Analysis of the vitality measurement and correlation factors of urban waterfront space

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Abstract. The long-term development of the city benefits from the creation of space vitality, and the vitality of waterfront space is an important factor that constitutes the city's characteristic landscape. This paper uses mobile phone signaling data to measure the development trend of waterfront space from the perspective of crowd vitality through nuclear density analysis, paired sample test, and OD matrix analysis. In addition, the influencing factors of waterfront space development differences are measured by Geographic Weighted Analysis (GWR), so as to provide scientific theoretical basis for the layout of waterfront space construction in new cities. The study found that the construction of the waterfront space of the Qijiang River shows the trend of waterback development. The vitality of the waterfront space at different moments shows that the waterback trend of the waterfront space is more obvious during the day. And the main influence mechanism of the vitality of the waterfront space shows that the vitality of the waterfront space has a great correlation with the public service and commercial land, green space, residential land, the diversity of public facilities, the number of residents and the density of the road. Therefore, it is necessary to put forward the development strategy of waterfront space to optimize the regional development.

1. Introduction

With the emergence of the post-industrial age, the function of waterways and waterfront spaces in many cities has shifted from serving as main transportation channels and ports to leisure areas. It is believed that waterfront areas provide opportunities for a large number of urban renewal projects, to make cities more attractive and create new spaces for living, working, and recreation [1] [2]. In this context, many cities in the Pearl River Delta will take the riverside, the bay, and the waterfront as strategic areas to improve the quality of the city and display its characteristics. Relevant plans such as the design of the Guangzhou Pearl River bank, the transformation of the coastal river in Shenzhen, the "Nine Bay" space design in Zhuhai, and the Seven Rivers in Zhongshan show the importance of the city's "to the water" development. On the other hand, however, “despite well-designed waterfront spaces, the public utilization rate is still low, resulting in a lack of urban vitality ” [3]. The low-level construction and overdevelopment in urban development have caused serious waste and destruction of the resources on the bank[4]. Urban roads separate the waterfront space from the city, and the dense logistics and storage bases and wholesale markets on the docks have largely hindered the landscape and experience of the water itself. All these have led to the "waterback" development trend of urban production and life.
However, the development of urban "to the water" or "waterback" development is more of an empirical judgment, and there is no conclusive data to confirm its related factors. Therefore, the vitality measurement of waterfront space, that is, using a data or a method to measure the vitality of waterfront space, can better judge the development of urban "to the water" or "waterback" development of waterfront space.

“Since the post-industrial era, waterfront projects are criticized for offering a kind of bread-and-circus imaginary to the public paying for their design, engineering, construction and maintenance [5], while those who benefit most from such waterfront space investments are the private property owners who develop housing, commercial and retail uses at or adjacent to such sites[6]” [7]. However, there are still many successful cases of waterfront space revival. The regeneration of waterfront space on the Hudson River in Lower Manhattan, New York, USA is a good example. It shows that a more comfortable small grid and urban core living areas supported by business, commerce, residence, tourism and other functions are more attractive than the coastal highways and super-large buildings and other port terminals, warehousing logistics, shipyard industry and other production areas.

Of course, the shaping of the above-mentioned waterfront space and the enhancement of the coastal vitality is only qualitative analysis and based on experience. The impact of such factors as road network, land use and function on the vitality of waterfront space in those success stories is not supported by relevant data research.

In recent years, under the trend of digitalization, the concept of cities is changing, the development needs of cities are constantly being updated, so the urban design methods also need iterative evolution, and high-quality, fine design. “The era of information explosion generated by digital technology and novel data sources has recorded almost all human activities” [3]. Many scholars have carried out multi-angle research work using big data, which has provided great help in exploring the law of urban development and the status of cognitive space development. Existing studies have analyzed the physical space factors and social environmental factors that the vitality of the city. The studies include land use, suitable building density, humanization scale, mixed function, street connectivity, network relationship and fractal characteristics of urban texture, etc. The literature shows that the built environment of the city will have a significant impact on the general regional vitality [8] [3].

In the process of urban waterfront renewal, research on the relationship between waterfront space and cities is not uncommon. However, they focus on the transformation of the function of the waterfront space [9], with a focus on leisure, sightseeing and leisure, cultural conservation, marine research and ecological experience [10]. The quantitative research of waterfront space based on the user's angle is obviously inadequate, and the use of geographically weighted regression model (GWR) is obviously insufficient. It is rare to study the spatial heterogeneity of the factors influencing the vitality of the waterfront space. Therefore, this paper attempts to use multi-source data, make vitality measurement to test the state of "to the water" or "waterback" in urban waterfront areas. And this paper carries out quantitative analysis from the aspects of location, land use, facilities and population, and find the correlation factors of waterfront space. And further explore the built-up environmental factors that affect the dynamic development of heterogeneous waterfront space.

2. Research methods and sources of data

2.1. Sources of data

Regarding the study of urban structure from the perspective of behavioural activities, traditional techniques are either based on a small sample survey or based on statistics such as censuses. Mobile phone signalling data records the daily behaviour of each user and the way they use urban space. Therefore, the combination of all mobile phone signalling data of the time and space law, can be used to study the structure of urban space.

This paper selects 10 consecutive days of Zhongshan City mobile phone signaling (taken from November 2018), which contains about 921.1 million non-commuter OD data, as well as 2.113 million per-time dynamic point data. These data are used to analyze and evaluate the characteristics of the
dynamic use of the watersurface space of the Qijiang River. Using simultaneous mobile cell phone signaling data to extract 12030 residence data, to count the waterfront space resident population.

This paper counts the current construction land area within the scope of the study and uses it to characterize the differentiation of unit land of waterfront space. This paper obtains about 1023 million facilities data of large-scale public service facilities in the waterfront space of the Qijiang River through the Gaode MAP (An open map data source that includes maps, positioning, navigation, and route planning) POI, and uses it to characterize the functional diversity and agglomeration of the waterfront space, and analyzes of the influence of urban public facilities layout on the vitality of the waterfront space of the Qijiang River. Through the Gode Map API, this paper obtains the minimum driving time from each research unit to the center of Zhongshan and town centers, and is used to characterize the centrality of the waterfront space location.

2.2. Research methods
The research first measures the vitality of waterfront space through mobile phone signaling data to evaluate the current status of waterfront space development. According to Jan Gehl’s theory [11], measuring the level of vitality in a location can be based on whether the location provides enough potential opportunities for interaction, that is, the ability of space to gather active groups, so the ability to gather is the most direct manifestation of space vitality. The activities of people in space always change dynamically with time, and the length of time the activity gathers also reflects the vitality of the space. That is, in the morning, day, noon, and night of the day, the crowd gathering activity reflects the dynamic characteristics of space. To this end, the mobile phone signaling data of the waterfront space for ten consecutive days was selected, and ArcGis was used for spatial positioning. The core density and SPSS mean comparisons were used to analysis of the overall vitality aggregation characteristics, statistical analysis of the dynamic aggregation characteristics of time period. Measure and interpret the current development characteristics of waterfront space.

In terms of causal mechanism analysis of the vitality of waterfront space, the regression analysis is carried out from the dimensions of waterfront space location, land use, facilities and residential population, which includes the proportion of urban construction land, unit residence, facility diversity, road network density and location center degree, including public facilities land, green space, residential land, industrial storage land, etc. And through geographically weighted regression, the influence mechanism of the physical environment in the waterfront area on the spatial vitality is analyzed (see Figure 1).

![Figure 1. Methodology Frame.](image-url)
2.3. Classic documentation
This paper selects Zhongshan Qijiang River as the object of study. Qijiang River is Zhongshan's mother river, with a total length of 39 kilometers. It runs through the urban area of Zhongshan city. The waterfront area of The Qijiang River is an iconic area of the formation and development of Zhongshan City, which embodies the human and historical style of Zhongshan Old Town. Now Zhongshan Qijiang River through the policies such as the “governance of the Qijiang River, dress up the mother river”, "one river on both sides" and other policies and planning improvement, has become a window to show the history and culture of Zhongshan and its cultural features. Therefore, the Qijiang River and its waterfront space were chosen as the research object.

In order to measure the water affinity of the basic activities of the city, the scope of this study is the waterfront space (about 92km²) and its outer bank 500 meters (5min walking range), and selected the outer 500-1000 meters of the bank as the waterfront periphery space (about 67km²) and compare with it. Finally, the space unit is divided into space units at a width of about 500 meters (a total of 666) for further study.

3. Analysis of the spatial vitality of the waterfront lot

3.1. Dynamic space aggregation features
This article takes the data with the same destination (D) in the mobile phone signaling non-commuting OD data as the total vitality of the area where D is located. Nuclear density analysis of units within 500m and 500-1000m of waterfront space via Arcgis (see Figure 2). You can see the spatial distribution of crowd activity. As shown, it can be seen that the crowd of both 500m and 500-1000m has a higher concentration in the middle of Shiqi District, while the vitality in other areas is generally low.

![Figure 2. Comparison of the nuclear density of 0-500m and 500-1000m of the waterfront space in Zhongshan City Center.](image)

Excluding the space unit of the angle between the tributaries of the Qijiang River (These space elements are irregular in shape and no comparable space beyond 500m can be found), the remaining 534 space units was paired the vitality for T-test by SPSS (see Table 1). The following results were
obtained. It can be seen that the vitality of the crowd inside and outside 500m shows significant correlation (p<0.00), and the spatial vitality mean of 500-1000m waterfront is greater than 500m of spatial vitality. The high-energy area inside and outside the 500m waterfront space is similar, it can be seen that the high vitality of the space is affected by the overall development of the region. On the whole, the waterfront space of the Qijiang River shows the trend of waterback development, and the development of the waterfront area is greatly influenced by the difference of urban space.

Table 1. Comparison of the dynamic 500m and 1000m mean of the waterfront space.

| Mean value                      | N  | Standard deviation | Standard error of the mean | p    | Sig. |
|---------------------------------|----|--------------------|---------------------------|------|------|
| 500m vitality of waterfront space | 8507.389 | 267 | 13642.728 | 834.921 | .000 |
| 1000m vitality of waterfront space | 10652.498 | 267 | 16572.298 | 1014.208 | .899 |

3.2. Dynamic characteristics of time-sharing

Statistics of mobile phone signaling data within 500m and 500-1000m in the 500-1000m waterfront space unit at 12 times per day (statistics are taken every two hours), and comparing the dynamic data differences in rest days and working day waterfront spaces. It can be found that the vitality of the 500m waterfront space is higher than that of the 500m waterfront space. It can even be found that there is a similar change in the vitality of the waterfront space on weekdays and rest days: from 7 a.m. to a gradual increase in the vitality of the waterfront space, with two small peaks of vitality at 13 noon and 19 p.m., and a decrease after a significant increase in vitality around 23 p.m. (see Figure 3&4). That can be considered that the dynamic distribution characteristics of the waterfront space time period are very similar to the habits of the population, but also can be seen that the surrounding area of the waterfront is mostly residential areas.

Figure 3. Comparison of the vitality of the waterfront space on weekendays.

Figure 4. Comparison of the vitality of the waterfront space on weekendays.
Figure 5. The ratio of the vitality of the waterfront space within 500m to the vitality of the waterfront space of 500-1000m at each moment.

Count the number of vitality during the rest day and working day, and calculate the ratio of the vitality of the waterfront space within 500m to the vitality of the 500-1000m waterfront space at each moment. And use this to characterize the size of difference in the vitality of the waterfront space within 500m and the waterfront space within 500-1000m at each moment, that is, the smaller the ratio, the stronger the waterfront, and the weaker the waterfront. It can be seen that the daytime waterfront space activities are more likely to waterback, the difference between the two is more prominent on weekdays. From this, it can be inferred that the waterfront space crowd waterback activities are mainly daily commuting activities, and the waterfront space has “to the water” recreational activities show is not obvious (see Figure 5).

3.3. Crowd attraction in waterfront space
Based on the appeal of mobile phone signaling non-commuter OD data in Zhongshan City, the establishment of OD matrix analysis shows that the main source of waterfront space is community residents or village residents near the waterfront space, mainly concentrated in the central group, and peripheral areas communicate less with waterfront space (see Figure 6). Among them, the waterfront space of the Qijiang River basin in Shiqi District is denser with the people in the surrounding area, and the space attraction is wide.

Figure 6. OD linkages targeted to waterfront space.
Through ArcGIS, the mobile phone signaling OD data to the waterside space of the Qijiang River is generated and measured, the spatial topological distance between the communities and the space unit within 500m of the Qijiang River waterfront space is used as an alternative indicator of the actual travel distance, and the number of people travelling from each community to the waterfront space for activities is calculated (see Figure 7). The maximum number of sources of the water-side space of the Qijiang River occurs when the group's travel distance is 1-1.5 km, indicating that the activity groups traveling to the water-side space of the Qijiang River mainly travel for short distances. With a travel distance of 1.5 km as the threshold, when the distance is greater than 1.5 kilometers, the number of people attracted with the increase of travel distance decreases. And when the travel distance is within the 1.5-5 km range, the number of people attracted by the waterfront space decreases rapidly with the increase of the travel distance. When the travel distance is more than 5km, the waterfront space attracts fewer people and no large fluctuations.

![Figure 7. The curve of the coastal vitality with the travel distance.](image)

4. Influence factors of waterfront vitality

4.1. Selection of related factors

The mechanism analysis of the vitality of urban waterfront space is based on the angle of the influence of the material space environment carrying the activities of the population on the crowd activity. So the waterfront space within 500m of the Qijiang River zone is the research object, and the waterfront space is divided into 380 research units at a distance of about 500m. This study quantifies and compares the differences in factors such as the center degree, land use, population, realistic road construction and POI facilities of each unit. Finally, the above factors and the spatial unit of the population vitality to do a geographically weighted regression analysis, to explore the impact of the Qijiang River waterfront space vitality mechanism.

4.1.1. The center degree of the waterfront space location ($W_t$). The center of the location expresses the degree of connection between the urban waterfront space unit and the city center. On the one hand, it represents the location importance of the waterfront unit, its own attraction to the population, on the other hand, expresses the closeness with the city center: the closer it is to the city center, the more attractive it is to the crowd activity [12]. The time from the space unit of the waterfront space of Qijiang River (within 500m) to the center of Zhongshan and each town center is used to represent the location centrality of each unit of the waterfront space. This study through the Gaode map API to obtain each waterfront unit to the government at all levels of driving travel time (ignoring the level of the government differences), and consider the shortest time as the expression of distance from the waterfront space unit to the center of city. Considering the number is too large, z-score standardization is use for date processing. That is, the center degree of the waterfront space location:
4.1.2. Land use ratio and residential population \((X_i & V_i)\). The basis of the current situation of waterfront space is to be able to carry the material and environmental basis of crowd activities [13]. There are various types of land for waterfront space. Among them, the land that can directly reflect the development and construction of urban built-up areas mainly includes public service and commercial land (land A$B$), green land (land G), residential land (land R) and industrial land (land M) [14]. This paper selects the above-mentioned types of land area and the number of residents to measure the current situation of waterfront space basis. In order to more intuitively reflect the impact of different land use on the vitality of waterfront space, calculate the proportion of various land use in each unit, and use z-score to standardize the land use ratio data and residential population of each unit. That is to say the land use ratio and the residential population:

\[
W_t = \frac{(T_{min} - \bar{T}_{min})}{\sigma T_{min}}
\]

\[
X_i = \frac{(S_{ij} - \bar{S}_{ij})}{\sigma S_{ij}}
\]

\[
V_i = \frac{(R_i - \bar{R}_i)}{\sigma R_i}
\]

Where \(S_{ij}\) represents the proportion of i-class land area within j cell, \(R_i\) represents the number of people living per cell.

4.1.3. Features of the water-side space POI facility \((H)\). Facilities have direct attraction to the crowd. In order to better evaluate the degree of opening of the waterfront space, this paper obtain seven types of facilities through the Gaode Map POI, including catering facilities, entertainment facilities, shopping facilities, transportation facilities, tourist attractions, housing facilities and enterprise density. The diversity of the Shannon index is used to observe the influence of the Qijiang River on the distribution of surrounding facilities. That is:

\[
H = - \sum (P_i)(\ln P_i)
\]

In which \(H\) represents the diversity of facilities in the waterfront space, and \(P_i\) represents the ratio of the number of i-facilities to the total number of facilities.

4.1.4. Road network density \((D_i)\). Road network density is one of the basic indicators to evaluate the reasonableness of urban road network, which is used to describe the length and average distribution of roads in the region and can reflect the level of road supply in an area. That is, a region has a higher density of road network, the region's development is better, the access to the region is easier [15]. In this paper, the road network density of each cell is calculated by the current road data to evaluate the road accessibility of each cell and to adopt z-score standardized processing, as a result the road network density is:

\[
D_i = \frac{[L_i/S_i - (\bar{L_i}/\bar{S_i})]}{\sigma (L_i/S_i)}
\]

Where \(L_i\) represents the road length of cell i, \(S_i\) represents the area of cell i.

4.2. Geo-weighted regression analysis

Through Arcgis analysis of the vitality of the waterfront space, calculated Moran I index is 0.799 (0.799>0), the p value is 0.00, which means statistically significant correlation (p<0.01). So the result shows a strong spatial self-correlation of the coastal space vitality. Considering the correlation and heterogeneity of waterfront spatial vitality, this study uses geo-weighted regression analysis to verify the relationship between the above 8 factors and the vitality of waterfront space, which can better reflect the influence of the material space of the waterfront space on the vitality.

Through Arcgis geo-weighted regression analysis, the adjust \(R^2\) is 0.90, the AICc value is 187.91, so the regression model has a very strong fit and explanation is sufficient, and the “cond” balance of the analysis results is between 0-30, indicating that there is no local strong multi-collinearity: Local \(R^2\) is both higher than 0.96, so the regression model fits very well with the dependent variable.
From the calculation results (see Table 2), it can be seen that the influence coefficient of influencing factors in each region is not the same because of the geographically weighted regression. From the median and global average of the parameters of GWR regression, the number of residents is positively correlated with the vitality of the waterfront space and more relevant. The factors that have a second degree of positive correlation with the waterfront space vitality are road network density and ABG three types of land. Therefore, for the waterfront space, enrich commercial land, increase the diversity of public facilities, and optimize the blue-green space for the development of waterfront space has obviously improved. The vitality of residential land and waterfront space shows a negative correlation trend, so the waterfront space should be properly controlled residential land construction. The location of the waterfront space and MW-type land and the vitality of the waterfront space did not show a strong correlation.

| Minimum value | Quartile | Median | Three-quarters | Maximum value | Global average |
|---------------|----------|--------|----------------|---------------|---------------|
| H             | 0.049    | 0.001  | 0.012          | 0.018         | 0.038         | 0.006         |
| Vi            | 0.662    | 0.754  | 0.811          | 0.870         | 0.994         | 0.830         |
| Wt            | -0.228   | -0.019 | 0.003          | 0.000         | 0.014         | -0.031        |
| Di            | -0.005   | 0.038  | 0.093          | 0.122         | 0.152         | 0.086         |
| X_R           | -0.092   | -0.067 | -0.054         | -0.001        | 0.039         | -0.040        |
| X_M           | -0.056   | -0.007 | 0.003          | 0.017         | 0.031         | 0.000         |
| X_G           | 0.016    | 0.033  | 0.049          | 0.077         | 0.171         | 0.062         |
| X_AB          | -0.019   | 0.034  | 0.050          | 0.062         | 0.108         | 0.046         |
| R2            | 0.91     |        |                |               |               |               |
| Adjust R2     | 0.90     |        |                |               |               |               |
| AICc          | 187.47   |        |                |               |               |               |
| Bandwidth     | 0.07     |        |                |               |               |               |
| ResidualSquares | 30.75   |        |                |               |               |               |

5. Conclusion and discussion
Both Jan Gehl [11] and Jacobs agree that "the physical environment of urban space provides a place for people to move and carry a diverse urban life." "The dynamic space is the space that people are willing to gather to use, and the gathering space that produces the activity, that is, "people and their activities, living places interwoven". Some domestic scholars such as Wei [16] have pointed out that the heterogeneous vitality of cities, that is, spatial differentiation, is the driving force of the development and upgrading of urban vitality. The vitality of waterfront space is an important factor that constitutes the characteristic landscape of the city, and the characteristics of urban social activities of the waterfront space and the benign guidance of the waterfront environment to human behavior are the important contents of the construction of the waterfront city.

The study found that the dynamic distribution of waterfront space characterized by mobile phone signaling showed an obvious non-equilibrium. Through the mobile phone signaling for ten consecutive days of non-commuter vitality statistics, the vitality density of the waterfront space is higher in Shiqi District, while most of the other areas show low vitality phenomenon. Secondly, through the mean test of the vitality of the people within 500m and 500m-1000m in the waterside space of the Qijiang River, the results show that the vitality of the 500m-1000m population is greater than the vitality of the population within 500m, although there are few parts of the area (such as the middle of Shiqi District) showing the trend “to the water”. But overall, the water-side space of the Qijiang River shows the trend of waterback development. Thirdly, the coastal space crowd activities show stronger day vitality, the night is weaker; but the waterback of the day is more obvious and the waterback is weaker characteristics at night. It can be seen that the dynamic characteristics of the waterfront space are similar to the habits of residence. And the waterback characteristics of the working day are more significant, which shows
that the water-side space of the Qijiang River is mainly composed of living space and employment space, while the resting space does not show a more obvious distribution of water. Fourthly, the main source of the coastal space activities in the community near the waterfront space. As the distance between the community and the waterfront space increases, the number of people attracted decreases, with the largest number of people attracted within 1.5km of the waterfront space.

Using the GWR model to explore the influence factors of the vitality of the waterfront space of Qijiang River in central Zhongshan city. We can see that public service and commercial land, green space, facility diversity and residence number have a strong positive correlation with the vitality of the waterfront space. And the residential land and waterfront space vitality show a negative correlation trend. So the waterfront space should be properly controlled residential land construction. But there are still things worth noting. 1) The proportion of residents and residential land appears in the weighted geographical regression equation at the same time, but the positive and negative coefficient sits in the opposite direction, which means that the limited residential land in the waterfront area should adopt high-density development mode, which can reduce the isolated impact of the access community and ensure a certain number of activities; 2) The factors that have positive correlation with the waterfront space vitality are road network density and ABG three types of land. Therefore, the waterfront space bank should enhance its publicity attributes, increase the construction of blue-green space, and enhance the vitality of the waterfront space by increasing the diversity of public space and providing more recreational space for people.

In general, the measurement research in this paper not only confirms the general design experience, but also gives the scope of the potential factors precisely through empirical data. The design and construction of waterfront space should encourage the construction of diversified public service facilities, while giving full play to the unique advantages of waterfront space, strengthening the construction of space quality in the waterfront area, especially to enhance the space supply of public green space and ensure accessibility. The residential land in the waterfront area should be controlled within the appropriate proportion and pay attention to the intensive nature of land development. Not only to avoid the spread of closed community in the near water area, but also to protect the popularity of the area, and finally ensure the vitality of the development of the waterfront space.

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