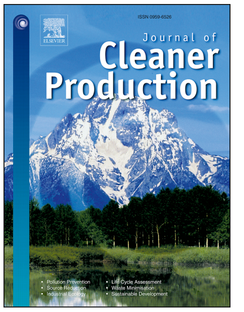

Piloting a capital-based approach for characterizing and evaluating drivers of island sustainability- An application in Chongming Island

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Piloting a capital-based approach for characterizing and evaluating drivers of island sustainability- an application in Chongming Island

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Abstract

Islands have been a focal point of sustainable development efforts. To understand the dynamic evolution of island sustainability is of great importance. In this study, a capital-based approach is piloted for measuring sustainability in Chongming island along with its interactions with nearby mainland Shanghai, and to estimate the dynamic changes along with its responsible drivers. Initially, as per the capital-based approach, a three-tier indicator system with 31 indicators is developed to reflect sustainability by five capitals, namely, natural, social, human, financial and physical capitals. Subsequently, a detailed analysis is conducted to analyze the dynamic changes of each capital from 2000 to 2017 for both Chongming and mainland of Shanghai. Results show that: natural, physical and financial capitals followed a significant increasing trend, whereas a slight decline was observed in social capital. Also, no specific trend was noted in human capitals for both study regions. Furthermore, as compared to the island, mainland seems to develop a higher sustainability for the respective time span. It is recommended that Chongming island should focus on strengthening social and human capital in future. A wider and new public-private partnership is encouraged to improve public participation. This framework clearly depicts the dynamic evolution of sustainability, would help stakeholders to identify the restricting elements hindering the overall sustainable development, make it understandable and comparable for decision makers to monitor gaps and proposing initiatives to reduce inequalities.

Keywords

Islands, Sustainability Index, Sustainable Development, Indicator System, Capital

1 Introduction

Islands are vulnerable to global climate, environmental and socioeconomic changes and thus become a focal point of sustainable development efforts (Bass and Dalal-Clayton, 1995; Maul, 1996; Kerr, 2005). Due to limitations in the characteristics of islands such as, small area, geographical isolation, and relatively fragile ecosystems (Woodroffe, 2008; Nunn, 2009), islands are facing a vast restriction in development as compared to the neighboring mainland. Continental islands are bodies of land that lie on the continental shelf of a continent (Beate M.W. Ratter, 2018). Among all types of continental islands, fluvial islands are particularly vulnerable as they typically locate in coastal flood-plains, often lack geo-stability over decades to millennia, face uncertain disturbances from river, ocean as well as nearby coastal socio-ecological systems with relatively small areas and flat topography (Osterkamp, 1998). Meanwhile, unsustainable development and utilization of human-induced factors (e.g., human-induced subsidence) often exacerbate the islands’ environmental vulnerability. In the meantime, climate change has induced uncertainty in estimating the parameters and produced a tremendous impact on the physical and chemical ecosystems for small islands and Small Island Development States (Duvat et al., 2017; Ourbak and Magnan, 2018; Petzold and Magnan, 2019). With new stakes of the Anthropocene in islands context, the anthropogenic factors should not be ignored in island sustainability studies (Chandler and Pugh, 2018; Pugh, 2018; Wu et al., 2019).

With the footprint from the Millennium Development Goals to the Sustainable Development Goals (SDGs), sustainability has been growing explosively over the past few decades (Kates et al., 2001; Robert et al., 2005; United Nations, 2015). Its conceptual framework has evolved in various disciplines such as social-ecological systems, environmental policy and management, biology, civil engineering, etc. (Folke et al., 2002; Kuhlman and Farrington, 2010; Bettencourt and Kaur, 2011). The study on island sustainability has focused on tourism (Lim and Cooper, 2009), fisheries (Newton et al., 2007), climate change (Hay, 2013) and ecosystem service (Feagin et al., 2010). However, despite its popularity and frequent application, there is limited understanding of how to assess and measure sustainability of islands as a complex social-ecological system. Thus, a study that systematically assesses the state of sustainability in an island is imperative. There is also a need for improvement to account for dynamics of sustainability over time and across space (Xu et al., 2020). Further, it provides a better understanding and landmark to the islands that are yet to be developed globally. Evaluation of sustainability index can portrait a better decision-making policies and adjustment for the island development.

Quantitative methods for constructing sustainability metrics is a rapidly developing area of sustainability research (Parris and Kates, 2003; Hák et al., 2016). Debates are ongoing for the optimal selection of suitable indices that best describe sustainability in present and future scenarios. Shi et al. (2004) conducted a sustainability assessment for the Chongming island, China’s largest fluvial island, between 1990 and 2000 from three sub-systems, namely, environment and resources, economic development, and society sustainability index. Costanza et al. (2007) suggest a four-capital framework to monitor sustainable well-being and sustainability by built, natural, social and human capitals. Sharifi and Murayama (2013) reviewed seven selected neighborhood sustainability assessment tools and indicated that most of the tools are not doing well regarding the coverage of social, economic, and institutional aspects of sustainability. Polido et al. (2014) reviewed sustainability and environmental assessment in islands from the last 15 years, suggesting to promote research on capital-building in small islands. Due to the complex structure of the concept of sustainability, there is no universal procedure or criteria to evaluate sustainability at an island scale.

Here we developed an indicator system to track the dynamic change of sustainability of the Chongming Island, a fluvial island social-ecological system, as well as that of its closely-related mainland area. Together they form the megacity Shanghai. Thus, the study emphasized on collecting and evaluating the datasets on historical, cultural and social aspects for the Chongming island. In context, a capital-based approach is adopted for measuring the drivers for island sustainability and its associated dynamic changes from the year 2000 to 2017. Furthermore, the dynamic changes have been analyzed for the island and its interactions with the mainland Shanghai is closely monitored in the present study. The study performed on the Chongming island and mainland Shanghai, is of national importance and global financial hub, to understand the various impact of island on the nearby mainland, which is not analyzed before in the previous studies. The previous studies performed on the island were based on the old development plans and policies, thus, this study analyzed how the latest advanced policies and strategies have cumulatively affect the sustainability of the island and the mainland. Also, due to climate change and human interventions, the strategies cannot be deployed based on the previous studies (say last 10 years) and a latest analysis must be performed for a more informed and effective decision-making process. Hence, a robust technique is described in the present study for the current years to perform the sustainability assessment for an island along with its interactions with the nearby mainland.

The five capitals model forms a basis for understanding sustainable development through the lens of the economic concept of wealth creation or ‘capital’. All economies utilize these five types of capital usually. Examining all sections of the five capitals model together, as a larger and collective unit, is where sustainability, stewardship and increased opportunity are realized. This framework provides a better holistic understanding towards the island sustainability. Hence, the following three objectives were developed: 1) to develop an indicator system to reflect island sustainability based on a capital-based approach; 2) to analyze dynamic changes of each capital from 2000 to 2017 and 3) to identify potential drivers and challenges in development toward sustainability.

2 Study Area

The Chongming Island, with a total area of 1,200 km^2, is China's third largest island and largest alluvial island. Located at the mouth of the Yangtze River (32°27’N-31°52’N, 121°10’E-121°55’E, Fig. 1). Chongming is flat (3.5-4.5 m above mean sea level on average) with a coastline of about 195 km (Chongming Statistics Bureau, 2000). It belongs to the north subtropical maritime climate zone. The river network in Chongming is dense (1.95 km/km^2), consisting of 1119 rivers with a total river length of 2028 km (Che et al., 2006). Agro-ecosystem is the top land use and provides a large proportion of the food supply in Chongming (Huang et al., 2008). Meanwhile, the location of Chongming makes it prone to multi-hazards, such as typhoon, rainstorm, flood, etc. According to historical disaster records, the total direct economic losses from disasters was about 500 million RMB during 1984-2018. Among all natural disasters, typhoon had highest impacts (Supplementary Fig. 1).

While being a nearshore island with only about 10-20 km of distance from mainland, Chongming remains the most remote and underdeveloped district among Shanghai’s 16 districts. While Chongming is the largest in terms of geographic area (almost 20%), it is also the smallest in terms of population (678 thousand in 2018, about 3%) and Gross Domestic Product (GDP) (1% in 2018), making it the least developed district in Shanghai (Fig. 2). The total population in Chongming declines steadily in recent decades, while total population in Shanghai keeps increasing. The proportion of Chongming population to Shanghai decreased from almost 8% in 1978 to less than 3% in 2018. Meanwhile, GDP and GDP per capita in Chongming keeps increasing with economic development (Fig. 2b), by 2018 its percentage in Shanghai's total GDP was almost halved from the peak value of 2.2% in 1988.

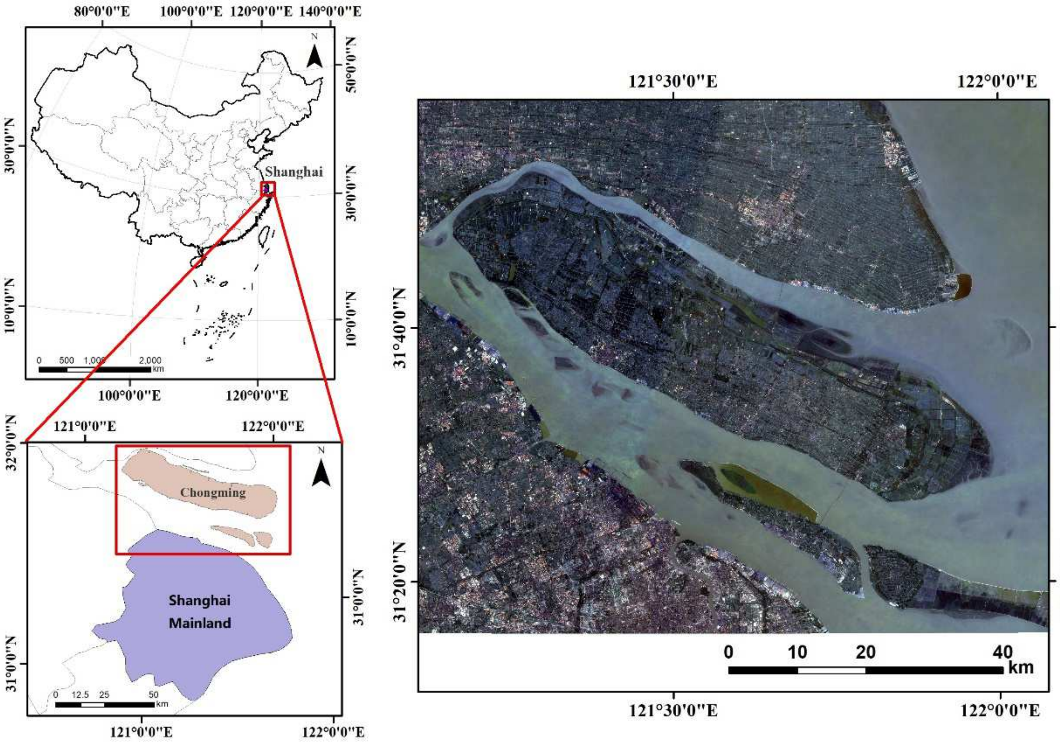

Fig. 1 Location of Chongming Island.

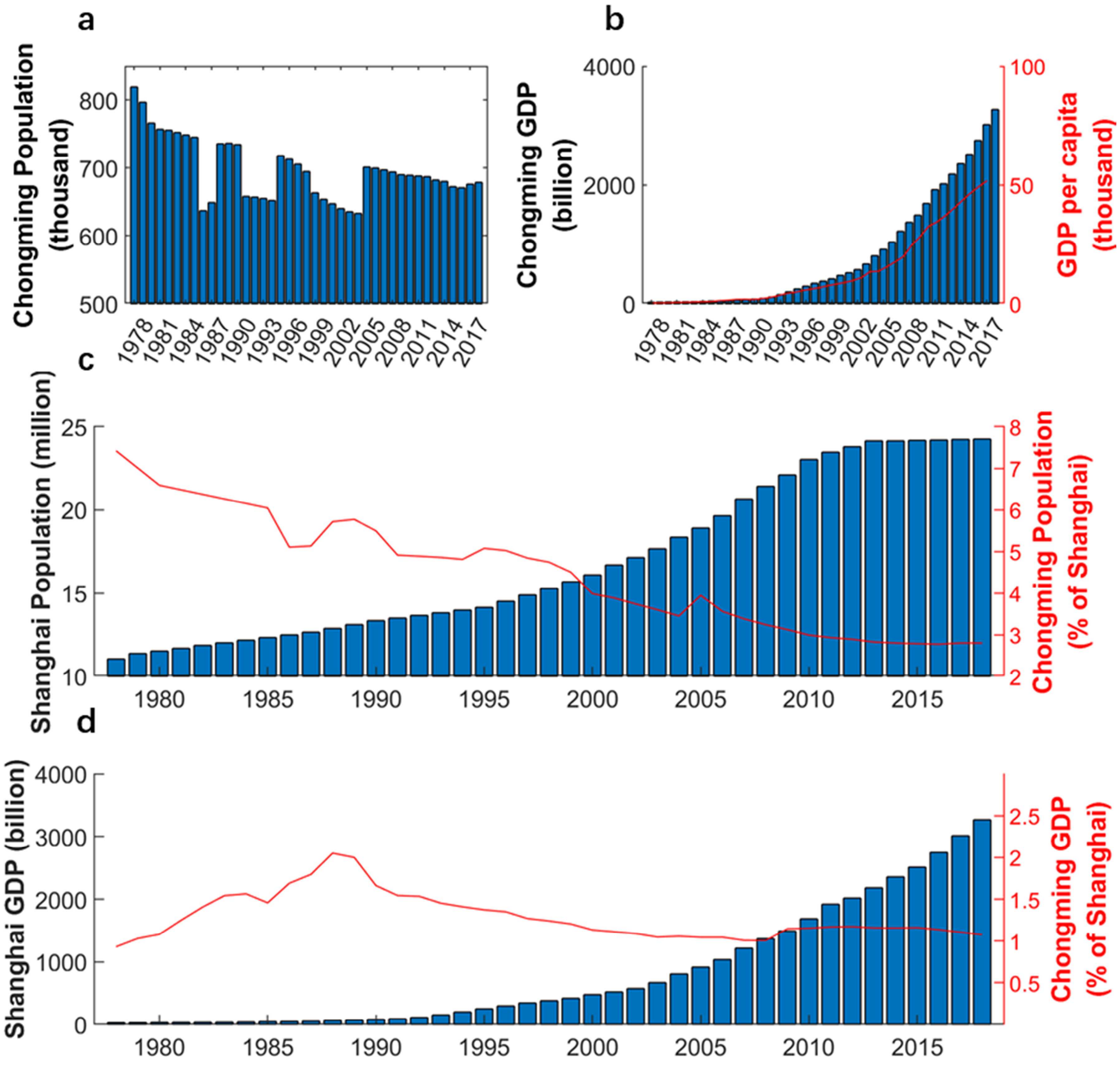

Fig. 2 Changes of population and GDP in Chongming from 1978-2018. a) changes of population in Chongming; b) changes of GDP and GDP per capita in Chongming; c) changes of total population in Shanghai Municipality, and ratio of Chongming population to Shanghai total population; d) changes of total GDP in Shanghai Municipality, and ratio of Chongming GDP to Shanghai total GDP.

3 Methods

The methodology adopted in the study includes two main steps: the development of the indicator system and the application to assess the sustainability of study area.

3.1 Developing an indicator system

Adapted from several frameworks (Smith et al., 2001; Mayunga, 2007; Michel-Kerjan, 2015; Cai et al., 2016), we developed a capital-based metric indicator system of sustainability, that goes beyond the conceptual phase and offers a structured way to operationalize and measure island sustainability. It is built on the key assets viz. social, human, physical, financial and natural. These capitals are viewed as an interdependent capacity that capture the core capacities of a region system. The study is in continuation with the previous case studies (Shi et al., 2004; Keating et al., 2014; Gu et al., 2018) and considered socioeconomic aspects of Chongming Island. Accordingly, a three-tier system with 31 sub-indicators has been constructed (Table. 1).

Table. 1 The indicator system of sustainability based on the capital-based approach in this study.

Capital	Level	Variables	Relationship to sustainability
Human Capital	Education	Percentage of population with college diploma	+
		Percentage of population with high school diploma	+
		Illiteracy rate	-
	Population change	Natural population growth rate	-
	Occupation	Percentage of primary-industry employees	-
	Age	Percentage population under 18 years old	+
		Percentage population over 60 years old	-
Financial Capital	Economic Status	GDP per capita	+
	Income	Per capita disposable income of urban residents	+
		per capita disposable income of rural residents	+
Physical Capital	Infrastructure investment	Fixed asset investment per capita	+
	Medical facilities	Number of beds in health institutions per 10,00 people	+
		Number of medical technical personnel per 1000 resident population	+
	Building code	Percentage of concrete housing	+
	Transportation	Cargo volume per capita	+
Social Capital	Social dependency	Old (over 65) and young (less than 15) to laboring population between 15 and 65 years	-
	Household structure	Percentage of sole-elder households	-
		Percentage of divorced population	-
	Urban-rural disparity	Percentage of urban residents receiving subsistence allowances from the government	-
		Percentage of rural residents receiving subsistence allowances from the government	-
		Difference of residents' disposable income between urban and rural households	-
	Floating population	Net mechanical rate (immigrants from other places to household registration system (Hukou))	-
Natural	Air quality	Annual daily mean concentration of SO_2	-

Capital		Annual daily mean concentration of NO_2	-
		Mean concentration of inhalable particulate	-
	Water quality	Ratio of river with water quality higher than III	+
	Investment in environmental protection	Ratio of investment in environmental protection to local GDP	+
		Ratio of industrial wastes treated and utilized	+
	Natural buffer	Forest coverage rate	+
		Green coverage rate	+
		Urban green space per capita	+

3.1.1 Human Capital

Human capital usually refers to the quality of citizens (Smith et al., 2001). It can be measured by various criteria such as education, population change, occupation and age.

Education level is an important variable with strong association to resident income, quality of life, job opportunities, etc. (Cutter et al., 2010). People working in the primary activities such as agriculture, animal husbandry and fishery are often more vulnerable in facing both environmental and economic uncertainties, because of their higher dependency on natural conditions and relatively weak economic power in markets. The rate of change in population indicates the speed of population growth along with its associated regional development. In China, the natural growth of population has been declining and the society is aging, with more and more elders who are considered to be more vulnerable (Gu et al., 2018).

3.1.2 Financial Capital

Financial capital denotes available economic resources that people can use to improve their livelihood and the government uses to invest for the society (Mayunga, 2007).

Income is usually the ideal indicator for the socioeconomic status of residents. The level of income reflects the living levels of residents (Masozera et al., 2007). Disposable income per capita in rural and urban areas are selected respectively. Abundant wealth develops the region and provides strength to improve their living conditions (Cutter et al., 2010). GDP is one way to measure the production activities of a region over a certain period of time and it is also an important indicator for measuring the level of regional economic development. Here GDP per capita is considered to reflect the economic development.

3.1.3 Physical Capital

Physical capital includes the indirect aspects of economic activity, such as infrastructure, residential housing and medical facilities (Mayunga, 2007). Thus, physical capital can be measured through building code, medical facilities, transportation and infrastructure investment.

House with concrete structure are more stable and indicate better living conditions, thus the proportion of concrete housing area is used to present building code (Omidvar et al., 2012). Medical service is important to meet the needs by residents. The density of medical service is presented by health equipment and medical technical personnel. Infrastructure investment includes investment in transportation and public infrastructure, etc. It is difficult to collect continuous infrastructure data at the county level. Thus, fixed asset investment per capita is considered as the proxy variable to represent physical capital. Transportation reflects the mobility of a system. Higher cargo volume per capita indicates a higher flexibility in transportation.

3.1.4 Social Capital

Although the social capital can be defined in various ways, there is always a common emphasis on the aspect of social structure, harmony, equity and social network (Minamoto, 2010). It can be measured through social dependency, household structure, urban-rural disparity and floating population.

Social dependency refers to the ratio of nonworking-age population to working-age population. A higher social dependency indicates the pressure on economic productive, working population in society. High urban-rural disparity is a potential threat to inclusive development. The study considered the disposable income difference between urban and rural residents. Additionally, households whose per capita monthly income is lower than certain local standards receive subsistence allowances from the local government. These residents are usually incapacitated and in an economically disadvantageous situation. Thus, proportion of residents who receive subsistence allowances from government in rural and urban areas are also considered. Two variables of household structure are accounted, namely the percentage of sole-elder households and the percentage of divorced population. Higher ratios of the solo-elders and divorced people indicates more instability in a society as it may suffer more problems during adverse circumstances. Floating population is a terminology used to describe a group of people who reside in a given population for a certain period of time for various reasons, but are not generally considered a part of the official census count. Due to household registration system (namely Hukou) in China, the floating population are largely excluded from the local welfare system, thus it may lead to the instability of society. In Shanghai, migrants account for about 41% of the total population who are mainly living in rental housing (Wang et al., 2012a). Thus, net mechanical rate refers immigrants from other places to household registration system.

3.1.5 Natural Capital

Natural capital refers to natural resources that reflects the abundance and stability of the natural system. It can be measured through environmental investment, air quality and nature buffer.

The variables are considered in context to the investment in environmental protection to local GDP and waste treatment to reveal the input efforts in environment protection. Three variables are employed to reflect local air quality for the study region. Water quality is determined by river ratio with good water quality (namely water quality grade higher than III grade). The water quality grade is classified by more than 30 variables (COD, N, P and heavy metals) based on Environmental Quality Standard for Surface Water in China. The study initially attempts to use the air quality index (AQI) to understand the air quality for the study region. However, as per the government records and database available, AQI is documented for air quality only after the year

2013. Although, AQI is widely adopted and accepted to analyze the air quality of the region, but no dataset is available before the year 2013, which constraints the use of this particular index to analyze air quality. Therefore, the study considers these three parameters such as SO_2, NO_2 and PM to understand and analyze the air quality for the study regions. Natural buffer such as green space and forest, provides a good living environment and plays an important role in enhancing societal sustainability.

3.2 Data collection and process

Availability of long-term data plays a significant role in this kind of site-specific study. Regional datasets were acquired from multiple sources (Table. 1), mainly from statistical yearbooks and bulletins published by Chongming and Shanghai Statistical Bureaus from 2000-2017 (Chongming Statistic Bureau, 2018; Chongming County, 2018; Shanghai Municipal Statistics Bureau, 2007, 2017; Shanghai Water Authority, 2018). The fifth and sixth national population census in 2000 and 2010 (2000; 2010 census) (NBSC, 2001; 2011) were also used, as well as various historical statistical yearbooks which are included in the Chinese Socioeconomic Development Statistical Database (http://tongji.cnki.net).

All the available datasets were acquired for both the study island i.e. Chongming (hereinafter CM for convenience) and the mainland part of Shanghai, which comprises other 15 districts except Chongming (hereinafter SHM for convenience).

Raw count variables need to be transformed into percentages, rates, differences, or averages. Normalization refers to the transformation of variables, so that a common scale is adopted and can be compared by a common reference. Here a min-max normalization technique was performed on all variables (Patro, S. and Sahu, 2015).

Various methods exist in determining weights of different variables to be aggregated, such as analytic hierarchy process, principal component analysis, entropy-based method, etc. (Wu et al., 2017), some subjective and the others more objective (Ma et al., 1999). In this study, an entropy weighing technique is adopted to assign weights to different indicators. The entropy method is a widely used approach (Liu et al., 2018a), in which the weight values of individual indicators are determined by calculating the entropy and entropy weight (Zou et al., 2006). The greater the entropy is, the smaller the corresponding entropy weight will be. The amount of useful information that the target provides is thus low. If an indicator's entropy weight is zero, it provides no useful information and such indicator may be removed. The main steps of the entropy weight method include a) the formation of the evaluation matrix; b) the standardization of the evaluation matrix; and c) the calculation of the entropy and the entropy weight.

The entropy of the *i*th indicator is defined as:

$$H_i = -k \sum_{j=1}^{n} f_{i,j} \ln f_{i,j}, \quad i = 1, 2, 3......m \tag{1}$$

$$f_{i,j} = r_{i,j} / \sum_{j=1}^{n} r_{i,j}, \quad k = 1/\ln n \tag{2}$$

where H_i is the entropy of the i th indicator. When $f_{i,j}=0$, we suppose $f_{i,j}\ln f_{i,j}=0$. The weights of indicators to a specific category is calculated as described in eq. (3):

$$w_i=(1-H_i)/(m-\sum_{i=1}^{m}H_i) \quad (3)$$

Score of each capital is calculated from indicator scores obtained.

$$Score-capital=\sum_{i=1}^{m}w_iH_i \quad (4)$$

4 Results

Changes of five capitals from 2000 to 2017 are shown in Fig. 3. There are increasing trends for natural, physical and financial capitals for both SHM and CM from 2000 to 2017. While human capital fluctuates, social capital slightly declines.

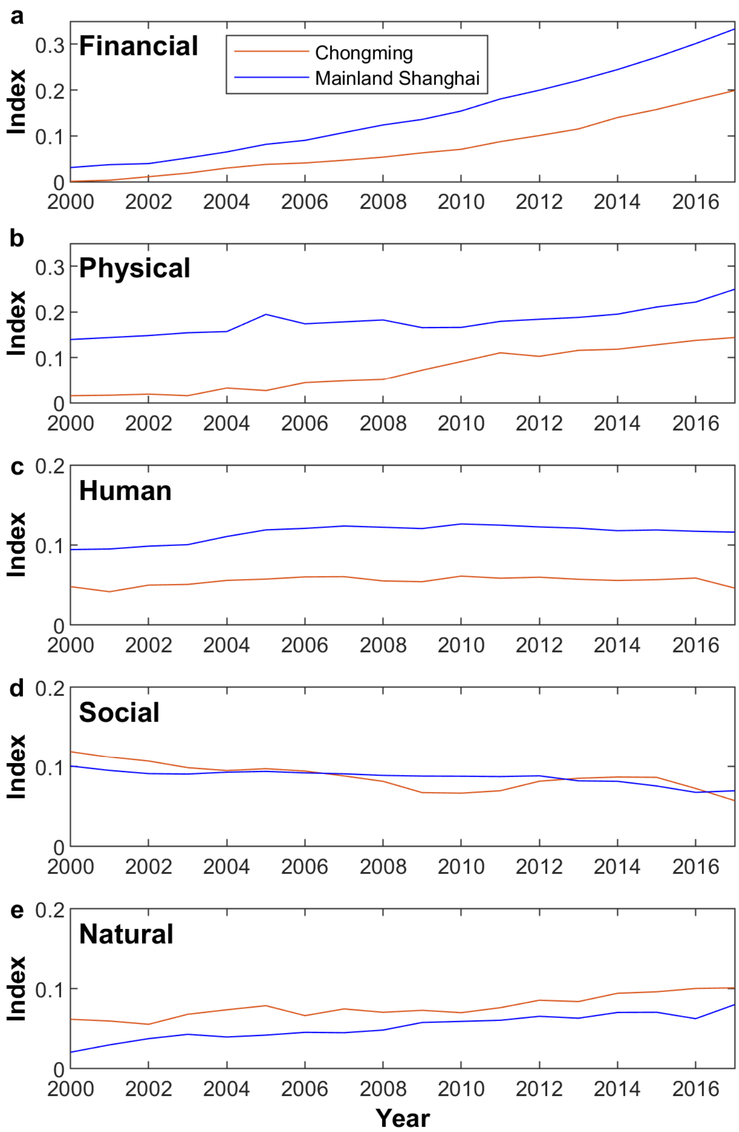

Fig. 3 Changes of a) financial, b) physical, c) human, d) social and e) natural capitals from

2000-2017 in Chongming and mainland Shanghai. Only human capital for Chongming shows an insignificant trend ($p<0.05$).

The trend of financial and physical capital for both CM and SHM shows a significant increasing trend over time (Fig. 3a, b). The gap of physical capital between SHM and CM is decreasing (Fig. 3b), while the gap of financial capital is widening (Fig. 3a). Fast economic development is a key contributor to increased financial capital, accompanied with increased resident income. GDP per capita in Shanghai reached 20,398 USD in 2018, 2.5 times of that in CM. CM had an inferior infrastructure level around 2000 compared with SHM. With huge financial capital of SHM, financial resources from SHM had transferred toward to CM by a series of infrastructure construction, such as bridges, tunnels and roads. Rapid development of the transportation infrastructure within the island has accelerated local transportation, effectively promoted local economic development and social stability, and has been proven highly resistant to extreme weather conditions. Since 2008, the growth rate of physical capital in CM is even slightly higher than that in SHM. With a large number of ongoing and near future (up to 2023) construction projects of high-speed railway and underground tunnels between CM and SHM (Chongming District, 2018), it is foreseeable that transportation infrastructure will continue to improve.

Human capital in CM follows a relatively flat trend, while that in SHM gained slow increase and is much higher in absolute term (Fig. 3c). Due to the negative population growth rate, the human capital observed a decreasing trend. On the contrary, with the implementation of compulsory education, education attainment rate in CM increased, positively contributing to human capital. CM has experienced negative natural population growth since 1995. The absolute value of negative growth rate keeps increasing and is up to 5‰ in 2017. Student enrollment has decreased much faster in CM than SHM, while elders has increasing much faster (Supplementary Fig. 2). Many colleges and universities locate in SHM, attracting and providing higher education to students from all over the country, and locally as well.

A slight decreasing trend has been observed for social capital in both CM and SHM (Fig. 3d). Factors including population aging, increasing urban-rural disparity, and divorce rate contribute to decrease in social capital. The income gap between SHM and CM becomes larger, which leads to unbalanced development and inequality. Nearly one third of residents in CM engage in primary industry, while this number is only about 2-3% in SHM. The imbalance of population age structure is more sever in CM due to the shortage of youths. CM Island's aging population rate reached 36.4%, which is the highest district in Shanghai (Shanghai Research Center on Aging, 2019). Those elders are characterized as low income, low educated and dependent on primary industry, and mainly distributed in CM. CM has been depopulating not only due to natural growth, but also because it gradually loses attraction to local young residents due to its low economic development, rural-based landscape and inconvenient traffic facilities. It leads to a large proportionate of elders live in CM. The sole-elders in CM is much higher than SHM, with 5% and 2%, respectively. This aggravates CM aging problem and reduces social capital.

Regarding natural capital, increasing trends were observed throughout for SHM and CM (Fig.3e). Natural capital in CM in 2000 is higher than SHM, the gap of natural capital is narrowing until 2017. The growth rate of natural capital for SHM is higher than CM. Shi et al. (2004) found that development process of Shanghai between 1990 to 2000 was at the cost of environment and resource degradation, while social and economic development in CM was restricted to protect environment and resources. The degrading trend in 1990s has been largely reversed as the importance of environmental protection and ecological civilization increases in the policy arena. For instance, forest coverage has increased from 3.1% to 10.74% in SHM from 2000 to 2017.

Sustainability of the two with all five dimensions can be assessed using spidergrams (Fig. 4). In 2000, compared to SHM, CM is poor in financial, physical, and human capitals and relatively richer in natural and social capitals. While the former three capitals increased substantially by 2017, the latter two did not improve. Four capitals in SHM had substantial gains over the 17-year period, with most increase in financial and physical capitals. As a result, the two systems' overall patterns of sustainability become similar, though in absolute term, SHM is much better than CM. Five capitals interact with each other. For example, increase of financial capital could help reduce poverty and inequality, which could increase social and human capitals. More official revenue could be invested in environment protection, infrastructure projects, education and technology. Simultaneously, talents input, harmonious society, construction of important infrastructure, technological progress, efficient resource use and reduced pollution also stimulate economic development.

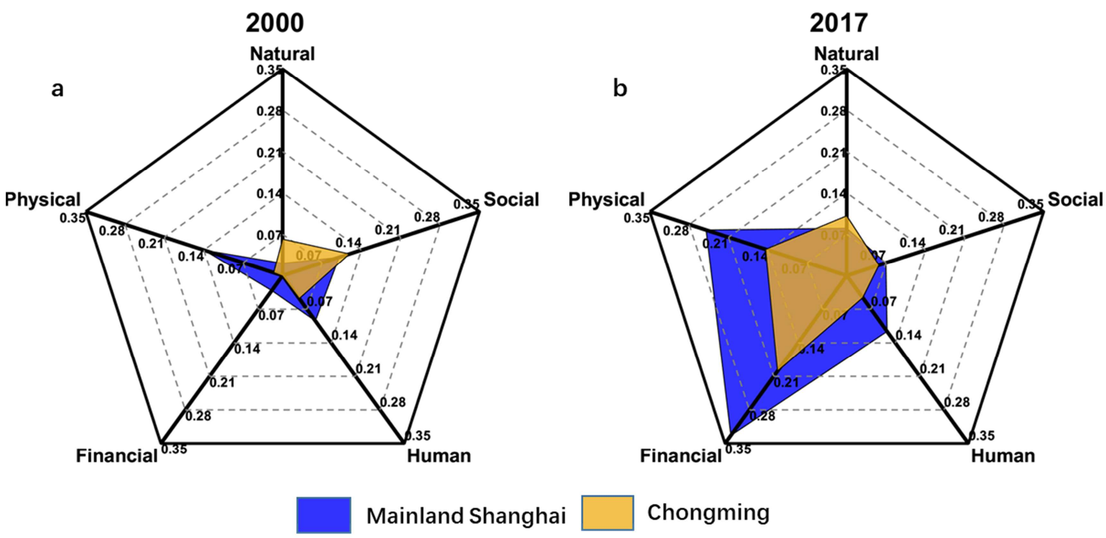

Fig. 4 Sustainability index of five capitals for mainland Shanghai and Chongming in 2000 and 2017.

5 Discussion

5.1 Interactions between Chongming Island and mainland Shanghai

With a fragile ecosystem and underdeveloped economy, Chongming's sustainability is highly dependent on that of Shanghai. Overall while SHM soared in economic development, CM lagged behind. The disparity of financial capital between CM and SHM keeps growing, with some used to help narrow the physical capital gap. Before 2009, the only way to reach CM island was through ferry, which takes at least 45 minutes one way. For every national holiday or even every Friday afternoon, many CM residents working in the SHM have to face a huge crowd to buy tickets for ferry waiting in queue for hours. The official opening of Shanghai Yangtze River Tunnel-Bridge in 2009 significantly increased connectivity and accessibility between CM and SHM, resulting in a huge boost to the local economy. The Chongqi Bridge opened in 2011, connecting to the nearby Jiangsu Province, further linked CM to the larger Yangtze River Delta region. The capital shift also enhanced the structure and layout of Shanghai's transportation system, accelerate the economic development and integration of the Yangtze River Delta region.

In the 1990s, environment protection had to give way to rapid industrial development, resulting in severe degradation of natural resources and ecosystems in SHM (Shi et al., 2004). As SHM further developed, especially after 2000, environment protection has become one of the government's main concerns. CM, now with rich natural capital, is regarded as strategically important for sustainable development of the whole Shanghai megacity. CM has leapt the phase of industrial development and transformed from a traditional agriculture-based economy to the development of a more service-based and circular economy, providing imperative ecosystem cultural services to people in Shanghai. Being proposed as an example of strengthening ecological services while maintaining economic development (Huang et al., 2008), CM has ascended to the center of the sustainability plan of Shanghai from a negligible corner in less than 20 years.

5.2 Evolution of intuitional engagement

The abovementioned changes toward island sustainability could not take place were critical institutional changes not realized. Institutional arrangement and governance also play an extremely important role in island sustainability, but it was not easy to be represented by indicators. We carefully went through changes in institutional development and related policies, and identified three stages of institutional development of CM. Each stage is characterized by issuing a series of schemes and plans, as shown in Fig. 5.

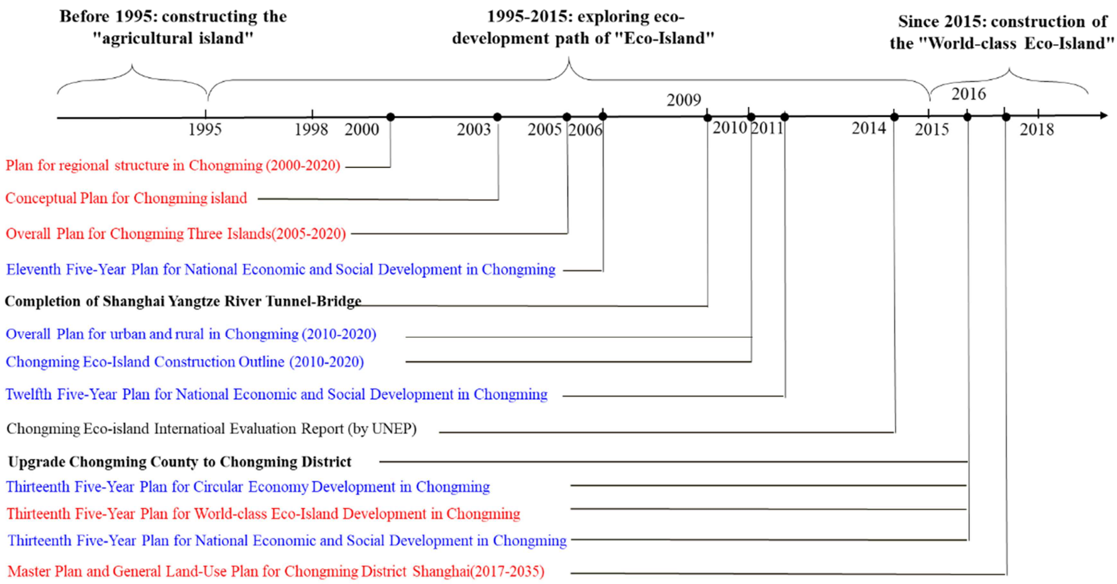

Fig. 5 History of construction of Chongming Eco-island, and its corresponding key plans from governments (red refers to provincial level policy, blue refers to local level policy and italic refers to big events).

Stage 1: Before 1995, the development of CM still followed traditional industrialization. CM played the role of production and processing based on raw materials for agricultural and by-products in Shanghai. There was yet no master plan designed for CM at the island level.
Stage 2: With the idea of green development, CM tried to explore eco-development path of “Eco-island” between 1995 to 2015. A series of overall plans for CM had been developed. In context of “eco-civilization”, CM is actively exploring and implementing a path towards eco-civilization beyond traditional industrialization (UNEP, 2014; Huang et al., 2008).
Stage 3: Since 2016, the vision of CM was designated as “World-class Eco-island”. It is characterized in six dimensions: 1) building a more resilient ecological environment, 2) efficient and intensive resource utilization, 3) prudent development of the urban and rural space, 4) harmonious human settlement quality, 5) low-carbon security infrastructure, and 6) more sustainable green development.
The construction of CM eco-island draws a lot more attention and investment from Shanghai municipal and Chinese national government (Miao et al., 2015). Total investment from provincial and local governments, from 2010 till date, has exceeded 44 billion RMB (~ 6.4 billion USD), which is 1.3 times the 2017 GDP of CM. After several decades of exploring and investing, CM has become a strong institutional capital in building eco-island (den Hartog et al., 2018; Ma et al., 2018; Xie et al., 2019). This approach provides an opportunity for CM to become a model to share valuable experiences around the world.

5.3 Islands sustainability in a changing environment

The sustainability development of CM in local, regional and global contexts can be conceptualized as three scales, namely, intracoupling, pericoupling, and telecoupling (Fig. 6, Wu et al., 2019; Liu et al., 2018b). The CM's sustainability intra-couples with SHM. Meanwhile, CM's natural capital and sustainability development also contribute to Yangtze River Delta, to national ecological civilization, and even contribute to commitments to SDGs. For instance, CM is rich in biological diversity and natural resources, and is an internationally important transit site on the East Asian–Australasian Flyway for migratory birds (Tian et al., 2008; Chen et al., 2018). This five-capital-based framework aligns with multiple SDG targets, mainly contributing to 15 out of 17 SDGs (Fig. 6). The indicators in human and social capitals mainly contribute to SDG 1 (No poverty), SDG 2 (Zero hunger) and SDG 3 (Good health and well-being). The natural capital positively contributes SDG 6 (Clean water and sanitation), SDG 7 (Affordable and clean energy), SDG 11 (Sustainable cities and communities), SDG 14 (Life below water) and SDG 15 (Life on land). Physical capital improves SDG 9 (Industry, innovation and infrastructure), SDG 12 (Responsible consumption and production) and etc. Financial capital mainly contributes SDG 8 (decent work and economic growth). Because of the integrated nature and coupled nature-anthropogenic system, the framework is also characterized by synergies and co-benefits for several other SDGs, SDG 13 (climate action) for example.

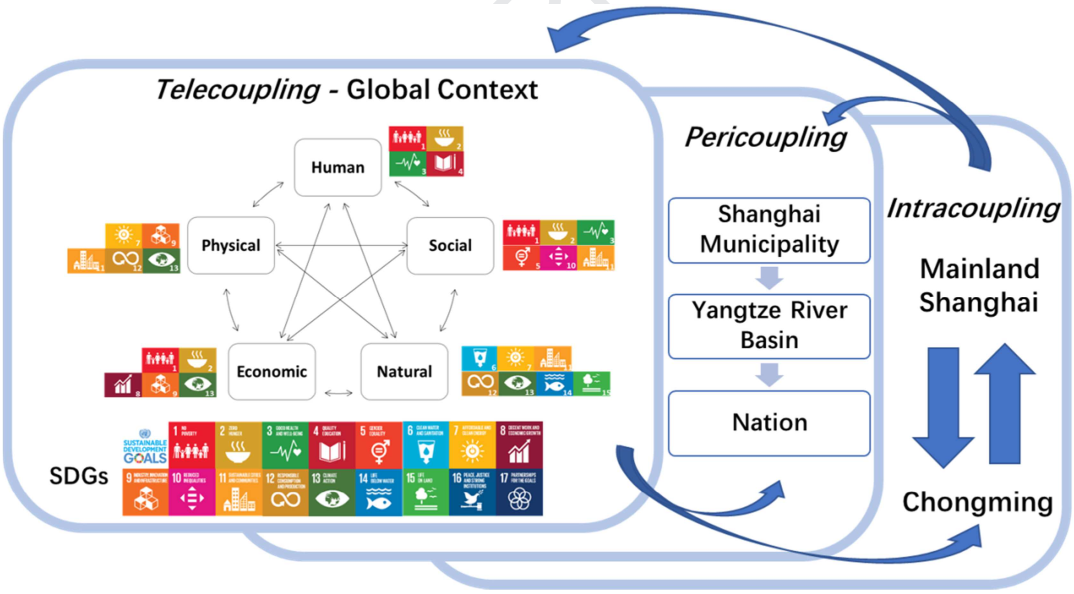

Fig. 6 Chongming under the five-capital-based framework corresponding to the SDGs in a metacoupled world (adapted from Wu et al., 2019; Liu et al., 2018b**).**

CM is a sending system that provides water, flood, recreation and other natural capitals, while SHM, Yangtze River Delta, nation, even globe is a receiving system. Meanwhile, island is an also receiving stress from global, delta and local system. For instance, CM is facing extreme natural hazards such as tropical cyclones, extreme rains, etc., and slow onset hazards such as global sea level rise, coastal erosion, and salt water intrusion (Huang et al., 2008; Wu et al., 2019). It is projected 50% of the island will be inundated by 2100 with south bank of CM suffers great overtopping, considering sea level rise, land subsidence, storm surges and failure of protection (Wang et al., 2012b). Sea level rise and salt water intrusion threaten the drinking water quality of urban residents and the security of the Shanghai's fresh water supply (Lyu and Zhu, 2019). It also poses huge threat on flood and waterlogging control as high sea level blocks flood discharge and drainage (Deng and Fan, 2002; Chen et al., 2015). Coastal erosion has been observed in Dongtan coasts in Chongming due to sea level rise as well as reduced sedimentation in upstream of the Yangtze River Basin (Wang et al., 2014). An island is not sustainable unless it is able to cope with, adapt, recover from external adverse events in a timely and efficient manner. Since its inception, the sustainability has observed closely with many advancements in vulnerability and resilience framework about analyzing the solution (Cutter, 2014; Keating et al., 2014). A methodology is required that is proactive in nature such as sustainability as compared to vulnerability and resilience, to have a better understanding (Adger et al., 2005; Kelman, 2018).

5.4 Recommendations

Based on our findings, the social and human capitals are relatively slow, as compared with natural, financial and physical capitals. Therefore, the government should focus on various strategies and policies to strengthen the social and human capital.

The problem of aging island has also been observed in other islands (Browne and Broderick, 1994). Human capital is the endogenous factor and “engine” of economic growth and development. Low human capital encapsulates planning and management in islands in various ways (Connell, 2018). High-education population outmigration is because island’s socio-economic environment is not able to support their development. The development could not rely on local residents. Thus, it is recommended to urgently build a system to attract young and high-educated population to work in CM so that scientific outcomes would be carried out in reality. The government should provide public service such as revamping health, education and pension systems in facing a low birth-rate and aging society.

It is observed that there is a huge trade-off between development and sustainability (Connell, 2018). In order to protect Chongming ecosystem, Shanghai and Chongming authorities restrict urban development to certain locations and control the population size in the island. This effort loosely connected with the need of local inhabitants. Many local residents grumble about economic opportunities being taken away because of the eco-island policy (Grydehøj and Kelman, 2017; Ma et al., 2018). According to Ecological Redline Policy from Shanghai municipal government (2018), land area of 51 km^2 and maritime area of 1126 km^2 in CM are identified as ‘ecological red lines’, contributing nearly 60% of Shanghai. It indicates in these redline areas environment protection comes first with limited exploration of natural resources. With the proposal of eco-tourism, many residents are attracted to CM, which have a high pressure on tourism reception capacity. However, the tourism projects in CM are single, could not meet special needs for different crowds. Additionally, there are certain deficiencies in management mode, service levels and professional talents. While the aging of the population structure, the small family structure and tourists in need of diversification also brings severe challenge to island development. Thus, a new public-private partnership including enterprises, NGOs, universities and other private sectors could help to improve the public participation and lower the financial and human burdens of both government and local residents.

6 Conclusion

In this study, a capital-based approach is implemented to analyze the temporal changes in the island sustainability. A three-tier indicator system has been demonstrated to represent the five capitals of sustainability: natural, social, human, financial and physical capitals. By analyzing the data from multiple sources from 2000 to 2017, 31 indicators have been collected and calculated for CM and SHM. The finding shows that there are significant increasing trends for natural, physical and financial capitals for both SHM and CM from 2000 to 2017. While human capitals fluctuate and social capitals slightly decline. How to improve social and human capitals is the key challenge for local government. The local government should establish mechanism and strategies (such as a new public-private partnership) to stimulate inner development within the island.

Eco-island indicator system released by local government lay too much emphasis on ecological aspects and little emphasis on human aspects. This framework would help local residents, stakeholders, and governments to identify the restricting elements hindering the overall sustainable development. This quantification analysis clearly depicts the dynamic evolution of sustainability and their interaction between CM and SHM. Sustainability is a very complex concept that encompasses a great number of sub-concepts and contributing factors. Integration of social, natural, financial, physical and human factors in overall sustainability assessment significantly enhance our ability to understand change of the system. Due to limitations of statistical data, it is not possible to calculate sustainability with a more detailed indicator system or in a long-term time frame. This measurement approach may not perfectly represent the complexity of the concept, but more importantly, make it understandable and comparable for decision makers to monitor gaps and proposing initiatives to reduce inequalities. Henceforth, an effective decision-making approach can be implemented under multi-objective, multi-stakeholder environment, if the drivers can be ascertained that are restricting the development of any island or mainland. Though major factors can be quantitatively identified using this approach, functional mechanisms between these factors and sustainability are still unclear. According to Eco-island plan and population projection, it is apparent that the economic and infrastructure development will be upscaled both for island and mainland, Shanghai. The population projection for young, elders, etc., will rise in unproportioned manner. Therefore, it would be very difficult to perform complex analysis keeping in view the restriction policies and limited datasets available for the present study. However, similar study could be performed for other islands where there is no limitations and restriction on the use of datasets.

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Conflict of interest

The authors declared that they have no conflicts of interest to declare.

We declare that we do not have any commercial or associative interest that represents a conflict of interest in connection with the work submitted.