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Leveraging Digital Technologies for Public Health Education in High-Density Community Spaces: A Geospatial Analysis

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Abstract: Public health education (PHE) plays a crucial role in mitigating the impact of public health crises, particularly in the context of high-density and aging populations. This study aims to address the challenges posed by these demographic trends in community public service spaces (CPSSs) by integrating geospatial and population data. Using bivariate spatial autocorrelation analysis, this research investigates the relationship between PHE and social determinants of health across 40 CPSSs in Macao. Additionally, it highlights the underutilization of digital technologies (DTs) in PHE. A non-participatory, short-term field survey and observational study were conducted to analyze PHE data quantitatively and descriptively in Macao's CPSSs. Moran's *I* and LISA index were used to test spatial autocorrelation at 90% and 99% confidence levels. The results revealed significant positive spatial correlations between the distribution of community public service institutions (CPSIs) and the population in southern Macao, as well as between the elderly population and PHE themes and formats. PHE topics predominantly focus on health/fitness, geriatrics, chronic diseases, and mental health. Despite this, PHE remains heavily reliant on offline formats, with limited integration of DTs. Challenges such as low digital literacy and limited acceptance of DTs among community workers and the public hinder their broader adoption. This study provides valuable insights for optimizing the allocation of health education resources in densely populated and aging urban areas, offering both practical recommendations and theoretical support for health policy making and implementation.

Keywords: digital technologies; public health education; community public service spaces

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1. Introduction

Since the outbreak of the global COVID-19 pandemic in 2019, the application of DTs in various industries and fields has increased rapidly, especially in the fields of medicine and healthcare. When dealing with large-scale public health emergencies, the government and medical institutions should not only pay attention to the treatment of patients but also prioritize public health services. This approach can enhance the public's readiness to deal with potential future public health crises. Especially in cities with high-density and aging populations, the dense living environment will lead to the lack of public activity spaces and a shortage of public health service resources per capita. Currently, most economically developed regions in the world are facing the challenge of an aging urban population. These problems will pose a significant public health risk to the government, health services, and the public. In the age of information technology, DTs can effectively improve the efficiency of education. However, it is currently underutilized in social PHE.

According to the World Bank website's ranking of countries and economies with open population density data in 2021, the top five countries with the highest population density values are Macao, Morocco, Singapore, Hong Kong, and Gibraltar [1]. As a place with the highest population density in the world, Macao's high-density living environment and increasingly prominent population structure problems have gradually led to more public health issues. Therefore, this paper aims to conduct a non-participatory short-term field survey of 40 CPSSs in Macao, using Macao as an example. The survey data were obtained through literature investigation, field investigation, and observation records. This paper discusses the current status of DTs in implementing PHE in densely populated urban community spaces. The main research questions include the number of instances in the 40 CPSSs surveyed in the field and the number of public service spaces in the community implementing PHE using DTs. It also explores the types of health education utilized, existing health education topics, and environmental attributes, such as regional factors related to the total population, population density, and other relevant attributes.

The research aims to use fieldwork combined with demographic and geospatial data analysis to explore the following research questions:

1: What is the status quo of applying DTs in CPSSs to facilitate PHE?

2: What are the challenges and opportunities when applying DTs to implement PHE in CPSSs in cities with high population density and aging populations?

2. Related Work

2.1. Educational Technology and Public Health

The term "technology" can be interpreted simply as a combination of tangible "hardware" devices (such as calculators, computers, handheld devices, mobile devices, smartphones, etc.) with "software" or other applications that provide an interface between the hardware and the user [2]. The impact of DTs on education has been significant since the discovery of its potential in education, which was enhanced by computer-aided instruction systems developed in the 1960s. However, there has always been a gap between the potential of online teaching in education and its actual impact on learning outcomes [3]. Despite the increasing use of computers and mobile devices in everyday life, there are few opportunities to apply technology in practical teaching scenarios [4]. Currently, the application of DTs in education is mainly concentrated in K–12 and higher education, with limited use in health education in social settings. The DTs applied in the field of education mainly include teaching videos and games combined with virtual reality (VR) and augmented reality (AR), online learning platforms, teaching integrated machines, teaching data analysis systems, student evaluation systems, etc. PHE involves educating the public on a comprehensive understanding of public health and responding effectively to complex health challenges [5]. DTs have the potential to promote health and disease prevention [6]. However, the current application of DTs in the health field focuses more on disease management than health education [7]. The application of DTs in PHE refers to the use of electronic tools to promote PHE and behavior change [8]. DTs can provide health education to the public remotely or in person through wireless communication, video, multimedia, Internet platforms, mobile electronic devices, etc. [9]. DTs can also be divided into three categories: mobile technology, non-mobile technology, and virtual reality [10]. Depending on the type of device, common "modern devices" include smartphones, tablets, wearables, gaming devices, VR and AR devices, and other VR devices. The other category is "legacy devices", such as desktop computers [8]. DTs can help reduce pressure on government healthcare systems by facilitating health education to the public. This can reduce the burden on public service workers and educators [11]. At the same time, PHE can effectively improve the public's health literacy, reduce the differences in learning results caused by the differences in knowledge background and cognitive levels through DTs, promote the exchange and understanding of health education information, and enhance the equity of PHE.

2.2. Application of DTs to Promote PHE in CPSS

In this paper, a community is defined as a social group composed of the residents in a specific area. Urban communities typically have large populations, dense housing, and diverse demographics. CPSSs serve as a physical location for residents to engage in daily leisure activities and also hold spiritual significance [12]. In densely populated cities, there is often a struggle with high-density housing, which gradually diminishes the availability of public space in urban neighborhoods, resulting in CPSSs [13]. Utilizing DTs effectively for PHE in CPSSs can enhance public digital literacy and health literacy, offering an efficient strategy to address public health challenges in densely populated cities with aging populations. The use of electronic technologies to support public health has been a prominent topic of global discussion. In particular, certain electronic health (eHealth) and mobile health (mHealth) tools can support and improve relevant workplace health promotion. Crilly developed a model that incorporates e-health tools into community pharmacy public health services, thoroughly examining how this digital approach enhances and supports the electronic operations of pharmacies [14]. By implementing electronic tools, community pharmacies can more effectively provide health services to the public, improving medication management and facilitating patient interactions [15]. In addition, Chiccarelli's research focuses on the public health impact of telemedicine on adolescent contraceptive care [16]. Paulino et al. proposed a life cycle model to improve workplace health promotion to improve the theoretical construction in the field of public health [17]. Unfortunately, despite the great efforts made by electronic technology in public health, the actual situation of the use of electronic technology is not optimistic. Most of the relevant studies have selected cities that are not unique and have relatively rich medical resources [18,19]. It is clear that when nations and regions formulate and implement policies or actions to encourage the public sector to adopt existing technological innovations, the level of acceptance and areas of focus may vary [20]. Particularly in densely populated areas, the factors that need to be addressed and considered may exhibit distinctive characteristics [21]. Therefore, we decided to choose Macau, one of the most densely populated regions in the world, as a representative to explore the issues related to public health in high population density.

3. Methods

3.1. Data Sources and Ethics

The research data includes two types: statistical data and spatial data. Statistical data primarily originate from public population and regional statistics released by the Statistics and Census Service of Macao, as well as data on PHE derived from field surveys. Spatial data were collected from the geographic information of the study area provided by the Baidu Map open platform. ArcGIS10.6 software was used to pinpoint locations and create maps. Field surveys involved gathering themes from posters and promotional materials distributed by community service institutions in Macao.

It is important to note that potential ethical and privacy concerns may arise when analyzing the themes of these materials. Many elderly individuals and marginalized groups face challenges in accessing and interpreting digital tools and resources, which can contribute to digital literacy bias in the promotional efforts of community service institutions. Although this bias does not affect the thematic analysis in this study, addressing cultural differences and digital literacy disparities among elderly populations is a critical area for future research.

3.2. Data Analysis

The population, geospatial data, and field survey data of Macao were analyzed. The heat map analysis was conducted on the regional distribution of the population and the number of CPSSs in Macao. Additionally, a descriptive analysis was performed on the number of PHE topics, and the data related to the format of PHE. Based on bivariate spatial autocorrelation analysis in spatial econometrics theory, spatial autocorrelation is an important indicator of the correlation between a phenomenon or an attribute value in the focal region and the corresponding phenomenon or attribute value in neighboring regions. Moran's I is an effective tool for measuring spatial autocorrelation between geographical elements and the attribute values being analyzed based on the location and value of those elements [22]. This study utilized GeoDa 1.18.0.0 software, employed the bivariate spatial autocorrelation model established on Moran's I, and examined the calculation of the local Moran index and LISA cluster map to investigate the spatial correlation among community, population, and PHE in Macao. Local spatial autocorrelation is typically measured by Moran's I index, which is calculated by Equation (1) [23]:

$$I = \frac{N\sum_{i=1}^{N}\sum_{j=1}^{N} w_{ij}(x_i - \overline{x})(x_j - \overline{x})}{W\sum_{i=1}^{N}(x_i - \overline{x})^2} \quad (1)$$

where: N is the number of spatial units indexed by i and j; x is the variable of interest; $\overline{x}$ is the mean of x; w_{ij} are the elements of a matrix of spatial weight with zeroes on the diagonal (i.e., w_{ii} = 0); and W is the sum of all individual weights w_{ij}.

3.3. Location of Study

Macao had a total population of 672,800 by the end of 2022, according to the seventh National Census Bulletin released by the National Bureau of Statistics [24]. According to the data from the Statistics and Census Service of Macao, the population density of Macao in 2022 was 20.6 per 1000 square kilometers, making it the highest populated density globally. Given this exceptionally high density and in line with recent research [25], Macao was selected as the study location to examine the implementation of PHE in densely populated urban environments. The study encompasses 23 distinct areas across the four regions of the Macao Peninsula, Taipa, Coloane, and Cotai City (Figure 1). Figure 1 provides a visual representation of the geographic distribution of these areas. Before selecting the sites for field investigation, we conducted research on relevant CPSIs through literature reviews and the official website of Macao. After considering factors such as types of institutions, target populations, and affiliations, a total of 40 sites were ultimately selected as survey locations for this study.

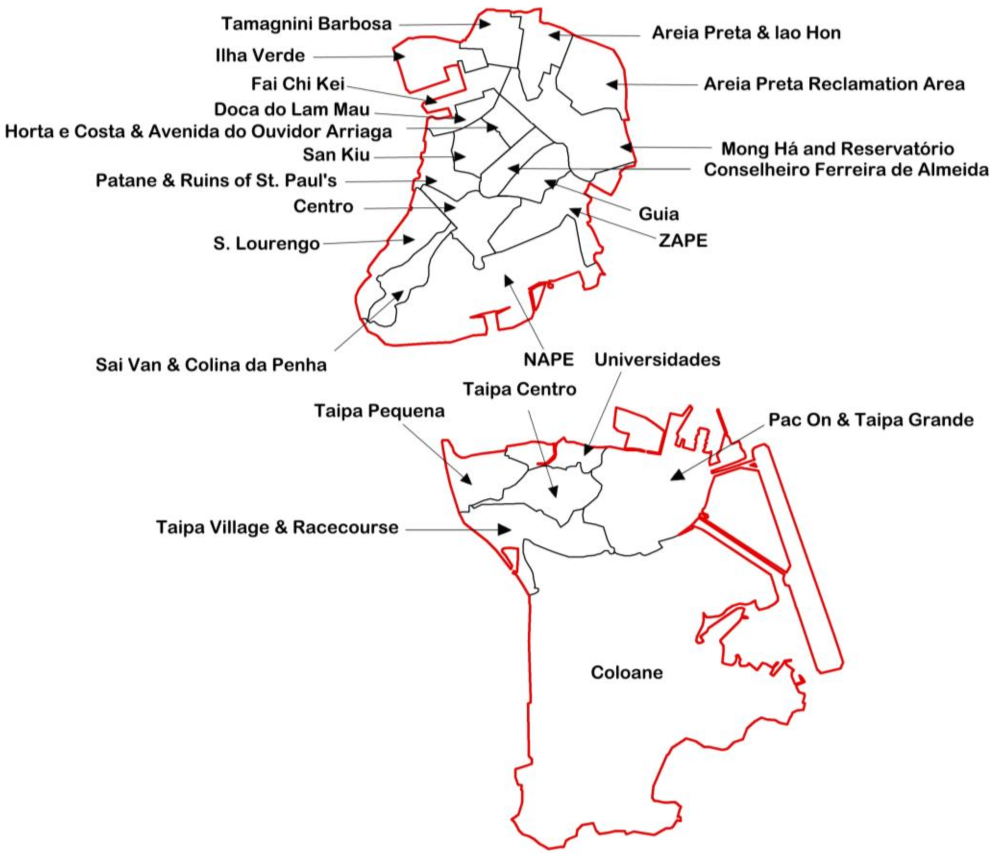

Figure 1. The area of research.

4. Results

4.1. Descriptive Analysis

From the perspective of the regional distribution of the Macao population, the resident population is mainly concentrated in the northeast side of the Macao Peninsula, the central area of Taipa, and the areas of Coloane and Cotai City (Figure 2a). From the perspective of age distribution, the population distribution in the age group of 0–14 years is essentially identical to that of the total population (Figure 2b). The population aged 15–24 is mainly concentrated in the northeast and southwest of the Macao Peninsula, as well as in Taipa, Coloane, and most areas in the east of Cotai City (Figure 2c). The number of people aged 25–44 and 45–64 is the largest, and the population distribution is the same as the total population (Figure 2d,e). The number of people over 65 years of age aligns with the general population trend (Figure 2f). The regional distribution of males and females mirrors that of the total population, although females are proportionally more numerous than males (Figure 2g,h). According to the international standard for the proportion of the elderly population, which is the percentage of the population aged 65 and above in the total population reaching more than 7% as a criterion for a country or region to be classified as an aging society, Macao's proportion has reached 12%, surpassing the standard by almost half. It shows that Macao, like most developed regions and countries, has entered an aging society.

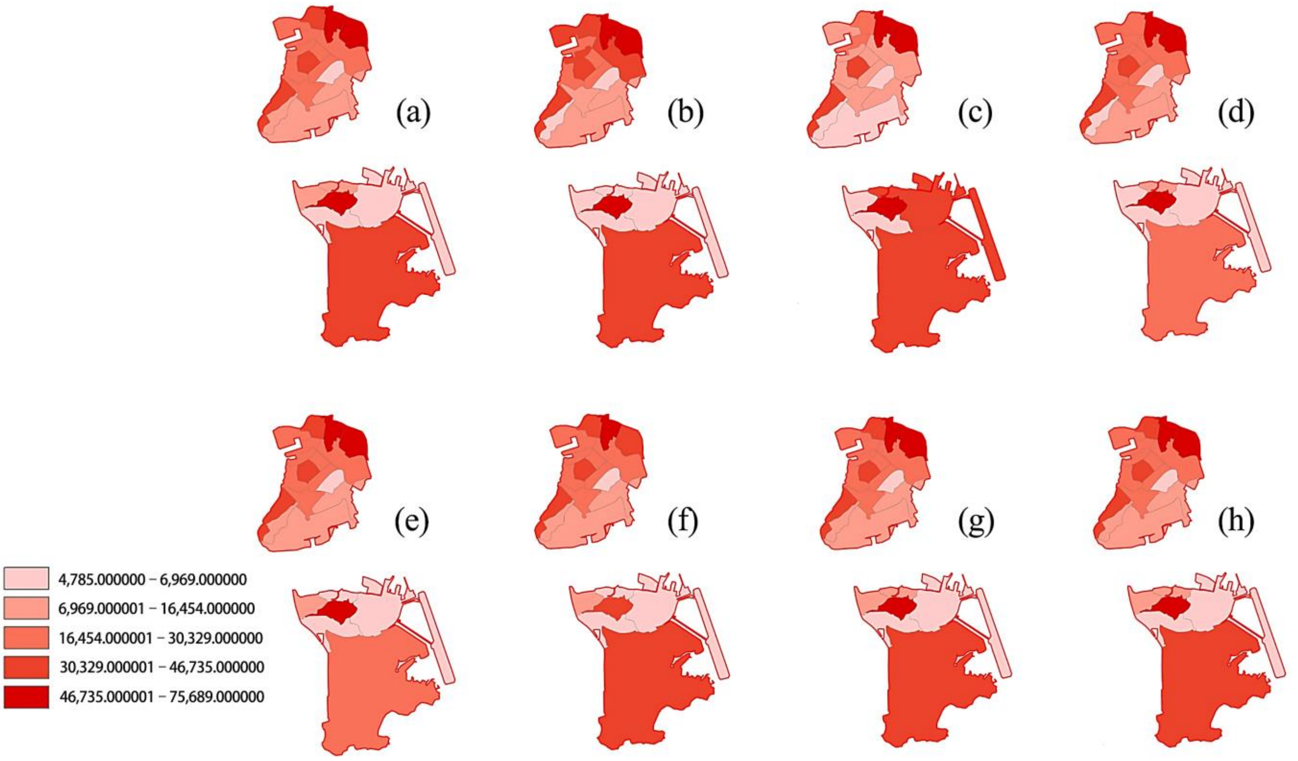

Figure 2. (**a**) The distribution of the whole resident population, (**b**) Age distribution of the resident population aged 0–14 years, (**c**) Age distribution of the resident population aged 15–24 years, (**d**) Age distribution of the resident population aged 25–44 years, (**e**) Age distribution of the resident population aged 45–64, (**f**) Age distribution of the resident population over 65 years of age, (**g**) Distribution of male resident proportion, and (**h**) Distribution of female resident proportions.

According to the Statistics and Census Service of Macao, the total population of Macao as of the first quarter of 2024 is 686,400. According to the 2021 Macao Census data, there are 72 institutions related to public health and social services in the Macao Peninsula, Taipa, Coloane, and Cotai City. On average, each region has about three social service agencies related to public health, with an average of one public service agency per 9533 people.

Among them, 43 CPSIs are dedicated to serving the elderly, representing half of all service institutions. This highlights the significance of the elderly population in public services. Based on the heat map illustrating the number of CPSIs in Macao (Figure 3), it is evident that, when considering the regional distribution of the resident population in Macao, although both the Macao Peninsula and Taipa have high-density populations, the CPSIs are more concentrated in the northern area of the Macao Peninsula.

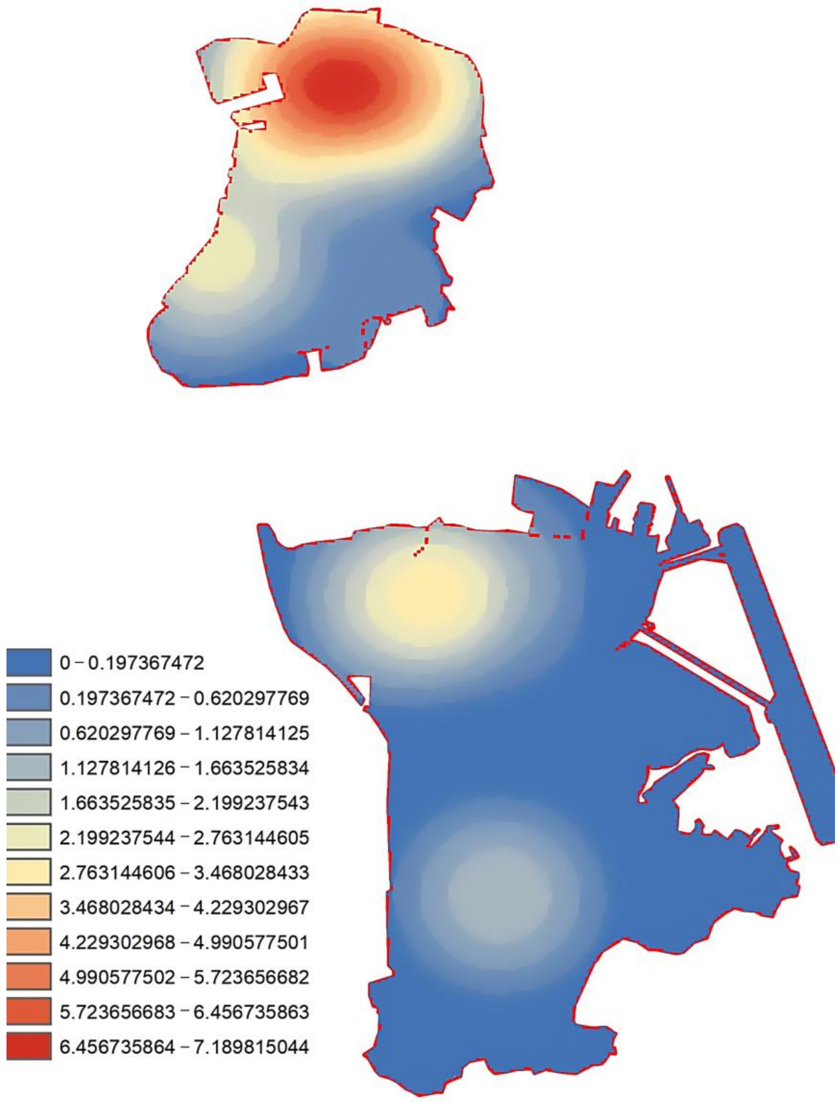

Figure 3. Heat map of the spatial distribution of CPSIs in Macao.

The 40 CPSIs surveyed can be divided into three categories: elderly care services, comprehensive community services, and specific population services (Table 1). According to the survey data statistics, twenty-one out of the 40 CPSIs surveyed have implemented PHE (Table 2). After classifying and sorting out the themes of health education, they can be categorized into ten educational themes (Figure 4): health/fitness, geriatric diseases and chronic diseases, mental and psychological health, health preserving, female health, children's health, sex education, cancer, first aid knowledge, and education for life. The top three areas are health/fitness, geriatric and chronic diseases, and mental health. Among them, eleven CPSIs conduct health education activities on health and fitness-related topics, such as traditional Chinese medicine aerobics, yoga, and dancing. Additionally, nine institutions provide health education for the elderly and chronic diseases such as Alzheimer's disease, gout, rheumatoid arthritis, high blood pressure, and hepatitis. Furthermore, nine institutions are engaged in mental health education, focusing mainly on female mental health and children's mental health education. In general, CPSIs in Macao primarily focus on providing health education to the elderly, children, women, and vulnerable groups. According to the survey data, the Macao Government places great importance on the health, fitness, and mental well-being of the public. These areas encompass a broad spectrum of public health issues and constitute a fundamental pillar of health education.

Table 1. Category, content, and quantity of CPSIs within the scope of research.

Classification of Institutions	Service Content of the Institutions	Amount
Services for the Aged People	Elderly center, Elderly care center, Elderly service center, Nursing home, Elderly activity center	18
Integrated Community Services	Community Center, Community Service Center, Neighborhood Associations, Comprehensive Service Center, Service Office	17
Specific Population Services	Women's Federation, Family Service Center, Youth Community Center, Youth Service Center, Parent-Child Center	5

Table 2. PHE implementation status in CPSSs.

Local Areas	Spatial Formats	Education Formats	Education Themes
Macao Peninsula	Indoor Space	Posters, Education Group	Fitness/Health
Macao Peninsula	Indoor and Outdoor Space	Brochures, Lectures, Match, Offline Activity, and Workshop	Health Preserving, Mental, and Psychological Health
Macao Peninsula	Indoor Space	Lectures, Education Group	Health Preserving, Sex Education, Fitness/Health, Mental and Psychological Health, and Female Health
Macao Peninsula	Indoor Space	Offline Course, Lectures, Offline Activity	Female health, Fitness/Health, Chronic Diseases, and Cancer
Macao Peninsula	Indoor Space	Offline activity, Education Group	First Aid Knowledge, Sex Education for Children
Macao Peninsula	Indoor Space	Lectures	Fitness/Health, Geriatric Diseases and Chronic Diseases
Macao Peninsula	Indoor Space	Education Group, Workshop	Health Preserving, Children's Health, and Fitness/Health
Macao Peninsula	Indoor Space	Brochures, Offline Activity	Cancer, Female Health, and Mental and Psychological Health
Macao Peninsula	Indoor Space	Offline Course, Offline Activity	Fitness/Health, Sex education, and Mental and Psychological Health
Macao Peninsula	Indoor and Outdoor Space	Offline Course	Health Preserving, Fitness/Health, and Mental and Psychological Health
Macao Peninsula	Indoor Space	Offline Course, Offline Activity	Children's Health

Table 2. *Cont.*

Local Areas	Spatial Formats	Education Formats	Education Themes
Macao Peninsula	Indoor Space	Offline Course, Brochures	Fitness/Health, Geriatric Diseases and Chronic Diseases
Coloane	Indoor Space	Lectures	Geriatric Diseases and Chronic Diseases
Coloane	Indoor Space	Offline Activity, Lectures	Mental and Psychological Health
Taipa	Indoor Space	Offline course, Offline Activity, and Brochures	Fitness/Health, Geriatric Diseases and Chronic Diseases, and Health Preserving
Taipa	Indoor Space	Education Group	Education for Life, Female Health, and Children's Health
Taipa	Indoor and Outdoor Space	Offline Course, Offline Activity, and Leaflets	Geriatric Diseases and Chronic Diseases
Taipa	Indoor and Outdoor Space	Workshop, Offline Course, and Online Video	First aid knowledge, Sex education, and Mental and Psychological Health
Taipa	Indoor and Outdoor Space	Offline Course, Offline Activity	Education for Life, Health Preservation, and Geriatric Diseases and Chronic Diseases

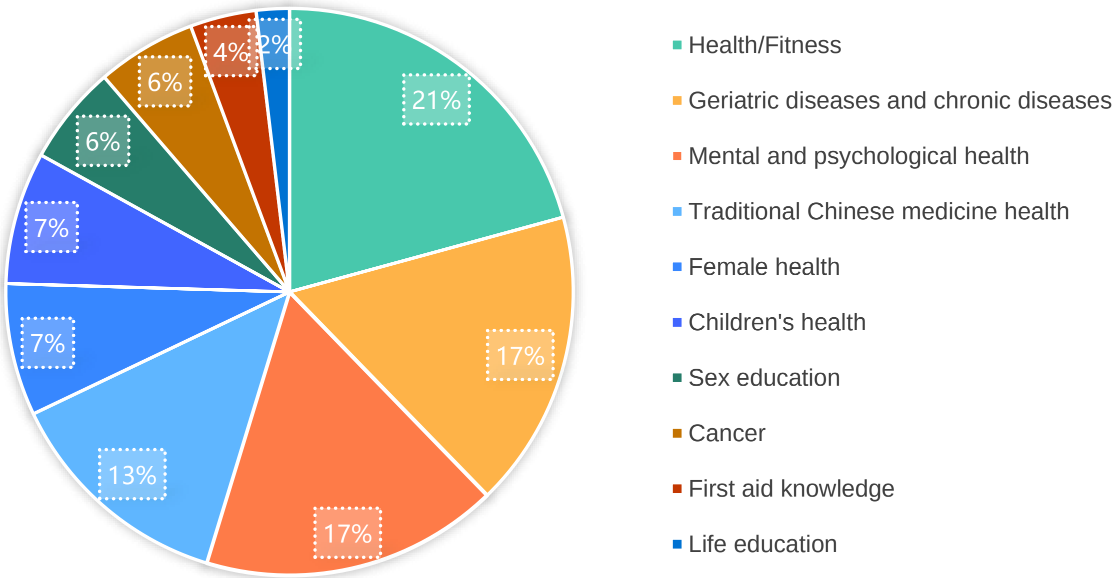

Figure 4. Types and number of PHE topics implemented.

The means of health education can be mainly divided into two categories: offline and online formats. The online format mainly consists of videos, games, and online lectures. The offline format primarily includes in-person courses, brochures, posters, leaflets, educational groups, workshops, lectures, and offline participation activities. The most widely used approach is to offer offline health education courses to the public. A total of eleven institutions offers in-person health courses to the public, including long-term and short-term options. These courses may be either free or paid. Additionally, free brochures, leaflets, and posters are provided to the public in CPSSs. Eight institutions provide free health promotion materials to the public in CPSSs. This format is fast and convenient, achieving the purpose of health education to the public with the least labor and time cost, and is widely used in CPSSs. In addition, eight institutions offer in-person health education activities to the public. Offline health education activities come in various formats and tend to be more interactive and engaging than traditional courses or reading health materials. This makes them a more popular and acceptable format of health education for the public (Figure 5).

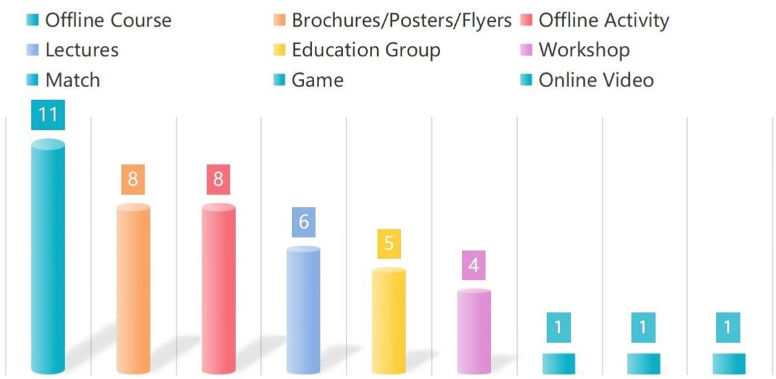

Figure 5. Type and number of forms of PHE implemented.

From the perspective of spatial, only four out of the twenty-one CPSIs have outdoor areas designated for health education activities, whereas the other seventeen institutions solely offer indoor spaces. The outdoor space, in the format of courtyards, small parks, and small squares, can provide a richer educational environment. However, the number of CPSIs with outdoor spaces is very limited. PHE is commonly conducted indoors, primarily in classrooms, activity rooms, open halls, meeting rooms, and other similar spaces.

4.2. Spatial Correlation Analysis

The scatter plot of the Moran index concerning the regional area and the population of residents aged 65 and over, as illustrated in Figure 6, reveals a Moran's I = 0.055. This indicates a slight positive spatial autocorrelation between the regional area and the population of residents aged 65 and older. The results of the LISA significance level diagram (Figure 7a) and the clustering diagram (Figure 7b) indicate a significant clustering pattern in the regions of Coloane and Taipa at a 99% confidence level (p = 0.001). This "high-high" relationship demonstrates a positive spatial correlation, suggesting a certain degree of association between the elderly population and spatial distribution in these two areas.

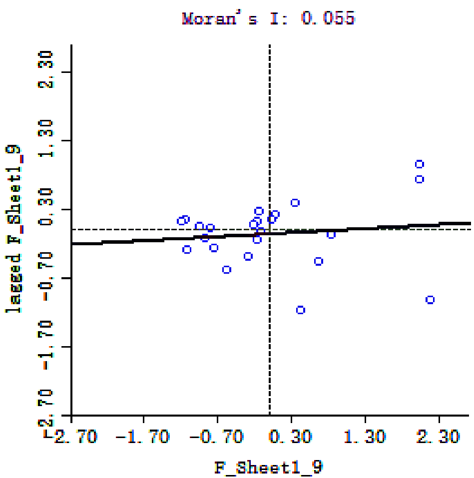

Figure 6. Scatter plot of Moran's I index for regional area and resident population over 65 years of age.

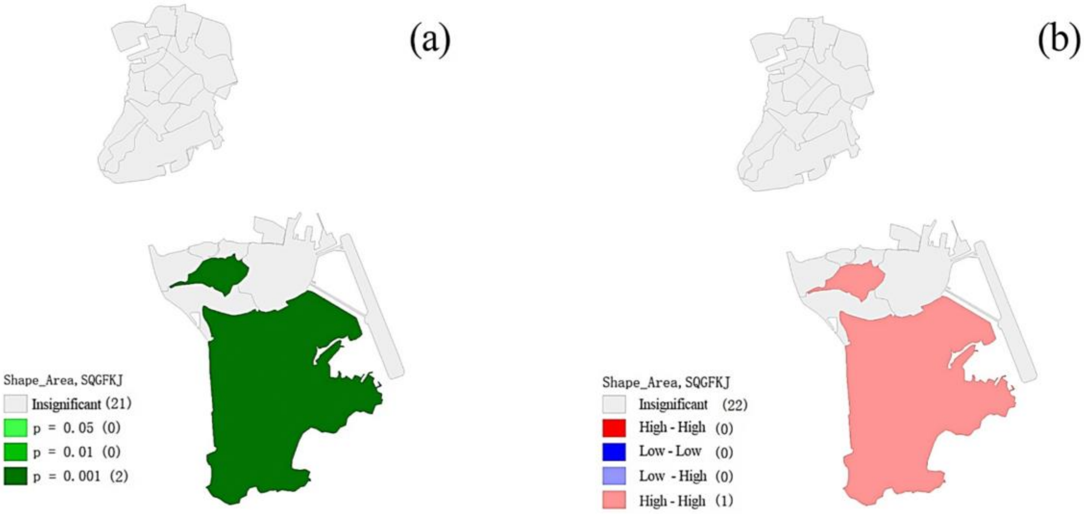

Figure 7. (**a**) The significant relationship between regional area and resident population over 65 years of age, (**b**) The cluster diagram of the relationship between regional area and resident population over 65 years of age.

The analysis of bivariate spatial autocorrelation to CPSSs is elucidated through the LISA significance level diagram (Figure 8a) and clustering diagram (Figure 8b). These visual representations illustrate the intricate relationship between the geographic area under consideration and the distribution of CPSSs. The results indicate that only Coloane Island exhibits a significant aggregation pattern at a 99% confidence level ($p = 0.001$), suggesting a pronounced clustering of CPSSs within this specific region. This high-high association reveals a positive spatial correlation, indicating that areas on Coloane Island with greater levels of CPSSs are spatially concentrated. The analysis presented in the LISA significance level diagram (Figure 9a) and the cluster diagram (Figure 9b) elucidates the relationship between the elderly population and the spatial distribution of CPSSs. The findings reveal a significant correlation in the southern part of Coloane in Macao, achieving a confidence level of 99% ($p = 0.05$; $p = 0.001$). However, this significant association is not observed in other regions of Macao. Within the southern area of Coloane and the central region of Taipa Island, three locations exhibit a strong positive correlation. This pattern indicates that in these areas, an increased number of elderly residents is associated with a higher availability of community public services. The LISA significance level diagram (Figure 10a) and clustering diagram (Figure 10b) provide critical insights into the relationship between the elderly population and the themes of PHE in Macao. The analysis reveals a significant correlation between the number of elderly residents and the variety of PHE topics in both the southern region of Macao and the central area of Taipa Island, with confidence levels found to be 99% and 90% ($p = 0.001$; $p = 0.05$), respectively. Specifically, there exists a strong positive correlation between the southern area of Coloane and the central area of Taipa, suggesting that regions with a higher elderly population tend to have a greater number of available PHE topics. This trend indicates that public health education resources may be more concentrated in areas that have a larger elderly demographic, potentially reflecting targeted efforts to address the needs and health literacy of this population group. Conversely, a weak negative correlation is observed in the northeastern area of Taipa, indicating that the relationship between the elderly population and PHE themes is less pronounced in this region. This suggests that factors influencing PHE topics may differ in the northeastern Taipa area and that the elderly population may not significantly drive the spatial correlation phenomenon observed elsewhere.

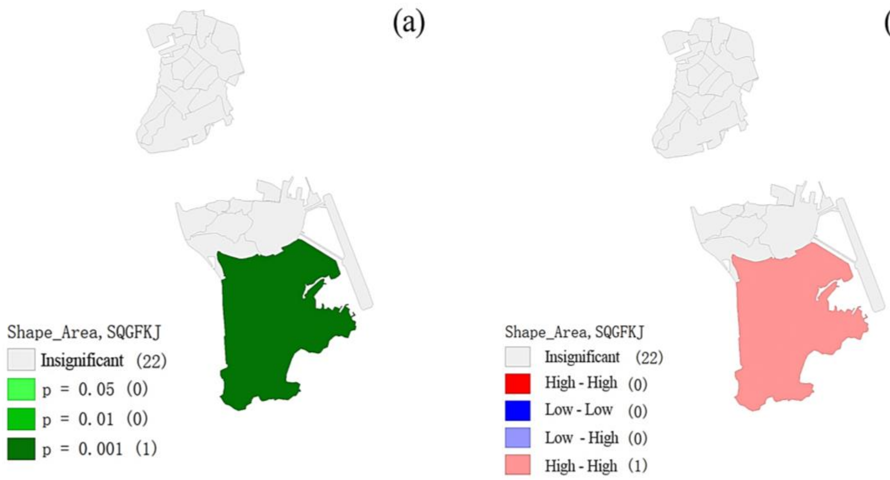

Figure 8. (**a**) The significant relationship between regional area and the number of CPSSs, (**b**) The cluster diagram of the relationship between regional area and the number of CPSSs.

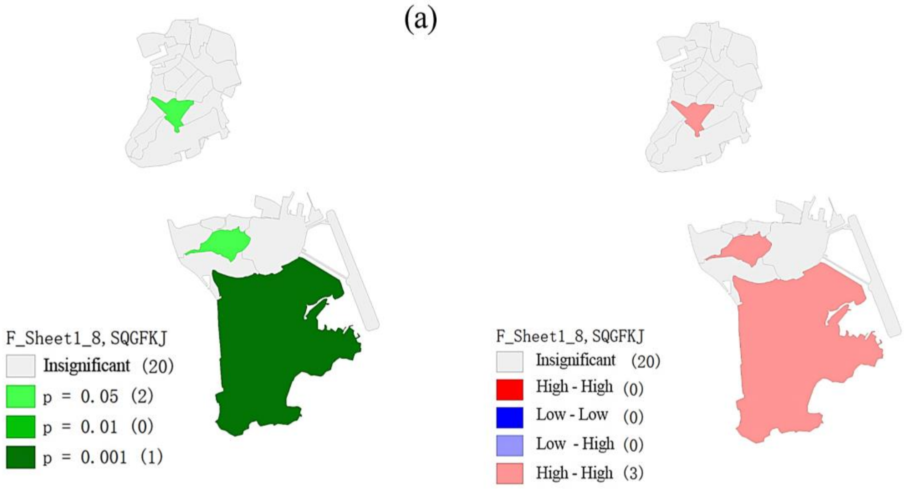

Figure 9. (**a**) Significance diagram of the relationship between the number of elderly population and the spatial distribution of community public services, (**b**) Cluster diagram of the relationship between the number of elderly population and the spatial distribution of community public services.

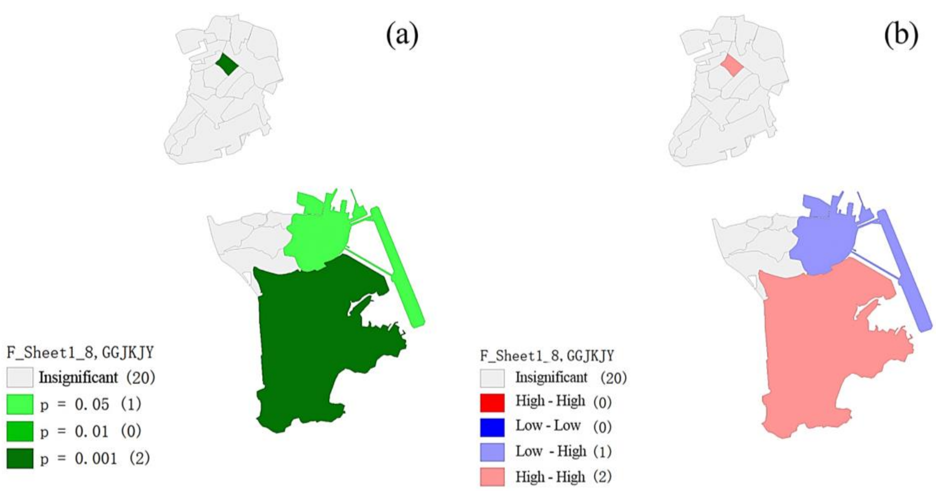

Figure 10. (**a**) The significant relationship between the number of elderly population and the theme of PHE, (**b**) The cluster diagram of the relationship between the number of elderly population and the theme of PHE.

5. Discussion

5.1. Challenges

5.1.1. Health Education in CPSSs Lacking the Integration of DTs

Through field investigation, it is found that PHE has been widely implemented in CPSIs in Macao. However, the current approach to implementing PHE is mainly through offline means, commonly through offline courses, events, or lectures, or through the posting of health promotion posters in the CPSSs and the provision of health brochures or leaflets. The most common multimedia devices used in offline course activities are those that play PowerPoint presentations or videos to assist PHE teaching. At present, DTs are rarely used in PHE, both online and offline. Only a small percentage of CPSIs use DTs in the PHE process, including in the format of online lectures through the website, the production of health education videos, and online interactive games. Most of the health education courses or activities offered by CPSIs are organized by their staff, and a few employs external experts or teachers to give lectures or teach. The number and variety of DTs used in CPSSs are very limited. The main factor hindering the widespread adoption of DTs in PHE is likely to be the relatively low level of digital literacy among community workers working in PHE, teachers, and the general public receiving health education. The low level of digital literacy among community workers and teaching personnel is the primary reason why DTs are challenging to be widely adopted in PHE. They are responsible for implementing educational practices, and their limited digital literacy can hinder the early-stage implementation of DTs in PHE. While the general public receives knowledge through DTs in the process of PHE, they lack more digital literacy in health education than daily digital literacy. To effectively improve the application of DTs in PHE, it is necessary to improve the digital literacy of these two groups of people at the same time.

5.1.2. Acceptability of Educational Behavior Implemented by DTs in a Social Environment

During the global COVID-19 pandemic and other public health crises, government and healthcare sectors continue to face challenges such as lack of funding, inadequate resource allocation, limited technological resources, and insufficient infrastructure development. These obstacles hinder the widespread adoption of DTs in PHE [26]. In the context of the increasingly serious global population aging trend, implementing health education in high-density urban spaces combined with DTs will be a challenge. From a pedagogical and sociological perspective, drawing on social learning theory and the social determinants of health. From the perspective of the role and influence of PHE, individual learning behavior is not only affected by the learning environment, personal learning behavior, and learning motivation, but also by individual income, education level, occupation, and other factors [27,28]. Research suggests that social determinants may play a more significant role in influencing health than medical care or making the right lifestyle choices. Research by De Santis et al. found that individuals with higher levels of education, greater income, and advanced digital skills are more likely to derive benefits from adopting healthy behaviors through DTs [29]. Older people, however, have lower digital skills, which makes it more challenging for them to access health education services provided through DTs compared to younger individuals [30]. Although some older individuals are willing to experiment with new technologies, the learning process through DTs will take much longer for them compared to younger individuals [31]. Older people are often excluded from engaging with DTs and services due to their lack of digital literacy, as well as inadequate access to necessary equipment and Internet connections. Access to the Internet and DTs affects older individuals' ability to obtain health information [32]. Moreover, older people's acceptance of DTs to promote their health requires facilitators to further encourage and advance the use of DTs [33–35]. Therefore, understanding how to utilize DTs to enhance the elderly's acceptance of health knowledge, bridge the digital gap between technology and knowledge acquisition, and subsequently enhance the digital health literacy of the elderly is a crucial issue that requires resolution. De Santis et al.'s study also found that in real-world conditions, DTs use declines if its relevance to health is not clear [8]. Governments and policymakers also need to be aware of the risks of using DTs in PHE when promoting their use. Meates et al. concluded that the impact of DTs on health and education has both benefits and risks. They suggested that governments and relevant personnel should carefully consider the risks when promoting DTs [36].

5.2. Opportunities and Suggestions

According to the survey and analysis results, half of the CPSSs in Macao have implemented PHE, but it is not balanced according to the population and regional distribution. It can be found that CPSSs that can implement PHE are more concentrated in the old city areas where the economy and business are good, and the population mobility is greater. Although the proportion of the population in newly developed areas continues to rise, the number of supporting CPSSs has not formed a proportion, resulting in the public in these areas not obtaining timely and adequate PHE. In the case of the same population density, older people in the new urban area find it more challenging to access PHE and DTs support than those in the old urban area. Therefore, the government and relevant departments should pay attention to the public health resources input in the newly developed areas and improve the regional inequality of health education resources.

With the increasing popularity of DTs in the field of medicine and healthcare, the associated costs of DT applications are decreasing, and technical resources are becoming more abundant. This trend allows DT to be widely utilized in PHE within real-world settings. According to the survey results in Macao, many cities with high-density and aging populations, such as Macao, conduct PHE in CPSS, but they lack the application of DTs. The application of DTs in health education and services is the future development trend of public health. In the future, DTs are expected to enhance the acceptance of health education among the elderly, individuals with lower education and income levels, and those with poor digital skills. It will also improve the effectiveness of PHE and reduce the cost of social education. Padilla-Gongora et al. found that older adults are interested in learning DT [37]. According to the results of random interviews with elderly people in the field survey, they have a positive attitude towards learning DTs, and their acceptance of DTs is the main obstacle to their learning of health knowledge through DTs. Reine et al.'s research shows that although higher levels of education are linked to increased use of DTs, they are not essential for accessing information [38]. If the appropriate DT is selected for the health education needs of the elderly population, it is necessary to deeply understand the needs of the elderly and their acceptance of technology to customize and design effectively. Through the investigation, it was found that a combination of questionnaires and interviews is more suitable for CPSIs service personnel to understand the needs of the elderly. However, since most elderly people have difficulties in reading and filling out questionnaires, the interview method is more appropriate for further research on the needs of the elderly. Additionally, interviews with PHE policymakers and relevant experts will also aid in understanding the policy opportunities and challenges in the implementation of DTs.

By enhancing the learners' positive experience with DTs, the successful implementation of any health education program is inseparable from a positive user experience. Only by strengthening the positive user experience can long-term effective health education behaviors be sustained [39]. The research by Pang et al. demonstrates that involving users or target groups in participatory design is advantageous for developing health information resources using online platforms. Involving older people in the design process of DTs and PHE is also one way to address the need [40]. The application DTs benefits both educators and the public. DTs can offer easily accessible and understandable health knowledge and information to the public, enhance the overall health literacy of the population, and provide convenient educational technology resources for public services and staff. Utilizing DTs to enhance the efficiency and convenience of health education in CPSSs presents an opportunity for the application of DTs in PHE.

According to the field survey data, it is evident that the elderly population actively participates in PHE activities. According to a random interview conducted with the elderly group during the field survey, the majority of elderly individuals expressed satisfaction with the health education activities or courses offered by the current CPSIs. Additionally, the staff at the CPSIs also endorse the institutions of various PHE activities. Enhancing the confidence of the elderly population and community service workers in utilizing DTs for health education presents an opportunity for the widespread adoption of DTs in CPSSs for health education.

Specifically, it is necessary to explore how to utilize DTs to help understand and convey health knowledge and information more easily when implementing PHE for the elderly through specific digital tools. For instance, certain mobile technologies and immersive technologies can provide health education through applications and online content, with their dynamic nature enabling users far from community service centers to access information more actively [41]. Some studies have shown that combining user-friendly interfaces with large fonts, voice accessibility, and simplified navigation can make mobile technology easier for older participants to use [42]. Immersive technologies, in particular, can offer a more engaging experience through interactive health education. Some lightweight VR systems are pre-installed with simplified and intuitive health education modules tailored to the needs of elderly users. For example, using VR technology to simulate scenes in elderly rehabilitation to manage elderly exercise and cognitive training can enhance the elderly's confidence in digital technology [43]. However, challenges such as high costs, complex technical optimization, and skepticism among elderly users regarding their relevance result in low acceptance. In practical implementation and promotion, careful selection and optimization of these tools remain essential. User-centered and participatory design can be a feasible direction towards PHE solutions for the elderly [40].

In addition, with the development of AI, more and more AI-based educational technologies are being used, adding vitality to the field [44]. In future work, we will continue to pay attention to the role and contribution that AI can bring to public health to further support the development of PHE.

5.3. Limitations

There are some limitations to our study. Firstly, during the survey site selection process, we relied on data from the official government website, potentially missing out on CPSIs that were not thoroughly screened. Secondly, the study did not conduct in-depth interviews with the general public or with relevant government and agency personnel. More research is needed in the future on the confidence and acceptance of the use of DTs among public and community service workers. The study will continue with a questionnaire survey of the public participating in PHE, as well as interviews with staff engaged in social and public health services and relevant experts.

6. Conclusions

Effective PHE through CPSSs and DTs can address urban challenges related to high-density populations and aging infrastructure. This survey reveals that current PHE formats are mainly offline, focusing on health, fitness, geriatrics, and chronic diseases among the elderly. By combining geospatial and population data, we analyze the relationship between PHE and social health determinants. The 40 surveyed CPSSs in Macao are categorized into elderly care, community services, and specific population services, with 21 providing PHE. Health education themes include health/fitness, geriatric and chronic diseases, and mental health, primarily delivered offline and indoors. Spatial analysis shows a stronger correlation between CPSSs and the population in southern Macao, as well as a significant link between the elderly population and education themes. Challenges in utilizing DTs include low adoption rates and insufficient acceptance of health education behaviors. This study highlights the opportunity to enhance DT integration into PHE, suggesting policies to bridge health literacy gaps, improve accessibility, and increase PHE effectiveness, thereby facilitating the dissemination of health knowledge and boosting confidence in DTs.

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