The Impact of Perceived Winter Riverside Environmental Characteristics on the Mental Health of Older Adults[*] : A Case Study of Harbin, China

YUAN Qing[1], LI Hongrui[2], LENG Hong[3]

Author Affiliations 1 Professor；2 Master's Student；3 Professor (Corresponding Author)，Email：hitlaura@126.com；1&2&3 School of Architecture and Design，Harbin Institute of Technology；Key Laboratory of National Territory Spatial Planning and Ecological Restoration in Cold Regions，Ministry of Natural Resources

ABSTRACT: Urban riverside spaces serve as important venues for older adults to engage in outdoor activities and connect with nature, and the perceived characteristics of these environments exert a significant influence on their mental health. Compared with ordinary seasons, the winter climate in cold-region cities has distinctive effects on both older adults and waterfront spaces. The pathways of influence under this specific climatic background require further investigation. Using the wintertime Harbin section of the Songhua River as the study area, this research employs structural equation modeling (SEM) to empirically examine the impact of perceived winter riverside environments in cold regions on the mental health of older adults and to identify the mechanisms through which their different behavioral activities operate. The findings reveal that: (1) The environmental characteristics of winter riverside spaces in cold-region cities that influence the mental health of older adults consist mainly of four dimensions: social, landscape, comfort, and activity elements. (2) The pathways through which environmental perception affects mental health include both direct effects and indirect effects mediated by behavioral activities. Specifically, social and landscape elements exert direct effects on mental health and also indirect effects by influencing behavioral activities, whereas comfort and activity elements influence mental health only indirectly through behavioral activities. (3) Different behavioral activities undertaken by older adults in riverside spaces play mediating roles in the mechanism by which environmental perception affects mental health, with waterfront interactions exhibiting the strongest mediating effect. This study clarifies the mechanism through which environmental characteristics of winter riverside spaces influence the mental health of older adults, providing insights for enhancing and transforming winter riverside spaces in cold-region cities.

KEY WORDS: winter riverside space; older adults; mental health; cold-region cities; behavioral activities

Introduction

Against the backdrop of population aging, mental health issues among older adults have become an increasingly important public health concern—declines in mental health not only result in deteriorating physical and cognitive functioning but are also linked to higher morbidity and mortality risks [1]. *The Report on National Mental Health Development in China* (2019-2020) indicated that nearly one-third of older adults experience depressive symptoms [2], highlighting a concerning mental health situation that urgently requires effective interventions. Urban waterfront spaces serve as key venues for older a-

dults' daily leisure activities, and their environmental characteristics are closely associated with the mental health of older adults [3]. Exploring this causal relationship is essential for improving urban waterfront environments, promoting healthy aging, and advancing the Healthy China initiative.

Waterfront spaces exert positive effects on residents' mental health, as reflected in their benefits for psychotherapy [4], emotional regulation [5], reduced depression scores [6], and enhanced subjective well-being [7]. Relevant studies have examined how individual attributes, the objective environment of waterfront spaces, and subjective environmental perceptions affect mental health. Existing studies confirm that residents' mental health is influenced by multiple individual attributes, including age, gender, income level, and physical health status [8]. The objective environment of waterfront spaces is mainly reflected in indicators such as the proportion of waterfront spaces within a certain distance [9], water body visibility [10], and accessibility [11]. An increase in the proportion of nearby waterfront spaces, greater water body visibility, and shorter distance between waterfront spaces and residences are all associated with a higher likelihood of better mental health among residents. Environmental perception refers to individuals' subjective feelings and psychological judgments about their surrounding environment and its changes, and it constitutes the psychological basis for environmental behavior [12]. Residents' environmental perceptions shape their behavioral activities and, in turn, exert positive or negative influences on their mental health. In recent years, scholars both in China and abroad have focused on examining how perceptions of the physical and social environments of residential areas influence residents' self-rated mental health. They have proposed that perceived attributes of the residential environment—such as aesthetic quality[13], walkability[14], and facility diversity[15]—exert significant positive effects on mental health. Similarly, favorable perceptions of social-environmental factors, including harmonious neighborhood relations and robust social capital, also contribute to residents' mental well-being[16]. Building on this foundation, some scholars have begun to focus on the relation-

ship between subjective perceptions of waterfront spaces and human mental health. Qualitative studies have discussed the relationships between perceptions of elements such as waterfront spaces' safety [17], accessibility [18], and vitality [19] and mental health; quantitative analyses have verified that meeting perceptual preferences, such as appreciation of beautiful waterscapes [20] and well-designed walkways [21], facilitates activities in waterfront spaces and thereby helps prevent mental health problems. In addition, some studies have noted that residents' mental health is closely related to the duration [22] and intensity [23] of their activities in waterfront spaces.

Seasonal variations have a significant impact on residents' mental health, and changes in season are correlated with symptoms such as depression, mania, and anxiety [24]. The prevalence of winter depression reaches as high as 10% worldwide, with 70% of cases diagnosed as recurrent major depressive disorder [25]. It is particularly common in cold regions of North America, Northern Europe, and cold-region cities in China [26]. Researchers have mainly explained the mechanisms of seasonal effects on mental health from physiological and behavioral perspectives. From the physiological perspective, serotonin is believed to play a key role in regulating anxiety and depressive emotions. During winter, the brain's serotonin system becomes less active, making people more prone to negative and passive emotions, thereby increasing the incidence of mental disorders. From the behavioral perspective, low temperatures in winter reduce or even eliminate healthy activities among residents, which in turn negatively affects their mental health [27]. Meanwhile, seasonal changes also significantly affect the environmental quality of waterfront spaces: although winter snowfall in cold-region cities creates additional opportunities for ice- and snow-related recreational activities, the range of waterfront resources perceptible to urban residents is markedly reduced during winter [28]. Older adults—whose physical resilience and overall health tend to be comparatively lower—are particularly sensitive to these environmental changes. Consequently, their willingness, frequency, and duration of use of winter waterfront spaces are adversely affected, thereby increasing their vulnerability to mental

health challenges.

Although studies on the relationship between waterfront spaces and residents' mental health have achieved some progress, several limitations remain: (1) Existing empirical studies mostly focus on the analysis of physical environmental characteristics, and pay little attention to the role of social environmental elements, so that a systematic set of environmental indicators has yet to be established; (2) In terms of study areas, most research focuses on coastal spaces, while inland riverside spaces remain underexplored; (3) Methodologically, most studies employ linear or logistic regression models to analyze correlations between riverside environments and residents' mental health, while exploration of the causal pathways through which waterfront environmental elements affect mental health is limited; (4) Research on the health benefits of waterfront spaces under specific climatic contexts remains insufficient. Based on the above, this study takes the winter riverside spaces along the Songhua River in Harbin as the research object, constructs a structural equation model (SEM) of perception of winter riverside environments, introduces older adults' behavioral activities in winter riverside spaces as mediating variables, and conducts a quantitative analysis of the variables affecting older adults' mental health in winter, as well as the mediating effects of different behavioral activities. This study aims to examine the mechanisms through which perceptions of winter riverside environments in cold-region cities affect the mental health of older adults, thereby providing a scientific basis for improving their mental well-being and for the planning and design of winter riverside environments in cold-region cities.

1　Research methodology

1.1　Model construction and research hypotheses

1.1.1　Construction of the indicator system

The environment that influences individual mental health includes both the social environment and the physical environment [29]. Drawing on existing domestic and international studies, this research integrates the waterfront environmental elements that influence older adults' mental health and classifies them based on the characteristics

of winter riverside spaces in cold-region cities. It ultimately identifies the following four categories of environmental elements: social elements, landscape elements, comfort elements, and activity elements. In cold-climate regions, the social environment influencing older adults in winter is primarily shaped by social elements. Drawing on prior studies and preliminary interviews, four indicators were identified to define the social elements of winter riverside spaces: perceived liveliness of the site, sense of belonging, cultural identity, and retail presence in on-ice spaces. The physical environment, in contrast, is influenced by landscape, comfort, and activity elements. Specifically, a beautiful landscape environment greatly encourages residents to engage with nature and stimulates positive emotions [30]. Moreover, seasonal factors significantly affect urban color conditions [31]. Therefore, this study selects four indicators for landscape elements: on-ice landscape conditions, waterfront landscape conditions, near-water landscape conditions, and winter color conditions. A safe and easily accessible physical environment can promote residents' mental health [32]. On this basis, considering that outdoor activities in cold-region cities should not last long during winter, three indicators were selected as comfort elements, namely walking safety in winter, accessibility of the site in winter, and resting suitability of facilities in winter. Abundant and diverse activity spaces are the foundation for attracting people to engage in healthy activities [33]. Therefore, three indicators were selected as activity elements: diversity of activity spaces, water proximity of activity spaces, and adequacy of activity spaces.

Older adults' behavioral activities are closely related to their mental health [34]. Based on field observation records, 20 types of wintertime behavioral activities of older adults in the southern riverside spaces of the Songhua River were identified. Referring to the suggestions of Pasanen T. P. et al. [35], and considering the characteristics of older adults' activities in cold-region cities, these were categorized into 3 types and 9 forms: near-water exercise, waterfront interaction, and other leisure activities (Figure 1). Near-water exercises include walking, equipment-based exercises, and stretching, among other types. Waterfront interactions include in-water, on-ice, and wa-

terside activities. Other leisure activities include individu- al, family, and social leisure activities.
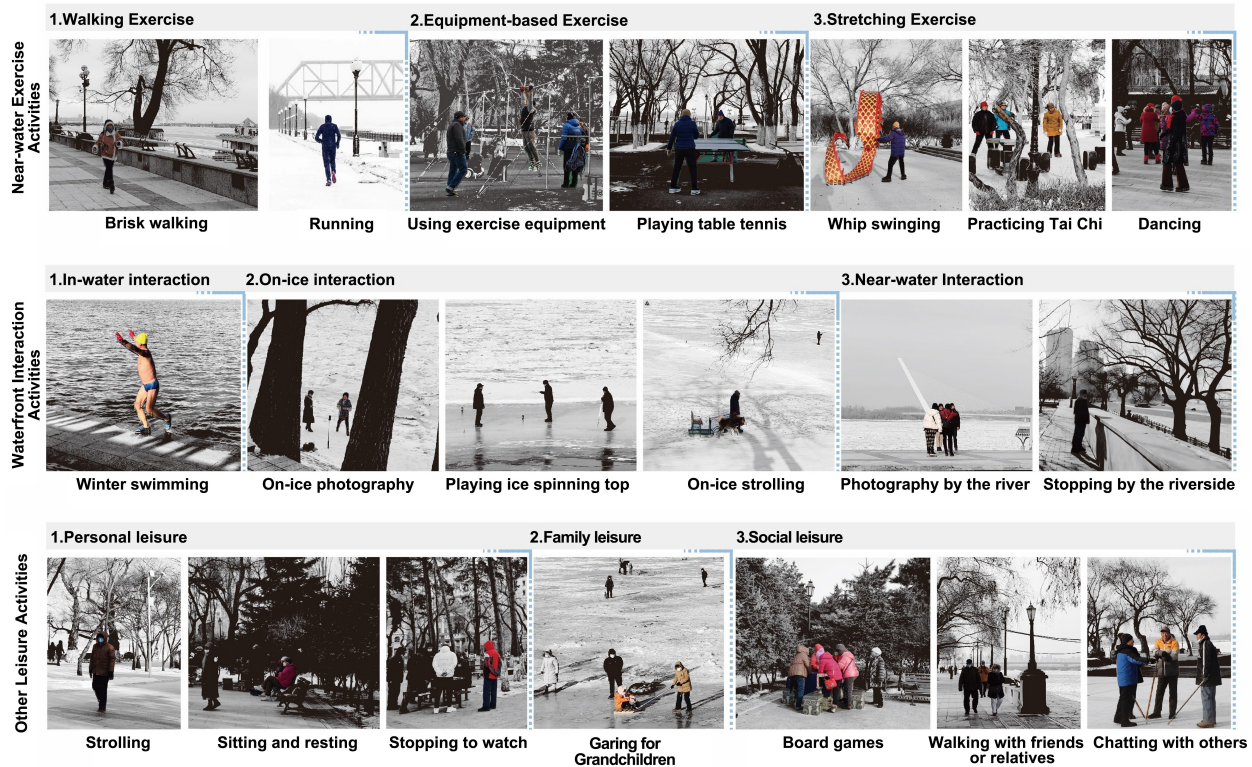

Figure 1   Classification of older adults' behavioral activities in winter riverside spaces

1.1.2   Construction of the conceptual model

Based on the Active Living Ecological Model[36], this study incorporates winter climatic factors, selects three common types of winter activities of older adults— near-water exercise, waterfront interaction, and other leis- ure activities—as mediating variables, and takes older a- dults' mental health as the dependent variable to construct a theoretical framework of perception of winter riverside environments (Figure 2). The conceptual model posits that perceptions of the physical and social environmental ele- ments of riverside spaces are directly or indirectly related to older adults' mental health. These environmental ele- ments influence older adults' activities, thereby affecting their mental health. Therefore, older adults' activities serve as mediating variables in the relationship between the riverside space environment and their mental health. The model hypotheses are as follows:

H1: Perceptions of environmental elements in winter riverside spaces have a significant positive effect on older adults' behavioral activities;

H1a: Perceptions of social elements in winter river-

side spaces have a significant positive effect on older a- dults' behavioralactivities;

H1b: Perceptions of landscapeelements in winter riv- erside spaces have a significant positive effect on older a- dults' behavioral activities;

H1c: Perceptions of comfort elements in winter river- side spaces have a significant positive effect on older a- dults' behavioral activities;

H1d: Perceptions of activity elements in winter river- side spaces have a significant positive effect on older a- dults' behavioral activities;

H2: Perceptions of environmental elements in winter riverside spaces have a significant direct positive effect on older adults' mental health;

H2a: Perceptions of social elements in winter river- side spaces have a significant direct positive effect on ol- der adults' mental health;

H2b: Perceptions of landscape elements in winter riv- erside spaces have a significant direct positive effect on older adults' mental health;

H2c: Perceptions of comfort elements in winter river- side spaces have a significant direct positive effect on ol-

der adults' mental health;

H2d: Perceptions of activity elements in winter riverside spaces have a significant direct positive effect on older adults' mental health;

H3: Older adults' behavioral activities significantly

mediate the relationship between perceptions of environmental elementsin winter riverside spaces and their mental health;

H4: The mediating effects of different types of behavioral activities in winter riverside spaces vary significantly.
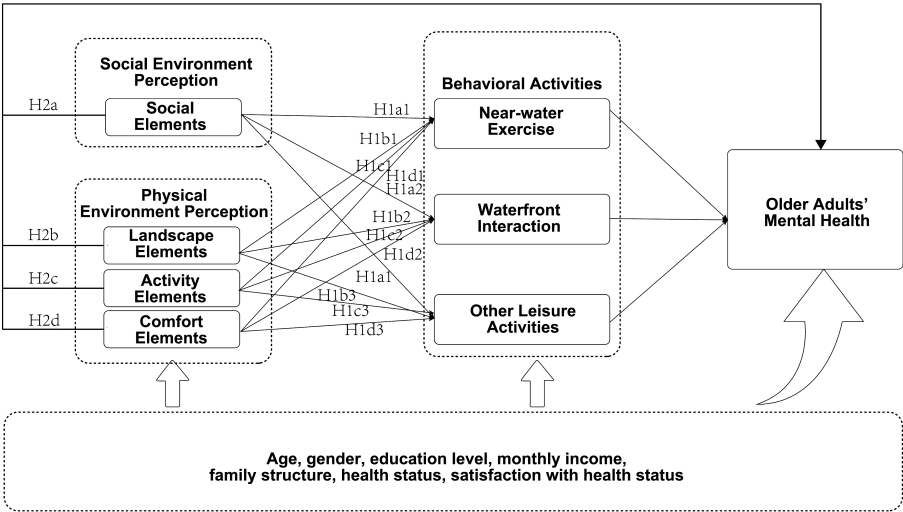
Figure 2　Hypothetical model
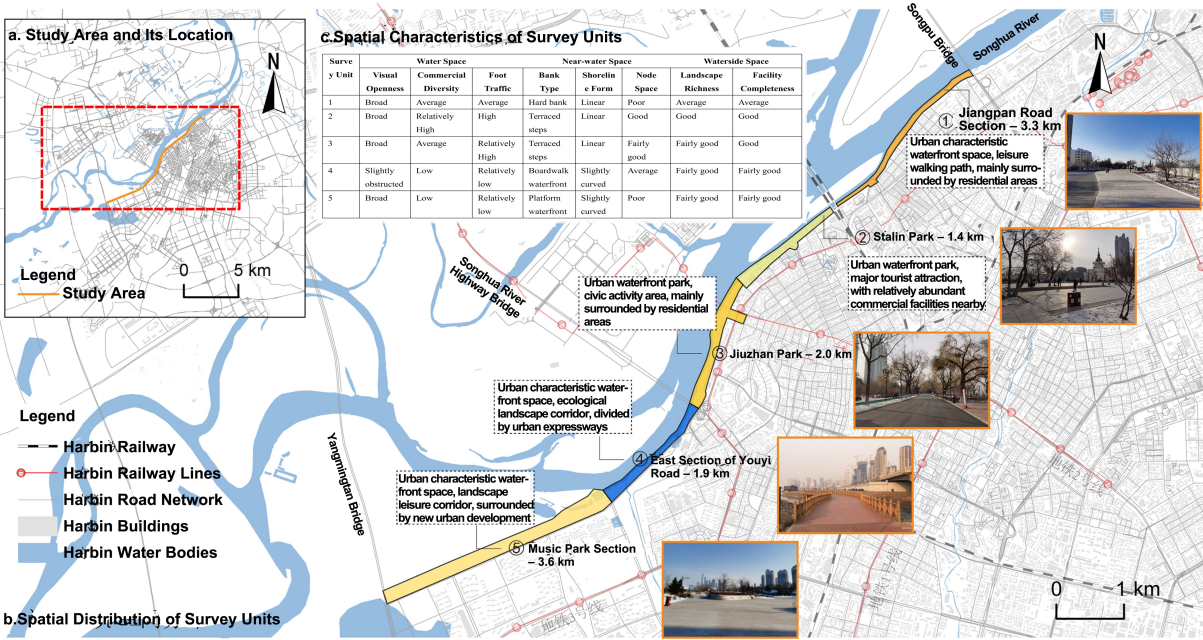
Figure 3　Study area and survey units

1.2　Questionnaire design and distribution

1.2.1　Area ofstudy

The site selected in this study is the southern riverside of the Songhua River in Harbin, stretching from Yangmingtan Bridge to Songpu Bridge. The Songhua River flows from the southwest to the northeast through Harbin's urban area. Its southern riverside, with attractive landscapes and abundant activity venues, serves as one of the most important leisure spaces to support the public life, social interaction, and recreational activities of local residents. As a typical cold-region city, Harbin has a harsh winter climate that has a profound impact on both the ur-

ban riverside landscape and the physical and mental health as well as activity choices of older adults. Consequently, riverside spaces face problems in planning, design, and management, such as monotonous design expression, insufficient expression of regional cultural elements, and limited site attractiveness.

In this study, the site was categorized based on the forms, facilities, and other environmental characteristics of winter riverside spaces, including on-ice, waterside, and near-water spaces, into five survey units: Songpu Bridge-Jingjie, Stalin Park, Jiuzhan Park, Gonglu Bridge-Shangjiang Road, and Music Park (Figure 3). These survey units include planar urban riverside parks, linear riverside walkways, and point-type riverside plazas, which collectively reflect the construction level of riverside spaces along the Songhua River and serve as representative examples among cold-climate city waterfronts.

1.2.2   Datasources

In November 2021, a pilot survey was conducted on the southern bank of the urban section of Harbin along the Songhua River, during which 42 valid questionnaires were collected. The questionnaire was subsequently optimized and adjusted based on the findings of this survey. Considering the particular characteristics of the winter climate in cold-climate cities, and incorporating factors such as the COVID-19 pandemic, weather, and temperature, the survey period was ultimately scheduled for mid-to-late December 2021. In each survey unit, 70 questionnaires were distributed using a convenience sampling method (encounter method), resulting in a total of 350 questionnaires across the five units. After collection and sorting, 25 questionnaires with missing or identical answers and 13 questionnaires indicating "serious illness" in health status were excluded, resulting in 312 valid questionnaires: 62 from Jiangpan Road, 63 from Stalin Park, 64 from Jiuzhan Park, 61 from the East of Youyi Road, and 62 from Music Park. The effective response rate was 89.14%. Analysis of the 312 questionnaire samples indicates that the gender ratio of respondents is nearly balanced at 1:1. The distributions of age, educational attainment, and income level approximate a normal distribution, suggesting that the sample data are highly representative.

1.2.3   Questionnaire design and variable measurement

The questionnaire used in this study consists of four sections: (1) basic personal information of older adults; (2) characteristics of older adults' behavioral activities in riverside spaces; (3) a mental health scale for older adults; and (4) a perception scale of the winter riverside environment. The first section covers demographic and health-related information such as gender, age, education level, monthly personal income, household composition, physical health status, and satisfaction with physical health. These individual characteristics that may influence health were included as control variables in this study. The second section investigates the behavioral characteristics of older adults in riverside spaces during winter and other seasons. The duration of older adults' near-water exercise, waterfront interaction, and other leisure activities in winter were selected as mediating variables. The third section investigates older adults' mental and emotional health over the past two weeks, which serves as the dependent variable in this study. The mental health scale for older adults is based on the "Warwick-Edinburgh Mental Well-being Scale" developed by Tennant et al [37]. The scale comprises 14 items that reflect three dimensions of mental well-being: positive emotions, positive psychological functioning, and satisfaction with interpersonal relationships. The total score ranges from 14 to 70, with higher scores indicating higher levels of positive mental health. The reliability and validity of the Chinese version have been effectively verified [38]. The fourth section serves as the core independent variable measurement for this study. A measurement scale for perception of riverside environment was developed by reviewing existing literature and related existing scales. This scale reflects subjective perception of the winter riverside environment through four characteristic dimensions: social, landscape, comfort, and activity elements. Respondents evaluated specific environmental elements according to their subjective impressions (see Table 1). Both scales in the questionnaire adopt the 5-point Likert scale.

1.3   Research and analysis methods

This study aims to empirically analyze the relationship between perceptions of the winter riverside environ-

ment and older adults' mental health. As indicated by the conceptual model presented earlier, the model contains multiple variables, including dependent variables, and includes certain environmental perception variables that are difficult to observe or measure directly. Conventional multiple regression analysis methods are inadequate for addressing the interrelationships among multiple variables across different dimensions. In contrast, the structural equation model (SEM), an advanced quantitative statistical method that integrates techniques such as Analysis of Variance (ANOVA), regression analysis, and path analysis, is capable of analyzing and handling complex multivariate relationships. It allows for the measurement of unobservable or hard-to-measure variables as latent variables and enables multiple mediation analyses. Therefore, this study adopts the structural equation modeling approach as the primary analytical method.

2　Data analysis

2.1　Descriptive statistics of the sample

Statistical analysis was conducted on the valid survey samples, with male respondents accounting for 50.64% and female respondents 49.36%. Most respondents were aged 66-70, with the majority having completedhigh school or technical secondary education, followed by those with junior high, college, university, or primary education. The majority reported a personal monthly income between 3,000 and 8,000 Yuan, and most of them lived with their spouses. In addition, the survey results indicate that the largest proportion of respondents classified themselves as "relatively healthy," and overall satisfaction with personal health was high, with 93.59% expressing neutral or positive satisfaction (see Table 2).

Table 1　Variable definitions and descriptive statistics

Category	Index	Variable definitions and measurement coding	Mean	Standard deviation
Individual Attributes	Gender	Female= 0; Male= 1	0.506	0.501
	Age	55—60= 1; 61—65= 2; 66—70= 3; 71—75= 4;> 75= 5	3.099	1.288
	Education level	Primary or below= 1; Junior high= 2; High school/technical= 3; College/undergraduate or above= 4	2.622	1.035
	Monthly personal income	< 3000= 1; 3000—5000= 2; 5000—8000= 3;> 8000= 4	2.365	1.028
	Household composition	Living alone= 1; Living with spouse= 2; Living with children= 3; Living with grandchildren= 4; Three-generation household= 5	2.712	1.303
	Health status	Very healthy= 1; Relatively healthy= 2; Average= 3; Relatively poor= 4	2.057	0.828
	Health satisfaction	Extremely satisfied= 1; Mostly satisfied= 2; Average= 3; Mostly dissatisfied= 4; Extremely dissatisfied= 5	1.913	0.923
Behavioral activities	Y1 Near-water Exercise	Average daily duration of near-water exercise in riverside spaces over the past week (1= < 0.5 h to 5= > 2 h)	3.430	0.929
	Y2 Waterfront interaction	Average daily duration of waterfront interaction in riverside spaces over the past week (1= < 0.5 h to 5= > 2 h)	3.300	0.966
	Y3 Other leisure activities	Average daily duration of other leisure activities in riverside spaces over the past week (1= < 0.5 h to 5= > 2 h)	3.390	1.070
Mental Health	Z1 Positive Emotion	I am optimistic about the future; I feel relaxed; I feel valuable; I am interested in new things; I feel energetic (1= Never to 5= Always, averaged across items)	4.032	0.956
	Z2 Positive psychological Functioning	I can handle problems well; My mind stays clear; I generally feel good about myself; I am confident; I can make decisions on my own (1= Never to 5= Always, averaged across items)	4.158	1.002
	Z3 Satisfaction with interpersonal relationships	I enjoy interacting with others; I feel close to others; I feel cared for; I feel happy (1= Never to 5= Always, averaged across items)	3.885	1.090

(Continued)

Category	Index		Variable definitions and measurement coding	Mean	Standard deviation
Subjective Perceived Environment	Social elements	X1 Sense of belonging	Many acquaintances in the space and harmonious interactions (1= Extremely dissatisfied to 5= Extremely satisfied)	3.545	1.024
		X2 Perceived liveliness of site	Busy and bustling with high pedestrian flow (1= Extremely dissatisfiedto 5= Extremely satisfied)	3.712	1.038
		X3 Cultural identity of site	Strong regional cultural characteristics (1= Extremely dissatisfied to 5= Extremely satisfied)	3.683	0.970
		X4 Retail presence in on-Ice spaces	Number and types of retail formats in the on-ice space (1= Extremely dissatisfied to 5= Extremely satisfied)	3.426	1.163
	Landscape elements	X5 Waterfront landscape conditions	Varied shoreline forms and ecologically friendly revetments (1= Extremely dissatisfied to 5= Extremely satisfied)	3.676	1.118
		X6 On-ice landscape conditions	Rich and attractive ice scenery (1= Extremely dissatisfied to 5= Extremely satisfied)	3.221	1.103
		X7 Near-water Landscape Conditions	Pleasant and rich near-water landscapes (1= Extremely dissatisfied to 5= Extremely satisfied)	3.131	1.157
		X8 Winter color conditions	Rich environmental colors (1= Extremely dissatisfied to 5= Extremely satisfied)	3.442	1.090
	Comfort elements	X9 Walking safety in winter	Anti-slip surface materials (1= Extremely dissatisfied to 5= Extremely satisfied)	3.599	0.946
		X10 Accessibility in winter	Convenient access to riverside spaces (1= Extremely dissatisfied to 5= Extremely satisfied)	3.587	0.930
		X11 Resting suitability in winter	Sufficient and comfortable indoor rest facilities (1= Extremely dissatisfied to 5= Extremely satisfied)	3.788	1.025
	Activity elements	X12 Variety of activity spaces	Various types of activity facilities (1= Extremely dissatisfied to 5= Extremely satisfied)	3.304	1.118
		X13 Water proximity of activity spaces	High degree of water accessibility (1= Extremely dissatisfied to 5= Extremely satisfied)	3.952	1.013
		X14 Adequacy of activity spaces	Appropriate area and sufficient facilities (1= Extremely dissatisfied to 5= Extremely satisfied)	3.516	1.209

The survey found that 62.82% of respondents engaged in riverside activities seven or more times per week during winter, of whom 18.36% visited twice daily. The majority of participants, at 78.52%, reported an average activity duration of 1 to 1.5 hours per session. In terms of activity types during the previous week, 80.77% of the older adults participated in near-water exercise, 47.44% engaged in waterfront interactions, and 21.47% took part in other leisure activities. Furthermore, the data analysis indicates that in winter, activity frequency declines compared with other seasons, activity types are significantly fewer, and activity duration is also reduced. Specifically, respondents' average activity frequency in other seasons was 13.8 times per week, compared with 7.14 times per week in winter. A total of 56.09% of respondents stated that activity types are more numerous in other seasons than in winter, while 59.61% reported that they visit riverside spaces more frequently in other seasons than in winter.

In this study, the average self-ratedmental health score among the respondents was 56.5. A total of 38.14% of them reached the threshold for high mental well-being (with 60 points designated as the recommended cutoff). Positive mental functioning had the highest mean score, followed by positive emotions, while satisfaction with interpersonal relationships scored the lowest. Interviews revealed that the older adults who regularly visited riverside spaces adapted better to changes in social roles, experienced less loneliness and anxiety, and exhibited better mental health.

Table 2   Basic information on the survey sample（N＝312）

Basic Info	Category	Proportion/%
Gender	Male	50.64%
	Female	49.36%
Age	55－60	14.42%
	61－65	17.63%
	66－70	28.85%
	71－75	21.79%
	＞75	17.31%
Education level	Primary or below	17.31%
	Junior high	27.56%
	High school / technical secondary school	30.77%
	College / undergraduate or above	24.36%
Monthly personal income	＜3000 yuan	24.36%
	3,000－5,000 yuan	31.41%
	5,000－8,000 yuan	27.56%
	＞8,000 yuan	16.67%
Household composition	Living alone	14.42%
	Living with spouse	42.31%
	Living with children	18.59%
	Living with grandchildren	7.05%
	Three-generation household	17.63%
Health status	Excellent health	25.64%
	Good health	48.72%
	Fair health	19.87%
	Poor health	5.77%
	Severe illness	0%
Health satisfaction	Extremely satisfied	38.14%
	Mostly satisfied	40.06%
	Average	15.38%
	Mostly dissatisfied	5.13%
	Extremely dissatisfied	1.28%

2.2   Modeltesting

2.2.1   Reliability and validity analysis

Based on valid questionnaire data, SPSS 25.0 was used to conduct KMO and Bartlett's sphericity tests on all variables. The results show that the KMO value was 0.924 (reference＞0.7) and the significance value in Bartlett's test was p＜0.001 (reference＜0.05), indicating that the variables were suitable for factor analysis. Based on this, the measurement model was subjected to reliability and validity testing. Only one observed variable had a stand-ardized coefficient slightly below 0.5, while all others exceeded 0.5, indicating that the measurement variables for each dimension effectively capture the latent traits of their respective dimension. The Cronbach's α coefficients for all dimensions were above 0.7, demonstrating that the questionnaire data possessed good reliability. The composite reliability (CR) values for all dimensions exceeded 0.7, suggesting that the observed variables of each latent construct had internal consistency. The average variance extracted (AVE) values for most dimensions were above 0.5, with a few approaching 0.5, indicating that the measurement model exhibited good convergent validity (see Table 3). Moreover, the square root of the AVE for each latent variable exceeded its correlation coefficients with other latent variables, confirming that the measurement model demonstrated discriminant validity among dimensions.

2.2.2   Model fit and path analysis

Using maximum likelihoodestimation, parameter estimation and goodness-of-fit testing were performed on the conceptual model. The fit indices are as follows (Table 4): $X^2/df=2.759$, $SRMR=0.065$, $RMSEA=0.075$, $GFI=0.872$, $AGFI=0.827$, $IFI=0.919$, $CFI=0.918$, and $TLI=0.899$. Generally, model similarity indices are considered acceptable when greater than 0.9, with values between 0.8 and 0.9 deemed tolerable; dissimilarity indices are considered acceptable when below 0.08. In this study, all model fit indices met the required criteria, indicating that the o-verall model demonstrates good goodness-of-fit. Path a-nalysis results (Figure 4) show that hypotheses H2c (the perception of comfort elements has a significant direct positive effect on mental health) and H2d (the perception of activity elements has a significant direct positive effect on mental health) were not supported. H1a exhibited a sig-nificant negative effect, indicating that social elements re-duced older adults' behavioral activities in winter, while all other hypotheses were supported.

2.2.3   Mediating effect testing

This study employed the Bootstrap method to exam-ine the mediating role of behavioral activities between the perception of winter riverside environments in cold-region cities and the mental health of older adults. Following the recommendations of WEN Zhonglin et al.［39］, 2,000

Bootstrap samples were set, and a 95% confidence level was used for iterative sampling. The results indicated that the mediating effect was partial. From the perception of winter riverside environmental elements to older adults' mental health, three paths exist: near-water exercise, waterfront interaction, and other leisure activities. Therefore, the three mediating variables were tested using the MacKinnon method to determine the significance of the paths.

The analysis indicated that at a 95% confidence level, the *prodclin* confidence intervals did not include zero, confirming the significance of all three mediating paths. That is, older adults' behavioral activities in winter significantly mediated the effects on mental health, whereby perceptions of the winter riverside environment influenced mental health through near-water exercise, waterfront interaction, and other leisure activities.
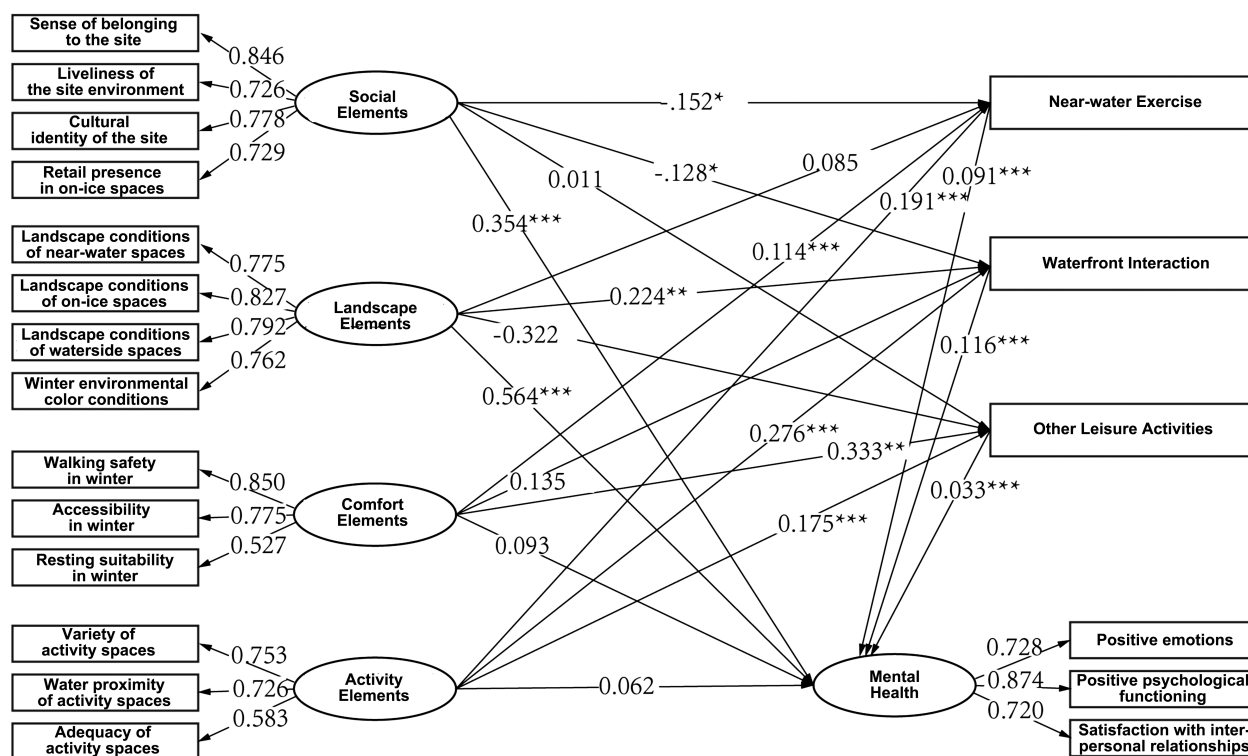

Figure 4　Standardized parameter estimates of winter riverside environmental perception affecting older adults' mental health

* Note：* *p* ＜0.01；** *p*＜0.05；*** *p*＜0.001．

Table 3　Reliability and validity of scales

Latent Variables	Observed variables	Standardized coefficients	Cronbach's α	CR	AVE
Social elements	X1	0.723	0.849	0.854	0.594
	X2	0.802			
	X3	0.724			
	X4	0.828			
Landscape elements	X5	0.742	0.868	0.868	0.623
	X6	0.819			
	X7	0.827			
	X8	0.765			
Comfort elements	X9	0.465	0.734	0.762	0.531
	X10	0.801			
	X11	0.857			

(Continued)

Latent Variables	Observed variables	Standardized coefficients	Cronbach's α	CR	AVE
Activity elements	X12	0.584	0.721	0.733	0.481
	X13	0.775			
	X14	0.707			
Behavioral activities	Y1	0.724	0.765	0.772	0.533
	Y2	0.816			
	Y3	0.640			
Mental health	Z1	0.710	0.815	0.820	0.604
	Z2	0.868			
	Z3	0.745			

Table 4　Model fit indices

Fit indices	X^2/df	SRMR	RMSEA	GFI	AGFI	IFI	CFI	TLI
Reference values	< 3	< 0.080	< 0.080	> 0.90	> 0.90	> 0.90	> 0.90	> 0.90
Test values	2.759	0.065	0.075	0.872	0.827	0.919	0.918	0.899
Fit evaluation	Good	Good	Good	Approved	Approved	Good	Good	Approved

3　Influence mechanism of perception of winter riverside environment on older adults' mental health

3.1　Influence of perception of winter riverside environment on older adults' mental health

When individualfactors are taken into account, the perception of winter riverside environments in cold regions had a significant effect on older adults' mental health, with improvements in each variable exerting direct or indirect effects on mental health outcomes. Based on the total effect value on older adults' mental health, the influence magnitude follows: landscape elements (0.499)> social elements (0.304)> comfort elements (0.220)> activity elements (0.140). These constitute four key dimensions of winter riverside spaces.

3.1.1　Perception of social elements

The perception of social elements can affect mental health directly (β= 0.354, p < 0.001) or indirectly through influencing waterfront interaction (β= −0.128, p < 0.01) and near-water exercise (β= −0.152, p < 0.01). Interview analysis indicates that a sense of place-based spiritual belonging and cultural identification exert significant effects on the mental health of older adults. A high number of acquaintances and harmonious interactions, as key sources of place-based spiritual belonging, promote social engagement in other leisure activities, extend activity duration, facilitate participation in organized near-water exercise, reduce loneliness, and encourage joint participation in waterfront interaction, thereby enhancing positive emotions and satisfaction with interpersonal relationships. A strong regional cultural atmosphere enhances older adults' cultural identification with the site, thereby increasing the frequency of riverside activities and promoting positive mental health outcomes. Contrary to previous studies, the perception of social elements has a significant negative effect on the behavioral activities of older adults. This may be due to the lively atmosphere of the site and the retail presence in on-ice spaces. On the one hand, under the COVID-19 pandemic, a lively environment can trigger older adults' concerns about virus transmission, thereby limiting their activity choices; on the other hand, retail commerce in on-ice spaces may lead to mixed crowds, which affects the activity experience of the older adults and the achievement of their activity goals.

3.1.2　Perception of landscape elements

The perception of landscape elements can directly influence mental health (β= 0.564, p < 0.001) or indirectly through affecting older adults' waterfront interaction (β= 0.224, p < 0.05). Among the landscape elements, the path coefficients for "on-ice landscape conditions" and "near-water landscape conditions" were relatively high, indicating that older adults place greater importance on on-ice and near-water spaces among all riverside spaces in winter. Based on previous research, in cold-region cities during winter, the climate causes trees to wither and be covered

by snow and ice, which greatly reduces landscape diversity. This in turn significantly lowers older adults' willingness to engage in outdoor activities, so their frequency and duration of going out in winter are much lower than in other seasons. This requires that, when planning and designing winter waterfront spaces, greater attention should be given to the landscape design of ice spaces and near-water spaces. Other factors, such as waterside landscape conditions and winter environmental color, also play important roles in attracting older adults to riverside activities and influencing mental health.

3.1.3　Perception of comfort elements

The perception of comfort elements exerts a significant positive influence on older adults' mental health via mediating effects. Specifically, comfort elements affect mental health by influencing older adults' near-water exercise ($\beta = 0.114$, $p < 0.001$) and other leisure activities ($\beta = 0.333$, $p < 0.001$). Among all observed variables, "walking safety in winter" had the highest path coefficient, indicating that safety is the most influential factor on older adults' activities and mental health in winter. Survey findings reveal that "resting suitability in winter" determines residents' duration of stay in riverside spaces. Respondents prefer to remain in areas with comfortable temperatures and indoor resting facilities. Meanwhile, "accessibility in winter" is another important factor influencing older adults' frequency of visits to riverside spaces.

3.1.4 Perception of activity elements

Perceived activity elements significantly and positively influence older adults' mental health, mediated by behavioral activity. Specifically, activity elements influence older adults' near-water exercise ($\beta = 0.191$, $p < 0.001$), waterfront interaction ($\beta = 0.276$, $p < 0.001$), and other leisure activities ($\beta = 0.175$, $p < 0.001$) in riverside spaces. Among the dimensions of activity elements, the factor "variety of activity spaces" had the largest path coefficient. Combined with interview analyses, the variety of fitness facilities and sports venues remains the most attractive factor for older adults, and can greatly promote near-water exercise, and thereby generate positive mental health effects. "Water proximity of activity spaces" is an important consideration for older adults engaging in waterfront

interaction. Respondents prefer riverside spaces with higher proximity to water. "Adequacy of activity spaces" provides conditions for older adults to engage in other leisure activities in riverside spaces.

3.2　Analysis of the mediating effect of older adults' behavioral activities on mental health

Taking waterfront interaction as the mediating variable is the most effective pathway through which riverside environments generate mental health benefits. Near-water exercises are the second most effective, and other leisure activities have the least effect. The mediating effect analysis results are 0.114, 0.089, and 0.017 respectively (see Table 5). Across the pathways, the mediating effects of the three types of behavioral activities are relatively small but exhibit significant differences. Specifically, near-water exercises play a significant mediating effect in the relationship between social, comfort, and activity elements and mental health. This indicates that winter riverside spaces with favorable perceptions of these elements can promote older adults' participation in near-water exercise, thereby enhancing their mental health to some extent. Waterfront interaction significantly mediates the relationship between social, landscape, and activity elements and mental health. It suggests that winter riverside spaces with favorable perceptions of these elements can stimulate older adults' waterfront interaction, thereby alleviating negative emotions and benefiting mental health. Other leisure activities play a significant role in mediating the relationship between comfort and activity elements and mental health. This indicates that older adults' winter leisure activities are highly dependent on these elements. Well-designed winter riverside spaces with favorable conditions of these elements can stimulate older adults to engage in other leisure activities.

4　Conclusions and discussion

4.1　Conclusions

As indicated by the results presented above, some aspects of Hypotheses H1 and H2 were supported, while Hypotheses H3 and H4 were fully supported. Among them, H1a was not supported; the perception of social elements in riverside spaces in winter by older adults in cold-region cities exerts a significant negative impact on their behavioral activities. H2c and H2d were not significant, indicating that perceptions of comfort and activity elements do

not have a significant direct effect on mental health. From the analysis, the following conclusions are drawn:

Table 5　Mediating effects of behavioral activities between perception of winter environmental elements and mental health（N＝312）

Paths Tested	Total effect	Direct effect	Total indirect effect	Indirect effects		
				Near-water exercise	Waterfront interaction	Other leisure activities
Perception of social elements → mental health	0.303**	0.331**	- 0.028*	- 0.013**	- 0.018**	0.003
Perception of landscape elements → mental health	0.499***	0.476**	0.023**	0.011	0.022**	- 0.010
Perception of comfort elements → mental health	0.220*	0.055	0.165**	0.067*	0.082	0.016**
Perception of activity elements → mental health	0.140*	0.080	0.060**	0.024**	0.028**	0.008*
Perceptionof winter environmental elements → mental health	1.162***	0.942***	0.220***	0.089**	0.114**	0.017*

Note: *** $p< 0.001$, ** $p< 0.05$, * $p< 0.01$.

1) When individual characteristics are controlled, the perception of winter riverside environments in cold-region cities has a significant impact on older adults' mental health. Landscape, social, comfort, and activity elements all have significant positive effects, ranked in descending order of influence.

2) Perceptions of riverside spaces in winter affect older adults' mental health either directly or througha mediating effect. Specifically, perceptions of social and landscape elements can both exert direct and indirect effects through behavioral activities, whereas perceptions of comfort and activity elements influence mental health only indirectly, through their impact on behavioral activities. In addition, perceptions of riverside environments in winter have a significant direct effect on older adults' mental health.

3) The mediating effects of different types of older adults' behavioral activities between perceptions of the winter riverside environment and their mental health were confirmed. The mediating effect of waterfront interaction is the strongest, followed by near-water exercise, while other leisure activities exert the weakest effect.

4.2　Discussion

In summary, the following recommendations are proposed for the planning and design of waterfront spaces in cold-region cities in winter: 1) Enhance the attractiveness of near-water spaces for winter. First, fully consider safety by ensuring the site is level and has good anti-slip properties. Second, in terms of winter landscape, make reasonable use of color design to highlight seasonal landscape features and enhance the unique aesthetic experience of waterfront spaces in cold-region cities in winter. Finally, in terms of micro-level spatial layout, planners should fully consider the current conditions of the space and the winter activity preferences of older adults, and adapt to local circumstances to create different forms of activity spaces. Building warm pavilions, windbreaks, and other indoor rest facilities can create a relatively comfortable activity environment; (2) Improve the interactivity of winter waterside spaces. On the one hand, temporary railings and barrier-free facilities should be added to meet the needs of older adults of different ages and physical conditions for engaging with water, and use climate-friendly materials with gentle texture and low thermal conductivity to improve the age-friendliness of riverside spaces in winter. On the other hand, while safety is ensured, the forms of the shoreline should be diversified to create varied spaces for waterfront interaction; (3) Improve the accessibility of on-ice spaces in winter. At the city level, overall planning guidance for existing ice spaces should be strengthened to address the problem of too few reserved activity areas, which hinders on-ice activities. At the district level, functional zoning of on-ice spaces in winter should be improved to ensure that retail commerce brings vitality while avoiding interference with older adults' ice activities. (4) Coordinate on-ice, waterside, and near-water spaces. Achieve a value-oriented shift for riverside spaces in winter: through the coordinated design of these three spaces, shape the landscape characteristics of cold-region cities' riverside spaces, highlight the narrative of the overall landscape, and demonstrate the aesthetic value of riverside spaces. By incorporating ice-and-snow culture, planners can create a unique cultural atmosphere in cold-region riverside spaces, further strengthening older adults' local attachment and identity, and en-

hancing the cultural value of riverside spaces. Fully consider the spatial requirements of older adults' activities. Provide open spaces, diverse activity facilities, and organize regular events to enrich older adults' routines in winter and demonstrate the social value of riverside spaces. On this basis, health interventions for older adults can be achieved through riverside spaces.

Under the "Healthy China" initiative, it has become a consensus that environmental support can promote improvements in residents' health. This study investigated the pathways through which perceptions of waterfront environments in cold-region cities in winter affect the mental health of older adults. It identified the differential mediating effects of near-water exercise, waterfront interaction, and other leisure activities, and offers new insights for the optimization and enhancement of riverside spaces in cold-region cities in winter. Nevertheless, this study has several limitations. First, the survey area and sample size were limited, as only the Songhua River section in Harbin was examined in depth, so the conclusions may not fully represent riverside environments in cold-region cities and require further empirical validation. Second, the representativeness of the sample of older adults remains to be improved: although random encounter sampling was conducted across different survey units, the concentrated survey period led to some uncertainty in the final sample structure. Third, in terms of indicator selection, only the environmental elements subjectively perceived within the site were considered, while objective environment elements in the surrounding area that may affect older adults' behavior and mental health were not included. These issues should be addressed in future studies

Sources of Figures and Tables

All figures and tables in this paper are prepared by the authors.

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