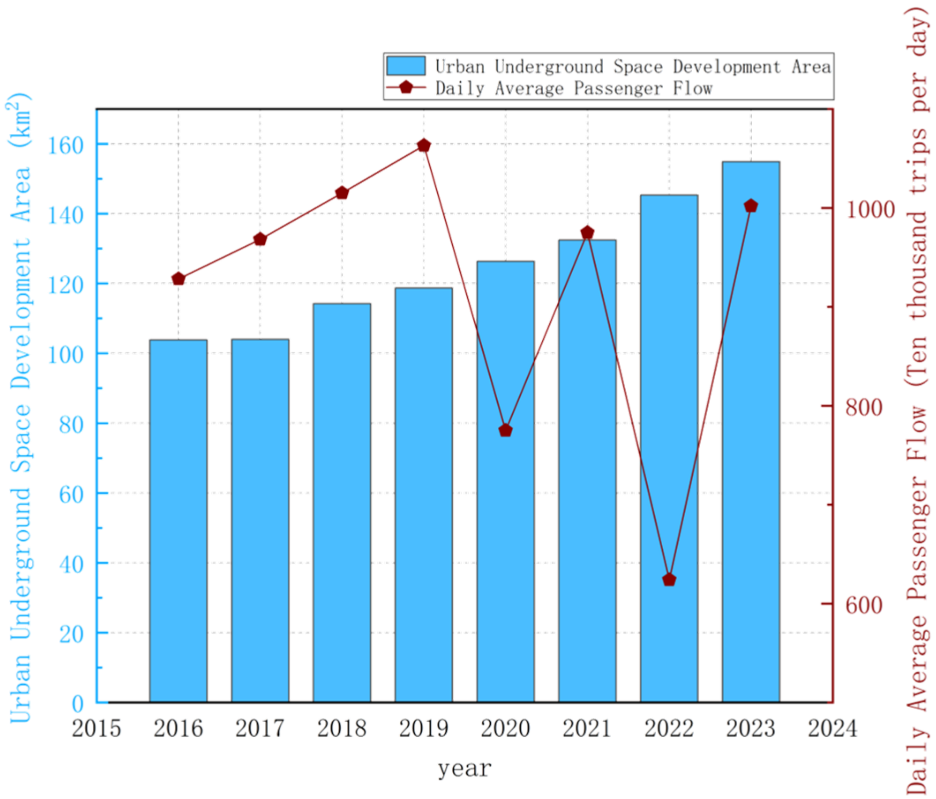

Figure 13. *Relationship Curve between Daily Average Subway Ridership in Shanghai and Urban Underground Space Development Area (2016–2023)*

After analysis, it is determined that there is a significant correlation between the total length of Shanghai's subway lines, average daily subway ridership, and overall railway passenger volume. Therefore, one variable was chosen among them; "railway passenger volume" was selected due to its broader scope and encompassing nature as an independent variable. Meanwhile, "subway line mileage" and "average daily subway ridership" are used for auxiliary analysis and supplementary explanation.

Based on the data analysis results, it is found that there exists a certain correlation between these independent variables and the scale of urban underground space development. Consequently, four independent variables were preliminarily selected: population density, GRDP, average sales price of residential commodity housing, and railway passenger volume. The sample data range from 2016 to 2022 for linear regression analysis.

3. RESEARCH RESULTS

3.1. Single factor regression

Firstly, the population density, GRDP, rail transit passenger volume and the average sales price of residential commodity housing are analyzed by single factor regression analysis with urban underground space development area, according to the results, the degree of influence is analyzed, and the significant factors are combined with the development area of urban underground space for multi-factor analysis.

Table 1. *Summary of Single Factor Regression Analysis Results*

Influence factor	Significance	Coefficient	Constant	Linear relationship
Population Density（x_1）	0.131	655815.246	-2442075035	$y = 655815.246x_1 - 2442075035$
GRDP（x_2）	<0.001	2717.238	18142557.27	$y = 2717.238x_2 + 18142557.27$
Rail Transit Passenger Volume（x_3）	0.105	-178.423	179889435.7	$y = -178.423x_3 + 179889435.7$
Average Sales Price of Residential Commodity Housing（x_4）	<0.001	2000.216	53612237.42	$y = 2000.216x_4 + 53612237.42$

The table shows that while population density and railway passenger volume have some impact on the development area of urban underground spaces, this influence is not significant. In contrast, GRDP and the average sales price of residential commodity housing significantly affect the development area of urban underground spaces.

3.2. Multiple factor regression

The analysis was conducted using four independent variables: population density, GRDP, railway passenger volume, and the average sales price of residential commodity housing. The model summary is shown in the table below.

Table 2. *Multiple Regression Analysis Model Summary*

Overview	Adjusted R^2	Durbin-Watson value
Variable：Population Density、GRDP、Rail Transit Passenger Volume、Average Sales Price of Residential Commodity Housing Dependent variable：Urban Underground Space Development Area	0.981	2.491

According to the table, 98.1% of the variation in urban underground space development area can be explained by the combined influence of population density, GRDP, railway passenger volume, and the average sales price of residential commodity housing. Additionally, the Durbin-Watson statistic is around 2, indicating that the samples for these four independent variables are mutually independent and there is no mutual influence among them.

Table 3. *Summary of Multiple Regression Analysis Results*

Influence factor	Significance	Coefficient	VIF
Population Density（x_1）	0.623	-61184.526	3.194
GRDP（x_2）	0.275	1108.445	21.619
Rail Transit Passenger Volume（x_3）	0.363	-34.548	3.727
Average Sales Price of Residential Commodity Housing（x_4）	0.228	1156.133	34.171
Constant	290641379.2		

From the analysis results, it is evident that the VIF values for GRDP and average residential commodity housing sales prices are excessively large. This suggests a mutual influence between GRDP and the average residential commodity housing sales price. Consequently, only one variable should be retained. Here, we choose to retain the GRDP and eliminate the average residential commodity housing sales price before conducting the regression analysis again. The results are as follows:

Table 4. *Summary of Multiple Regression Analysis Results*

Influence factor	Significance	Coefficient	VIF
Population Density（x_1）	0.819	29528.021	2.406
GRDP（x_2）	0.008	2295.177	3.089
Rail Transit Passenger Volume（x_3）	0.058	-73.409	1.551
Constant	-56967866.1		

After multiple regression calculations, the results indicate that the significance level P-value for GRDP is 0.008 < 0.05, and for rail transit passenger volume, it is 0.058, approaching 0.05, suggesting statistical significance at this level. We reject the null hypothesis that the regression coefficient is zero, indicating that the model essentially meets the requirements. Furthermore, all VIF (Variance Inflation Factor) values are below 10, with strict VIF values being less than 5, confirming there is no issue of multicollinearity. Therefore, the model construction is sound.

Based on the calculated coefficients for population density (x_1), GRDP (x_2), and railway passenger volume (x_3), the linear relationship between these three independent variables and urban underground space development area can be expressed as:

$$y = 29528.021 x_1 + 2295.177 x_2 - 73.409 x_3 - 56967866.1$$

4. CONCLUSION

1. Single factor regression analysis shows that population density and rail transit passenger volume have some impact on the development area of urban underground spaces, but these effects are not statistically significant. In contrast, GRDP and the average sales price of residential commodity housing significantly influence the development area.

2. The results of the multiple regression analysis indicate that GRDP and rail transit passenger volume have a significant impact on the development area of urban underground spaces. In comparison, population density has a relatively smaller influence. Together, these three factors can explain 98.1% of the variation in the development area of urban underground spaces, with a small remaining portion possibly influenced by other minor factors.

3. Under certain conditions, based on the linear relationship between the three independent variables and the development area of urban underground spaces, it is possible to preliminarily predict the demand and developmental trends for urban underground space. This provides some reference for rationally planning the development of such spaces.

ACKNOWLEDGMENTS

First and foremost, I would like to extend my most sincere gratitude to Professor Zhu Lei, the corresponding author of this thesis. Throughout the research process of the thesis, Dr. Zhu provided systematic guidance and constructive suggestions on the precise positioning of the research topic, the scientific control of the research direction, the in-depth guidance on data analysis, and the key links of thesis revision and improvement. Her professional competence and rigorous attitude laid a core foundation for the successful completion of the thesis and made outstanding contributions. At the same time, I sincerely thank the Shanghai Natural Resources Research Center for providing research funding for this study. The funding support has provided an important guarantee for the orderly conduct of the research work, data acquisition, analysis and verification, ensuring the smooth progress of this study.

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