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Direct and Indirect Loss Evaluation of Storm Surge Disaster Based on Static and Dynamic Input-Output Models

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Abstract: Storm surge disaster is one of the biggest threats to coastal areas. Over the years, it has brought serious losses to the economy and environment of China's coastal areas. In this paper, Guangdong Province is taken as the research object to evaluate the damage caused by storm surge disasters. First of all, regarding the three-industry classification standards of the National Bureau of Statistics, combined with the storm surge disaster assessment index system, the 10-sector storm surge disaster loss input-output table is compiled and analyzed. Secondly, the indirect economic losses of storm surge disasters between 2007–2017 are determined by calculating the direct and indirect consumption coefficients. Thirdly, based on the static input-output model, considering the time factor, the dynamic input-output model of storm surge disaster assessment is established to calculate the cumulative output loss under different recovery periods (30 days, 90 days, 120 days, 180 days, 360 days). The results indicate that: (1) the losses, after a storm surge, in the agricultural economy have the greatest impact on the manufacturing sector, and conversely, they have less effect on the science, education and health service sectors; as well as the construction sector; (2) taking the industry with the biggest loss ratio as an example, the recovery of damaged industries is relatively rapid in the early stage and tends to be stable in the later stage of recovery; (3) the total output loss calculated using the static input-output model is greater than that computed using the dynamic input-output model. Researching the assessment of the direct and indirect loss due to storm surge disasters is of great value and practical significance for the scientific and rational planning of the country's production layout, the maintenance of social and economic stability and the protection of life and property.

Keywords: storm surge disaster; static and dynamic input-output model; loss assessment

1. Introduction

The coastal areas of the world are home to more than 60% of the world's population, with people living in large and medium-sized cities located within a range of less than 100 km from the coastline. The coastal areas are also China's densely populated urban areas, with 14% of the country's land area accounting for nearly 45% of China's cities and 51% of the urban population, also accounting for 55% (2019) of the country's GDP and 57% (2019) of the fiscal revenue. Coastal areas have become the core and leading areas for China's economic development [1]. The marine economy has become the engine for the coordinated development of China's regional economy.

Coastal areas face a series of disasters, including climate change [2,3], sea-level rise and their related impacts [4–6]. Storm surge disasters are one of the most devastating marine disasters in coastal countries around the world [7,8]. They have a very serious impact on countries in the coastal zone all over the world [9,10], and storm surge damages have been increasing [11]. The United States, Japan, Australia, India and the Bay of Bengal are all affected by storm surge disasters [12,13]. Against the background of global warming and the sea level rising [14,15], the outburst of the storm surge disaster chain effect has become increasingly prominent, the loss caused to countries in the world has shown a rising trend year by year [16,17]. China is one of the countries in the world suffering the most frequently and seriously from storm surges [18,19]. According to the statistics reported in China's Marine Disaster Bulletin, 633 storm surge disasters occurred in China from 1949 to 2019, bringing direct economic losses of up to USD 47.88 billion. Among them, there were 158 storm surge disasters from 2000–2019, accounting for more than 90% of marine disaster losses. In 2019, 11 storm surges occurred along the coast of China, resulting in a direct economic loss of USD 1.68 billion, 1.34 times the average value of the past decade (USD 1.25 billion). Storm surge disasters have had a serious impact on the social and economic development in the coastal areas in China, and especially on marine economic security [20]. Carrying out research on storm surges and their impact on the socio-economic development and assessing the damage caused has practical significance for improving the capability of national disaster prevention and mitigation and is also a major demand for safeguarding national social stability and national economic security [21–23].

In the study of disaster damage assessment, researchers started early and had more results, but mostly focused on floods [24–29], typhoons [30,31] and landslide disasters [32], specific studies of storm surge disasters were less than the other disasters. As the cyclone of storm surge disasters and losses continues to grow, more and more scholars pay attention to the study of storm surge disasters [33–39]. Most scholars focus on the risks and ways to forecast them [40], few scholars have evaluated the economic losses. Especially, the research results of measuring the indirect disaster loss are few and are mostly qualitative descriptions [41,42]. The United Nations and the World Bank have defined indirect loss due to disasters as a decline in social production, a decrease in income, an increase in expenditures, etc. before the disaster recovery. At present, the methods of estimating the indirect economic loss due to disasters include system dynamics, econometrics, input-output, production function and general equilibrium modeling. Among them, the input-output (I-O) model and the computable general equilibrium (CGE) model are the two most commonly used methods [43–49]. In recent years, some scholars combine the input-output model with other methods to study loss assessment of natural disasters [50,51]. However, the model has the disadvantages of linear constraint and constant price. In disaster impact analysis, the input-output and CGE models are combined with agent-based models to improve the representation of migration [52]. Combined with meteorological, epidemiological and economic analysis, the macro-economic impact of a heatwave was studied using the supply-driven input-output model [53]. According to the econometric model group [54], a storm surge disaster was divided and the loss was evaluated. Using the depth loss curve, Cobb–Douglas production function and an input-output model [55], a comprehensive evaluation method of asset loss, production capacity loss and inter-sector fluctuation loss under the extreme rainstorm and flood scenario was established. The vulnerability of the interdependent sectors was assessed [56]. The most popular single-region input-output model was adopted for disaster impact evaluation [57].

A multi-sectoral CGE model and I-O model was constructed to assess the disaster loss caused by the Beijing "7.21 Rainstorm" in 2012 [58].

During the review, we found that there is much literature on the study of natural disaster loss, but few studies on the loss due to storm surges. Most of them focus on the measurement of overall economic loss from disaster and not on the indirect economic loss among industries. The input-output model is seldom applied in the field of indirect losses from storm surges and no comparative study on the static and dynamic input-output model was found.

This paper has the following innovations in the research on the losses from storm surges (Appendix A). To overcome the shortcomings, using the concept of time series, the static input-output model was extended to a dynamic input-output model to assess the economic loss. The input-output tables were designed to deal with storm surge disasters. The indirect economic losses from storm surges between 2007–2017 were determined by calculating the direct and indirect consumption coefficients. The static and dynamic loss values of the indirect economic losses were also measured, in contrast, to better guide disaster prevention and reduction work. Researching the assessment of storm surge (indirect) loss is of great significance to the protection of life and property, the ability and level of disaster prevention and mitigation of marine power disasters, with important overall strategic and forward-looking scientific value, application value and social significance.

The rest of the paper is structured as follows: The next section introduces the basic concepts of the static and the dynamic input-output model and builds an input-output table suitable for storm surge disasters. The third section empirically analyzes storm surges based on the static input-output model. While the fourth part is about the application of a dynamic input-output model. The discussion and conclusions are presented in the last section.

2. Data and Methods

2.1. Study Area

According to the China Marine disaster Bulletin, storm surge disasters cause great damage and serious losses to coastal provinces and cities (Figure 1) every year. According to the analysis of disaster losses such as population, crops, aquaculture, houses, coastal engineering and ships in coastal provinces and cities from 2007 to 2017, the temporal and spatial distribution characteristics of six different disaster losses in the coastal provinces of China are scientifically understood (Figure 2).

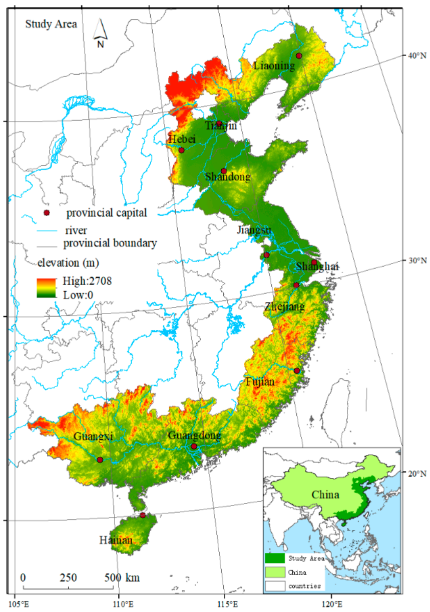

Figure 1. The coastal provinces of China.

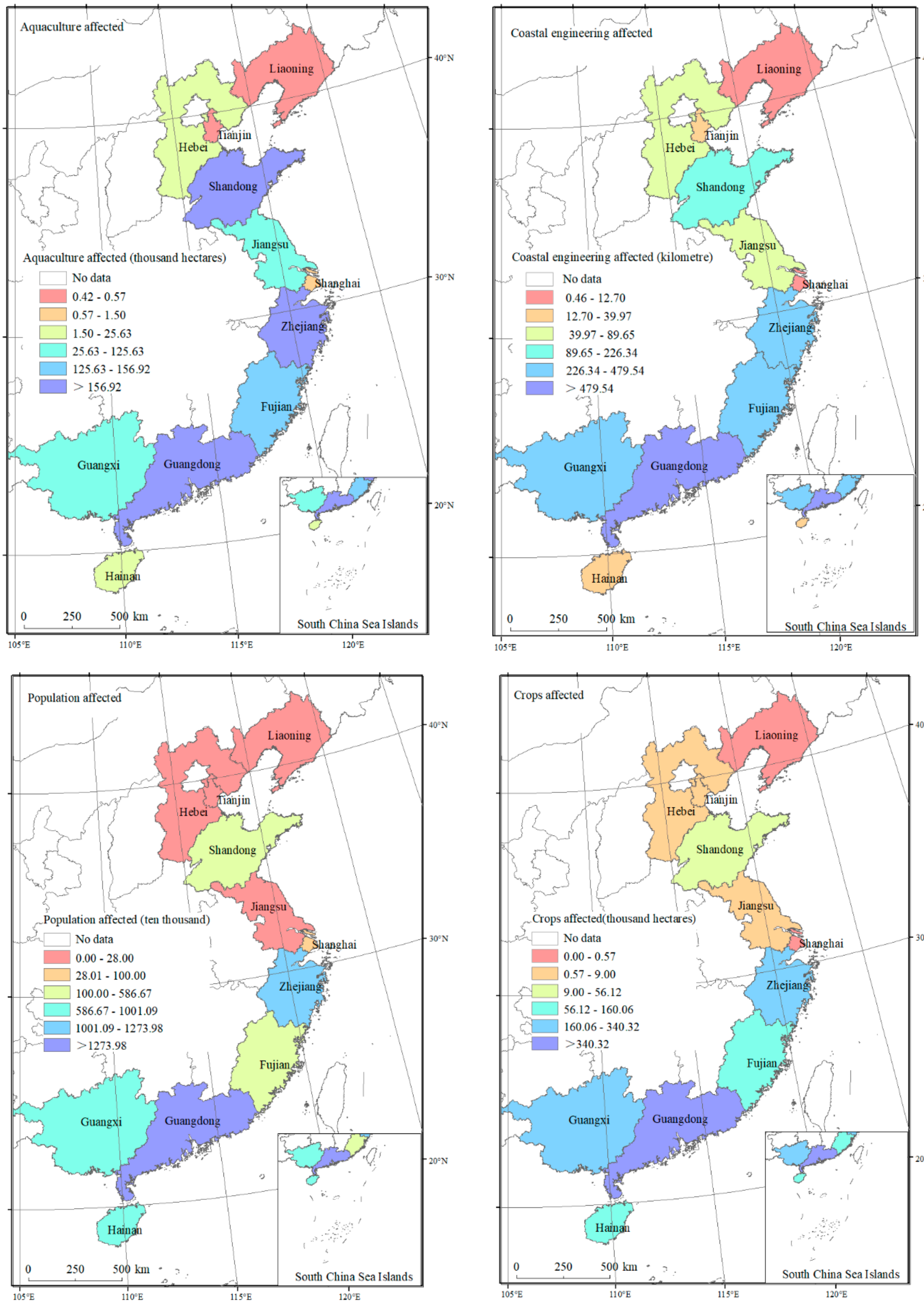

Figure 2. *Cont*.

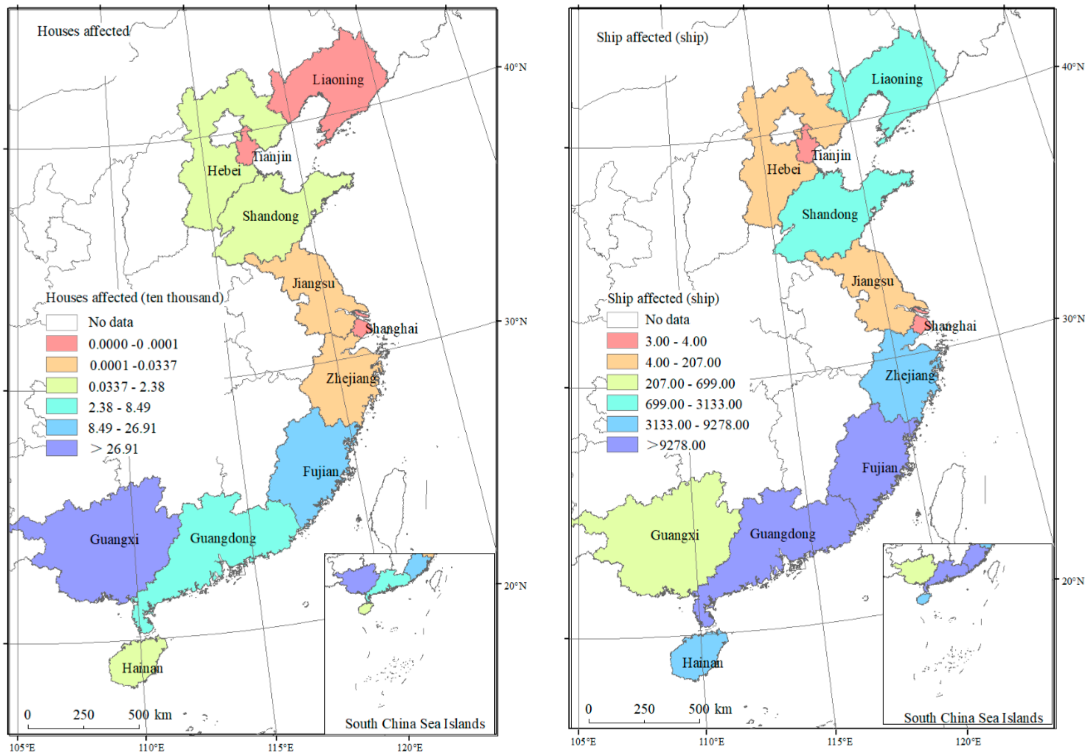

Figure 2. Divisions of six types of storm surge disaster damage in coastal provinces in 2007–2017.

Guangdong Province is located on the southern tip of mainland China, where storm surges are common. In this paper, Guangdong Province, as an object of study, was used to evaluate the indirect loss caused by storm surges, and the loss and related links were analyzed. The dataset references are from China's Marine Disaster Bulletin, the National Bureau of Statistics and the Chinese Input-Output Association.

2.2. Methods

2.2.1. Static Input-Output Model Construction

(1) Coefficient

Elements in the physical-value input-output table were measured in monetary units, among which rows and columns can be added to reflect the physical relationship between social product and the process of social product value formation. From the input-output table, the vertical is representative of the input source and the horizontal is representative of the use of the product. The input-output table is a checkerboard balance table consisting of rows and columns [59].

The value-based input-output table was unified for the unit of measurement of the whole table data to establish the relationship between the row direction and the column direction. After expanding its performance ability, the corresponding mathematical model was also enriched. Many of the economic factors derived from the input-output table made the data in the table closely linked, thus playing a more extensive role than the physical model.

The direct consumption coefficient, also known as the input coefficient, is denoted by $a_{ij}(i, j = 1, 2, \ldots, n)$. It refers to the value of the goods or services in the i product sector, consumed directly by the unit output of the j product sector during production and operation. The form of the table will be the direct consumption coefficient matrix or direct consumption coefficient table, generally expressed as the letter A. The direct consumption coefficient matrix is calculated as follows: using the total investment of the j product sector to remove the value of the goods or services of the i product sector is directly consumed in the production and management of the product sector X_{ij}, expressed as:

$$a_{ij} = \frac{x_{ij}}{x_j}(i, j = 1, 2, \ldots, n) \quad (1)$$

The complete consumption coefficient, also known as b_{ij}, is the sum of the direct and indirect consumption of goods or services in the i product sector for each unit of the j product that provides one unit for final use. The complete consumption coefficient matrix can be calculated by directly consuming the coefficient matrix A, the formula is:

$$B = (I - A)^{-1} - I \quad (2)$$

(2) Static Input-Output Model [60]

According to the static input-output model, the final output value can be obtained through the total output value of each sector of the economy. Similarly, from the loss of the final product, we can calculate the total output loss in each sector.

The total loss of agricultural products is recorded as ΔX_1. Assuming that the final product of the sectors other than the agricultural sector remains unchanged, the changes in the production capacity of other sectors are calculated based on the changes in the productive capacity of the agricultural sector, as expressed below:

$$\Delta X = (I - A)^{-1} \Delta Y \quad (3)$$

Since $B = (I - A)^{-1} - I$, $B_{n \times n}$ is the complete consumption coefficient matrix, $A_{n \times n}$ is the direct consumption coefficient matrix:

$$\Delta X = (B + I)\Delta Y \quad (4)$$

The output change of the entire economic system is:

$$\begin{pmatrix} \Delta X_1 \\ \Delta X_2 \\ \cdots \\ \Delta X_n \end{pmatrix} = \left(\begin{pmatrix} b_{11} & b_{12} & \cdots & b_{1n} \\ b_{21} & b_{22} & \cdots & b_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ b_{n1} & b_{n2} & \cdots & b_{nn} \end{pmatrix} + \begin{pmatrix} 1 & 0 & \cdots & 0 \\ 0 & 1 & \cdots & 0 \\ 0 & 0 & \cdots & 0 \\ 0 & 0 & \cdots & 1 \end{pmatrix} \right) \begin{pmatrix} \Delta Y_1 \\ 0 \\ \cdots \\ 0 \end{pmatrix} = \begin{pmatrix} b_{11}\Delta Y_1 \\ b_{21}\Delta Y_1 \\ \cdots \\ b_{n1}\Delta Y_1 \end{pmatrix} + \begin{pmatrix} \Delta Y_1 \\ 0 \\ \cdots \\ 0 \end{pmatrix}$$

In the above system of equations, the first equation is $\Delta X_1 = b_{11}\Delta Y_1 + \Delta Y_1$, thus $\Delta Y_1 = \frac{\Delta X_1}{1+b_{11}}$. That is, the final product of the agricultural sector is reduced by $\frac{\Delta X_1}{1+b_{11}}$, The middle loss due to the decrease in agricultural production capacity is $\frac{b_{11}\Delta X_1}{1+b_{11}}$. The reduction in intermediate consumption in other sectors will result from a decrease in the final agricultural output, while the decrease in total output in other sectors will be:

$$\Delta X_{j1} = b_{j1}\Delta Y_1 = \frac{b_{j1}\Delta X_1}{1 + b_{11}}, j \neq 1 \quad (5)$$

The total loss due to the decrease in gross agricultural output is expressed by L_1:

$$L_1 = \sum_{j=2}^{n} \Delta X_{j1} + \Delta Y_1 \quad (6)$$

The decrease in total output, except for this sector, resulting from the reduction of the final product in other sectors is:

$$\Delta X_{j1} = b_{j1}\Delta Y_1 = \frac{b_{j1}\Delta X_1}{1 + b_{11}}, j \neq 1, i = 1, 2, \ldots, 6 \quad (7)$$

Total loss from reductions in total output in other sectors:

$$L_i = \sum_{j=1}^{n} \Delta X_{j1} + \Delta Y_i, j \neq i \tag{8}$$

The total loss caused by the reduction of the total output of fisheries and other sectors was recorded as $L_i, i = 1, 2, \ldots, 6$, the total loss: $L = \sum_{i=1}^{6} L_i$.

2.2.2. Dynamic Input-Output Model Construction

(1) Coefficient

To connect the whole process of social reproduction through fixed capital formation, it is necessary to carry out a comprehensive analysis of the quantity, structure and effect of fixed capital formation, and introduce the coefficient to establish a dynamic input and output model. There are investments and fund occupancy coefficients, this paper mainly introduces the investment coefficient.

The investment matrix table (Table 1) is based on the total capital formation column vector of the second quadrant of the input-output table.

Table 1. Investment Matrix.

Investment Elements / Investment Sector	Fixed Capital Formation 1, 2, … , n, Subtotal	Inventory Increased	Total
1	$K_{11}, K_{12}, \ldots, K_{1n}, K_{10}$	K_{1m}	K_1
2	$K_{21}, K_{22}, \ldots, K_{2n}, K_{20}$	K_{2m}	K_2
…	…, …, …, …	…	…
N	$K_{n1}, K_{n2}, \ldots, K_{nn}, K_{n0}$	K_{nm}	K_n
Total	$K_{01}, K_{02}, \ldots, K_{0n}, K_{00}$	K_m	$\overset{0}{K}$

The investment matrix maintains the same inventory increase of products but expands the formation of fixed capital into an $n * n$ Investment Matrix named K. K_{ij} represents the amount of i-type investment products used in the sector j, the amount of i-type investment products needed by sector j to expand its production scale. $K_{i0} = \sum_{i=1}^{n} K_{ij}$ represents the total amount of product that the i sector uses for fixed capital formation. $K_{0j} = \sum_{j=1}^{n} K_{ij}$ represents the total amount of fixed capital formation used by the sector j. K_m is the number of products the i sector uses as inventory increases.

Based on the investment matrix, the investment coefficient is calculated as:

$$q_{ij} = \frac{k_{ij}}{\Delta X_j}(i, j = 1, 2, \ldots, n) \tag{9}$$

k_{ij} represent the number of i investment products required for the expansion of production scale; ΔX_j represents the j sector of the annual increase in production scale, in quantity:

$$\Delta X_j = X_j(t+1) - X_j(t) \tag{10}$$

q_{ij} represents the number of i products required for the increase of the unit output of the j sector, namely the investment coefficient of the j sector to the i product:

$$Q = K \cdot \Delta \hat{X}^{-1} \tag{11}$$

The investment coefficient is calculated directly using investment products, which are flow indicators. The flow indicator is an interval value reflecting changes in magnitude that occur over time. This indicator is additive, the sum of the indexes in the segmentations of a period is equal to the index value of the whole period. The investment coefficient, which represents the consumption quota, is linked to capital construction activities and reflected in the degree of demand for investment products in expanding the production scale.

(2) Dynamic Input-Output Model

The dynamic input-output model is a mathematical model that is built directly from the interdependence of dynamics and the quantification of causal relationships. In 1965 Leontief established a dynamic input-output model:

$$X(t) - AX(t) - D[X(t+1) - X(t)] = U(t) \tag{12}$$

where D is the investment coefficient matrix; $D[X(t+1) - X(t)]$ is the productive investment; $U(t)$ is the Final net demand $D[X(t+1) - X(t)] + U(t) = Y(t)$.

Order matrix $Q = -D^{-1}$ gets:

$$X(t+1) - X(t) = Q[AX(t) + U(t) - X(t)] \tag{13}$$

Order $l_i = \Delta x_i / x_i$ is the total loss ratio of the sector i, Δx_i represents the total loss in sector i caused by disasters, x_i represents the total output size of the sector i. The demand loss ratio of the sector i is $u_i^* = \Delta u_i / x_i$, Δu_i represents the loss of demand for the sector i caused by the disaster, u_i^* is the element of the matrix U^*, $U^* = X^{-1}\Delta U$. The above equation can be expressed as:

$$l(t+1) - l(t) = Q[A^* l(t) + U^*(t) - l(t)] \tag{14}$$

where

$$A^* = X^{-1}AX \tag{15}$$

the general solution of the Formula (8) is:

$$l_t = l(0)e^{-Q(I-A^*)t} + \int_0^1 QU^*(s)e^{Q(I-A^*)(s-t)}ds \tag{16}$$

Making the final demand of various sectors constant, $U^* = 0$, while $t \to \infty$, $l(t) \to 0$ The loss suffered by the sector has been restored over time. Only for the specific sector i,

$$l_i(t) = l_i(0)e^{-q_i(1-a_{ii}^*)t} \tag{17}$$

The total economic loss during the recovery period of the sector i is:

$$x_{it} \int_{t=0}^{T} l_i(t)dt \tag{18}$$

where x_{it} means the sector output value in unit time t.

2.3. Establishment of Storm Surge Disaster Input-Output Table

According to the marine disaster bulletin, combined with disaster economics theory, disaster economic loss assessment theory and sustainable development theory [61], the analytic hierarchy process (AHP) was used to analyze layer by layer, and the indicators were screened and stratified according to the interpretative structure model. The indirect loss assessment index system of storm surge disasters was constructed [62].

Input-output sectors were selected based on industry division [63] combined with the storm surge disaster assessment index system (Table 2) while referring to "The preparation method of input-output tables in China 2007", "The sector classification and national economic industry classification code comparison table of China 2007", "The preparation method of input-output tables in China 2012" and "The sector classification and national economic industry classification code comparison table of China 2012" [59,60]. Comprehensively considering the characteristics and types of disaster losses, the input and output sectors in the storm surge affected areas were merged into 10 industrial sectors.

Table 2. Assessment index system of economic loss due to storm surge disasters.

Direct economic loss	Direct economic loss in fishing and agriculture	Inundated crop area, damaged crop area, damaged area of marine aquaculture, value of damaged aquaculture facility
	Direct economic loss in the industry	Total area of damaged plants, value of damaged production equipment, value of damaged finished products, value of damaged unfinished products, raw material, offshore oil and gas mining equipment, oil field equipment, salt pan
	Direct economic loss in construction	Building material, buildings in construction, building equipment
	Direct economic loss in transport and postal services	Vessels, length of damaged urban road, wharf, submerged containers, posts and telecommunication equipment, dams, water conservancy and power supply facilities
	Direct economic loss in the tourist industry	Public facilities like park roads, buildings of sites, attractions of vegetation, casualties and other loss value
	Direct economic loss in living facilities	Collapsed buildings, value of indoor property damage
	Direct economic loss in human resources	Affected population, number of injuries, number of deaths
Indirect economic loss	Indirect economic loss in fishing and agriculture	Value loss due to salinization of farmland soil, fish pond stop-production, input of aquaculture facility rebuilding
	Indirect economic loss in the industry	Shut down days of damaged factories, factory shutdown loss, input of workshop rebuilding
	Indirect economic loss in construction	Days of stopped construction of building sites, loss due to delay of construction progress
	Indirect economic loss in transport and postal services	Communication interruption, traffic interruption, terminals out of service, coastal protection program rebuilding
	Indirect economic loss in the tourist industry	Attraction rebuilding, days of attractions shut down
	Indirect economic loss in living facilities	House rebuilding, restoration of living facilities
	Disaster relief	Rescue medical vehicle, sanitation facilities, medical aid, rescue service vehicles, rescue base station, government relief supplies, input of volunteers, government disaster-relief grants, corporate grants, donation of charitable funds, personal donation, government relief workers
	Ecological environment costs	Damaged mangrove area, biosphere damage, coast erosion, wetland destruction
	Derived disaster input	Groundwater pollution, disposal of post-disaster waste, prevention of disease, input of treatment

The main research object of this paper is the economic loss caused by storm surge disasters. The major industrial sectors involved include agriculture and fishery, extractive, manufacturing, construction, transportation and postal services. According to the research needs, the relevant industries were re-divided and merged, and the input-output sectors of storm surge disaster loss assessment were obtained (Table 3).

Table 3. Input-output sectors of storm surge disaster loss assessment.

Serial Number	Industry Segment	Detailed Division
01	Agriculture	Farming, forestry, animal husbandry and fishery
02	Extractive industry	Mining and washing of coal
		Petroleum and natural gas extraction
		Metal mining and dressing
		Nonmetal mineral mining and dressing
03	Manufacturing industry	Food production and tobacco processing
		Textile industry
		Textiles and clothing, footwear, leather and its products
		Timber processing and furniture manufacturing
		Paper printing, educational and sports goods
		Petroleum processing, coking and processing of nuclear fuel
		Chemical industry
		Nonmetal mineral products
		Smelting and pressing of metals
		Metal product manufacturing
		General and special equipment manufacturing
		Manufacture of transport equipment
		Manufacture of electric machinery and equipment
		Communication equipment, computer and other electronic equipment manufacturing
		Instruments meters, cultural and office machinery
		Manufacture of artwork and other manufacturing
		Waster and flotsam
04	Electricity, gas and water production and supply industry	Production and supply of electric power and thermal power
		Production and supply of gas
		Production and supply of water
05	construction industry	Construction industry
06	Transport and postal services	Transportation, warehousing, postal industry
07	Circulation sector	Wholesale and retail trade Hotels and catering services
08	Production and living services	Information service industry
		Finance industry
		Real estate
		Leasing and business services
		Compositive technical services
		Resident services and other services
		Water conservation, environment and public facilities management
09	Science and health services	Education
		Public health, social security and social welfare
		Culture, sports and entertainment
10	Social public services	Public management and social organization

3. Empirical Analysis of Storm Surge Damage Based on a Static Input-Output Model

3.1. Input-Output Table Structure of Storm Surge Disaster Loss

This paper takes the characteristics and effects of storm surges into consideration and evaluates the losses they cause. Based on the input-output table of storm surge disaster loss and "135 sector input-output table in 2007, Guangdong Province", "42 sector input-output table in 2007, Guangdong Province", "135 sector input-output table in 2012, Guangdong Province", "42 sector input-output table in 2012, Guangdong Province", and the storm surge disaster loss data of Guangdong Province over the years, the industry sector was divided into 10, as shown in Tables 4 and 5.

Table 4. Storm surge disaster input and output table in 2007 (unit: 10 thousand USD).

Flowmeter	Agriculture, Forestry, Animal Husbandry and Fishery	Extractive Industry	Manufacturing Industry	Electricity, Gas and Water Production and Supply Industry	Construction Industry	Transport and Postal Services	Circulation Sector	Production and Living Services	Science and Health Services	Social Public Services	Intermediate Use Part	Total Output
Agriculture, forestry, animal husbandry and fishery	4,949,118	8797	20,503,089	0	777,152	14,022	3,381,143	440,692	0	164,037	10,649,487	40,887,536
Extractive industry	14,666	1,975,404	31,962,550	7,739,739	1,171,414	2195	23,180	565	3045	4252	−28,870,674	14,026,336
Manufacturing industry	8,586,971	2,375,796	582,315,915	5,959,328	28,534,127	1,161,2676	85,54,421	21,702,776	8,783,386	2,479,463	236,690,791	917,595,650
Electricity, gas and water production and supply industry	531,911	575,775	24,459,363	25,089,216	8,932,648	130,609	1,785,029	1,154,274	419,677	505,481	−2,422,903	61,161,079
Construction industry	8484	3914	192,036	19,954	0	159,278	160,900	825,529	133,401	117,958	61,009,994	62,513,613
Transport and postal services	721,190	193,084	192,036	266,205	2,203,251	2,929,182	2,431,733	2,642,403	275,633	383,183	11,014,895	38,688,229
Circulation sector	298,527	157,758	17,168,547	291,265	1,781,004	1039789	2,248,808	4,573,103	766,703	1,103,768	46,484,811	75,914,084
Production and living services	1,149,991	479,871	33,923,501	2,951,324	4,105,809	4,535,041	11,713,723	27,885,859	1,875,243	2,218,009	65,140,335	157,087,263
Science and health services	8037	18,032	798,668	204,482	94,010	82,563	163,722	563,706	136,579	362,327	27,426,835	29,858,961
Social public services	45,163	0	0	0	0	542	0	20,634	1428	2503	18,236,418	18,306,688
Intermediate input part	16,314,058	6,006,047	726,081,745	0	47,599,415	20,505,896	41,069,434	49,202,766	12,395,094	7,340,982		
Total input	40,887,536	14,026,336	917,595,650	61,161,079	62,513,613	38,688,229	99,948,744	133,052,602	29,858,961	18,306,688		

Table 5. Storm surge disaster input and output table in 2012 (unit: thousand USD).

Flowmeter	Agriculture, Forestry, Animal Husbandry and Fishery	Extractive Industry	Manufacturing Industry	Electricity, Gas and Water Production and Supply Industry	Construction Industry	Transport and Postal Services	Circulation Sector	Production and Living Services	Science and Health Services	Social Public Services	Intermediate Use Part	Total Output
Agriculture, forestry, animal husbandry and fishery	7,178,588	1490	28,642,071	2899	1,097,490	4778	3,627,921	3,695,460	47,780	0	44,298,477	67,490,580
Extractive industry	22,182	2,961,224	41,221,937	20,070,319	2,315,533	489	163,980	15,200	0	0	66,770,864	20,448,975
Manufacturing industry	16,234,887	2,289,019	960,270,172	2,969,958	70,293,650	25,049,498	19,493,148	47,304,213	12,275,925	1,976,248	1,158,156,719	1,525,426,573
Electricity, gas and water production and supply industry	875,779	776,580	35,089,639	43,545,385	2,078,054	3,612,106	4,252,794	4,730,371	1,004,862	1,000,340	96,965,909	102,134,355
Construction industry	2782	0	762,727	411,606	6,350,039	82,060	392,387	903,671	180,818	181,265	9,267,355	126,871,594
Transport and postal services	604,897	309,847	762,727	2,182,869	3,261,883	13,435,762	8,907,226	6,005,760	957,158	931,707	66,166,152	88,466,232
Circulation sector	780,276	309,847	51,555,206	734,759	8,401,935	2,555,350	7,833,325	12,167,584	2,175,728	2,432,808	674,192	161,620,954
Production and living services	504,260	1,031,991	42,299,888	5,840,385	5,521,588	9,275,563	29,030,691	56,320,124	7,051,389	4,519,513	161,395,391	311,671,594
Science and health services	3398	30,173	797,639	65,108	127,538	128,860	396,482	1,858,591	1,159,939	454,316	5,022,043	61,998,261
Social public services	18,892	556	206,935	1645	19,537	10,687	30,451	300,719	16,689	513,515	1,119,627	35,790,145
Intermediate input part	26,225,942	8,519,120	1,189,606,863	75,824,934	99,467,246	54,155,152	74,128,406	133,301,692	24,870,290	12,009,710		
Total input	67,490,580	20,448,975	1,525,426,573	102,134,355	126,871,594	88,466,232	161,620,954	311,671,594	61,998,261	35,790,145		

3.2. Input-Output Table Data Processing

This paper applies direct consumption and complete consumption coefficients, which are widely used in the field. Based on the input-output table of storm surges, and the calculation principle of the direct and total consumption coefficients of 42 sectors in input-output tables in 2007 and 2012, the direct consumption and complete consumption coefficient of the input-output table of storm surges in Guangdong Province were obtained according to Formula (1) and Formula (2). The results are shown in Tables 6–9.

3.3. Analysis of the Static Input-Output Model Result

By referring to the China Maritime Disaster Bulletin, the direct economic losses caused by the storm surges in Guangdong Province in 2007–2017 were USD 349.86 million, USD 2235.07 million, USD 565.07 million, USD 443.77 million, USD 183.04 million, USD 253.19 million, USD 1075.36 million, USD 875.51 million, USD 416.81 million, USD 134.20 million and USD 776.96 million (Figure 3), among which the more serious loss-facing industries were the aquaculture industry and agriculture. By reading the relevant materials, this paper estimates the agricultural (agricultural, forestry, animal husbandry and fishery) total output economic loss based on 80% of the direct economic loss due to the storm surge disasters published by the State Oceanic Administration. According to Formula (3) to Formula (8), selecting 2007 as the base year, we assumed that the input-output relationship among the various branches of the national economy will remain unchanged. We analyzed and calculated the total output loss of agriculture and the indirect economic loss in Guangdong Province from 2007 to 2011 with the input-output model. Selecting 2012 as the base year, we analyzed and calculated the total output loss of agriculture and the indirect economic loss from 2012 to 2017, as shown in Table 10.

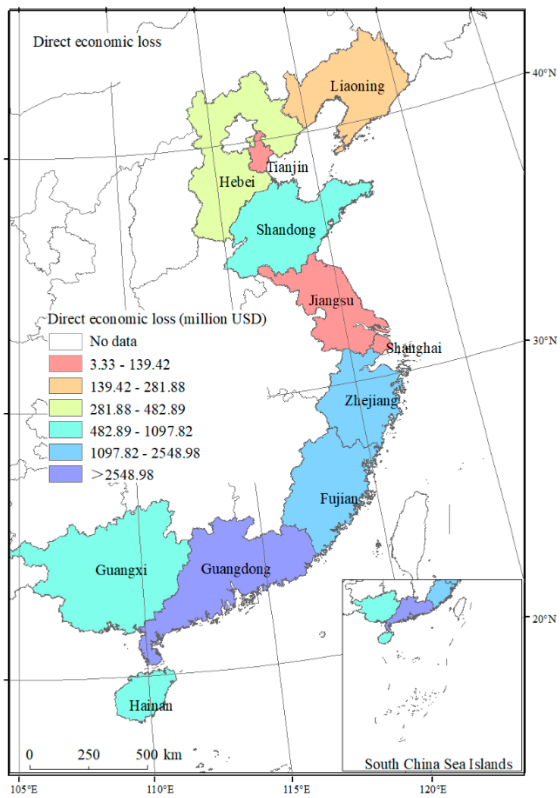

Figure 3. Direct economic loss in coastal provinces in 2007–2017.

Table 6. Storm surge tide direct consumption coefficient in 2007.

Flowmeter	Agriculture, Forestry, Animal Husbandry and Fishery	Extractive Industry	Manufacturing Industry	Electricity, Gas and Water Production and Supply Industry	Construction Industry	Transport and Postal Services	Circulation Sector	Production and Living Services	Science and Health Services	Social Public Services
Agriculture, forestry, animal husbandry and fishery	0.1210	0.0006	0.0223	0.0000	0.0124	0.0004	0.0445	0.0028	0.0000	0.0090
Extractive industry	0.0004	0.1408	0.0348	0.1265	0.0187	0.0001	0.0003	0.0000	0.0001	0.0002
Manufacturing industry	0.2100	0.1694	0.6346	0.0974	0.4564	0.3002	0.1127	0.1382	0.2942	0.1354
Electricity, gas and water production and supply industry	0.0130	0.0410	0.0267	0.4102	0.1429	0.0034	0.0235	0.0073	0.0141	0.0276
Construction industry	0.0002	0.0003	0.0002	0.0003	0.0000	0.0041	0.0021	0.0053	0.0045	0.0064
Transport and postal services	0.0176	0.0293	0.0161	0.0044	0.0352	0.0757	0.0320	0.0210	0.0092	0.0209
Circulation sector	0.0073	0.0112	0.0187	0.0048	0.0285	0.0269	0.0296	0.0291	0.0257	0.0603
Production and living services	0.0281	0.0342	0.0370	0.0483	0.0657	0.1172	0.1543	0.1775	0.0628	0.1212
Science and health services	0.0002	0.0013	0.0009	0.0033	0.0015	0.0021	0.0022	0.0036	0.0046	0.0198
Social public services	0.0011	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001

Table 7. Storm surge tide direct consumption coefficient in 2012.

Flowmeter	Agriculture, Forestry, Animal Husbandry and Fishery	Extractive Industry	Manufacturing Industry	Electricity, Gas and Water Production and Supply Industry	Construction Industry	Transport and Postal Services	Circulation Sector	Production and Living Services	Science and Health Services	Social Public Services
Agriculture, forestry, animal husbandry and fishery	0.1064	0.0001	0.0188	0.0000	0.0087	0.0001	0.0224	0.0119	0.0008	0.0000
Extractive industry	0.0003	0.1448	0.0270	0.1965	0.0183	0.0000	0.0010	0.0000	0.0000	0.0000
Manufacturing industry	0.2406	0.1119	0.6295	0.0291	0.5541	0.2832	0.1206	0.1518	0.1980	0.0552
Electricity, gas and water production and supply industry	0.0130	0.0380	0.0230	0.4264	0.0164	0.0408	0.0263	0.0152	0.0162	0.0280
Construction industry	0.0000	0.0000	0.0005	0.0040	0.0501	0.0009	0.0024	0.0029	0.0029	0.0051
Transport and postal services	0.0090	0.0152	0.0005	0.0214	0.0257	0.1519	0.0551	0.0193	0.0154	0.0260
Circulation sector	0.0116	0.0152	0.0338	0.0072	0.0662	0.0289	0.0485	0.0390	0.0351	0.0680
Production and living services	0.0075	0.0505	0.0277	0.0572	0.0435	0.1048	0.1796	0.1807	0.1137	0.1263
Science and health services	0.0001	0.0015	0.0005	0.0006	0.0010	0.0015	0.0025	0.0060	0.0187	0.0127
Social public services	0.0003	0.0000	0.0001	0.0000	0.0002	0.0001	0.0002	0.0010	0.0003	0.0143

Table 8. Storm surge disaster complete consumption coefficient in 2007.

Flowmeter	Agriculture, Forestry, Animal Husbandry and Fishery	Extractive Industry	Manufacturing Industry	Electricity, Gas and Water Production and Supply Industry	Construction Industry	Transport and Postal Services	Circulation Sector	Production and Living Services	Science and Health Services	Social Public Services
Agriculture, forestry, animal husbandry and fishery	0.1595	0.0208	0.0816	0.0207	0.0595	0.0321	0.0679	0.0218	0.0281	0.0304
Extractive industry	0.0422	0.2102	0.1464	0.2875	0.1361	0.0544	0.0334	0.0312	0.0514	0.0373
Manufacturing industry	0.7845	0.7046	2.043	0.7209	1.6088	1.0909	0.542	0.587	0.9779	0.5956
Electricity, gas and water production and supply industry	0.0669	0.1199	0.1555	0.7527	0.3323	0.0671	0.0745	0.0493	0.0779	0.0856
Construction industry	0.0012	0.0014	0.0021	0.0019	0.0021	0.0062	0.0039	0.0072	0.0058	0.0082
Transport and postal services	0.0406	0.0552	0.0665	0.0353	0.0805	0.1111	0.0542	0.043	0.0349	0.0433
Circulation sector	0.0287	0.0331	0.0691	0.0321	0.0727	0.0602	0.0511	0.0519	0.0522	0.083
Production and living services	0.093	0.1051	0.1793	0.1611	0.2068	0.2288	0.2401	0.275	0.145	0.2075
Science and health services	0.0017	0.0032	0.0043	0.0076	0.0053	0.0046	0.004	0.0055	0.0065	0.0218
Social public services	0.0013	0.0000	0.0001	0.0000	0.0001	0.0001	0.0002	0.0001	0.0002	0.0002

Table 9. Storm surge disaster complete consumption coefficient in 2012.

Flowmeter	Agriculture, Forestry, Animal Husbandry and Fishery	Extractive Industry	Manufacturing Industry	Electricity, Gas and Water Production and Supply Industry	Construction Industry	Transport and Postal Services	Circulation Sector	Production and Living Services	Science and Health Services	Social Public Services
Agriculture, forestry, animal husbandry and fishery	0.1381	0.0125	0.0659	0.0129	0.0545	0.0282	0.0434	0.032	0.0203	0.0124
Extractive industry	0.0414	0.2086	0.1235	0.4277	0.1094	0.0678	0.0408	0.0357	0.039	0.0373
Manufacturing industry	0.8128	0.4675	1.9065	0.4313	1.8189	1.0916	0.5876	0.6239	0.7102	0.3428
Electricity, gas and water production and supply industry	0.0662	0.1062	0.1368	0.8009	0.1269	0.1442	0.0906	0.0684	0.0712	0.0791
Construction industry	0.0011	0.0012	0.0029	0.0086	0.0552	0.0033	0.0044	0.0048	0.0046	0.0069
Transport and postal services	0.0194	0.0301	0.0189	0.061	0.0526	0.1958	0.0811	0.0374	0.031	0.0454
Circulation sector	0.047	0.0425	0.1139	0.0461	0.1503	0.0872	0.0881	0.0777	0.0735	0.0967
Production and living services	0.0581	0.1115	0.1442	0.1856	0.174	0.2244	0.2791	0.2724	0.1938	0.2049
Science and health services	0.0011	0.003	0.003	0.0034	0.0038	0.0041	0.005	0.0084	0.021	0.015
Social public services	0.0005	0.0002	0.0006	0.0003	0.0006	0.0005	0.0006	0.0014	0.0006	0.0148

Table 10. Storm surge disaster loss in various industries in 2007–2017 (unit: million USD).

Loss of Output in Each Sector		Loss in 2007	Loss in 2008	Loss in 2009	Loss in 2010	Loss in 2011	Loss in 2012	Loss in 2013	Loss in 2014	Loss in 2015	Loss in 2016	Loss in 2017
Direct Economic Loss		**349.86**	**2235.07**	**565.07**	**443.77**	**183.04**	**253.19**	**1075.36**	**875.51**	**416.81**	**134.2**	**776.96**
Agriculture	Agricultural total output loss	279.88	1788.06	452.06	355.01	146.43	202.55	860.29	700.41	333.45	107.36	621.57
	Final products of agriculture	241.38	1542.09	389.87	306.18	126.29	177.97	755.9	615.42	292.99	94.33	546.14
	Intermediate loss of agriculture	38.5	245.96	62.18	48.84	20.14	24.58	104.39	84.99	40.46	13.03	75.42
Associated Industries Sector	Extractive industry	10.19	65.08	16.45	12.92	5.33	7.37	31.29	25.48	12.13	3.91	22.61
	Manufacturing industry	189.37	1209.77	305.86	240.2	99.08	144.66	614.4	500.21	238.14	76.68	443.9
	Electricity, gas and water production and supply industry	16.15	103.17	26.08	20.48	8.45	11.78	50.04	40.74	19.4	6.24	36.15
	Construction industry	0.29	1.85	0.47	0.37	0.15	0.2	0.83	0.68	0.32	0.1	0.6
	Transport and postal services	9.8	62.61	15.83	12.43	5.13	3.45	14.66	11.94	5.68	1.83	10.6
	Circulation sector	6.93	44.26	11.19	8.79	3.62	8.37	35.53	28.92	13.77	4.43	25.67
	Production and living services	22.45	143.41	36.26	28.48	11.74	10.34	43.92	35.76	17.02	5.48	31.73
	Science and health services	0.41	2.62	0.66	0.52	0.21	0.2	0.83	0.68	0.32	0.1	0.6
	Social public services	0.31	2	0.51	0.4	0.16	0.09	0.38	0.31	0.15	0.05	0.27
Total indirect loss		255.89	1634.77	413.3	324.58	133.88	186.44	791.88	644.71	306.93	98.82	572.14

By analyzing the above table, conclusions were drawn as follows:

(1) The total agricultural output losses caused by the storm surges in Guangdong Province from 2007 to 2016 were USD 279.88 million, USD 1788.06 million, USD 452.06 million, USD 355.01 million, USD 146.43 million, USD 202.55 million, USD 860.29 million, USD 700.41 million, USD 333.45 million, USD 107.36 million and USD 621.57 million. In 2008, the loss of agricultural final product was USD 1542.09 million, and the indirect economic loss due to storm surge was the largest, which was USD 1634.77 million.

(2) Industries ranked from top-down according to the indirect loss caused by agricultural loss are as follows: manufacturing, production and living services, electricity, gas and water production and supply industry, extractive industry, transport and postal services, circulation sector, science and health services, social public services sector, construction industry. The impact of agricultural economic loss on the manufacturing sector is the strongest, indicating that the economic loss of agriculture is related to the economic loss in the manufacturing industry. The impact of agricultural economic loss on health education sectors, social and public service sectors and construction sectors shows that the agricultural economy is less than 0.2% in all sectors of the industry. Its impact on these industries can be neglected in a rough calculation. The specific results of the impact of the economic loss on the industries are shown in Figures 4 and 5.

(3) According to the input-output table in 2007, indirect economic loss accounted for 73.14% of the direct economic loss, accounting for 42.24% of the total economic loss. According to the input-output table in 2012, indirect economic loss accounted for 73.64% of the direct economic loss, accounting for 42.41% of the total economic loss. The indirect loss caused by storm surges accounted for a large proportion of the total loss. Attention should be paid to the prevention and reduction of indirect disasters.

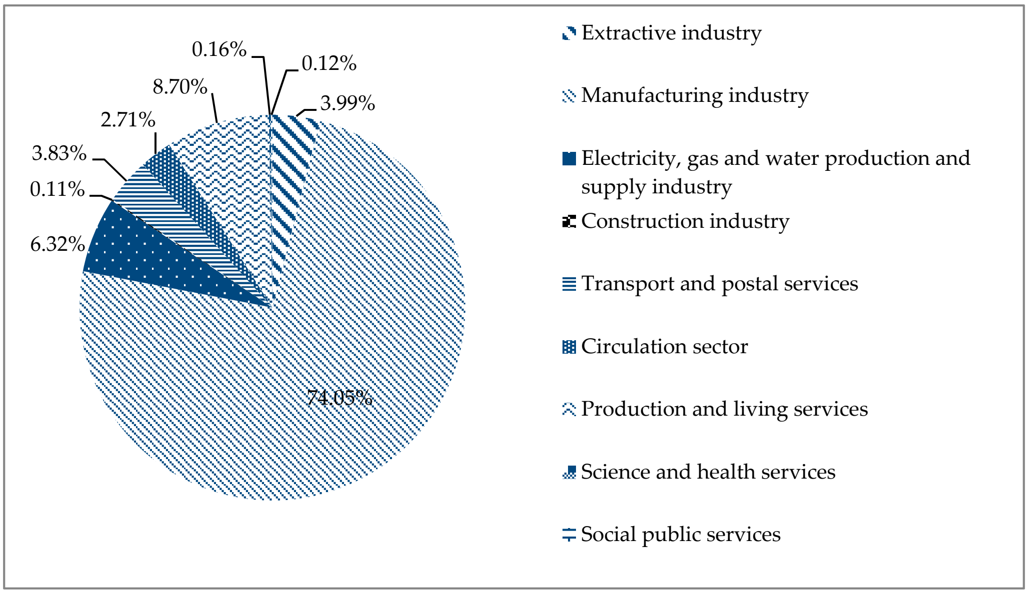

Figure 4. The proportion of the impact of the agricultural economic loss on other industries in 2007–2011.

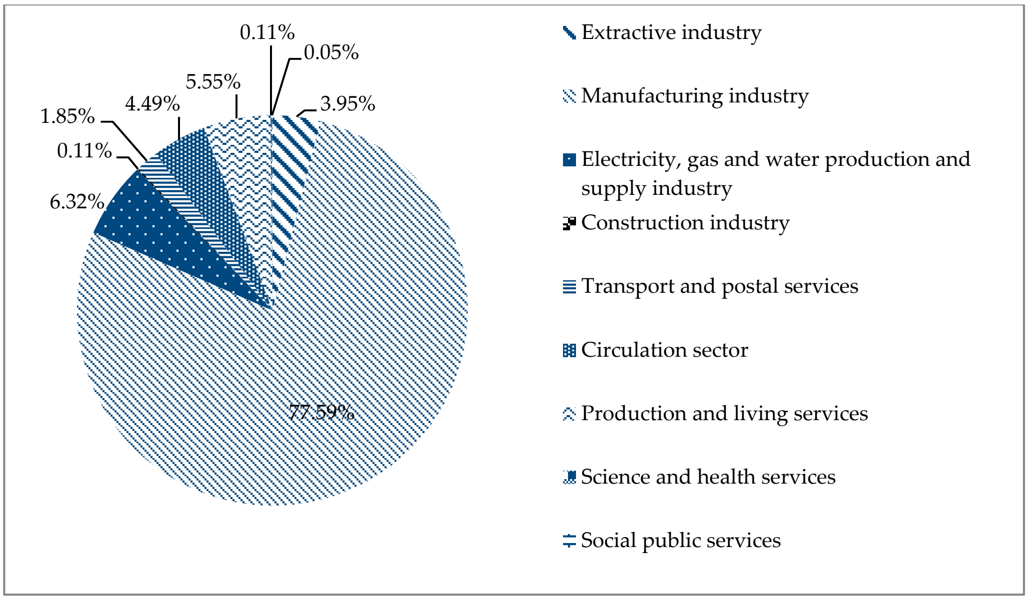

Figure 5. The proportion of the impact of the agricultural economic loss on other industries in 2012–2017.

4. Empirical Analysis of Storm Surge Damage Based on a Dynamic Input-Output Model

4.1. Model Data Processing

Taking the disaster data of Guangdong Province in 2017 as an example, and other years share the same calculation process. Based on the year 2012, assuming that the input-output relationship between the various sectors of the national economy is unchanged, the data of the storm surge disasters were derived from the China Marine Disaster Bulletin. The direct economic loss caused by storm surge in Guangdong Province amounted to USD 7.8 billion in 2017. According to the input-output table of storm surge damage (Table 5), the total output of different sectors except agriculture can be obtained as shown in Table 11.

Table 11. The total output of various sectors in 2017 (unit: USD thousand).

Sector	Total Output
Extractive industry	2,044,898
Manufacturing industry	152,542,657
Electricity, gas and water production and supply industry	10,213,435
Construction industry	12,687,159
Transport and postal services	8,846,623
Circulation sector	16,162,095
Life and production services	31,167,159
Science and health services	6,199,826
Social public services	3,579,014

Based on the direct consumption coefficient (Table 7), combined with the input-output table, the matrix A^* was calculated according to Formula (12) to Formula (15) in dynamic input-output model construction. The total output loss ratio in Guangdong Province was calculated as shown in Table 12.

The proportion of total output loss from large to small is as follows: extractive industry, electricity, gas and water production and supply, manufacturing, circulation, transportation and post and telecommunications, production and living services, social and public services, science and health services, construction industry. The proportion of total output loss reflects the proportion of the economic loss generated by storm surges in the year in the total production of the sector, which in turn reflects the overall impact on the sector. At the same time, the rate of industrial economic recovery and cumulative production is calculated. The loss value is based on the data.

Table 12. The proportion of total output loss in 2017.

Sector	Total Output Loss Ratio (%)
Extractive industry	0.110569
Manufacturing industry	0.029100
Electricity, gas and water production and supply industry	0.035399
Construction industry	0.000474
Transport and postal services	0.011977
Circulation sector	0.015882
Life and production services	0.010181
Science and health services	0.000969
Social public services	0.000763

4.2. Analysis of the Dynamic Input-Output Model Result

Judging from the total loss ratio, the extractive industry was most affected by the storm surge disasters in 2017. The extractive industry was selected for dynamic input-output model evaluation and analysis. The analysis of other industries was similar to that of the extractive industry.

The loss ratio of the extractive industry is 0.1106%, $l(0) = 0.0011$. It was assumed that after 60 days the extractive industry will recover to 99.95% of the original output, putting $l(60) = 0.0005$, into the Formula (17) it can be calculated that $q_{extractiveindustry} = 0.0154$. The extractive industry functional recovery situation is: $1 - l(t) = 1 - 0.0011e^{-0.0154(1-0.1448)t}$. During the 60-day recovery period, the recovery curve of the extractive industry is shown in Figure 6.

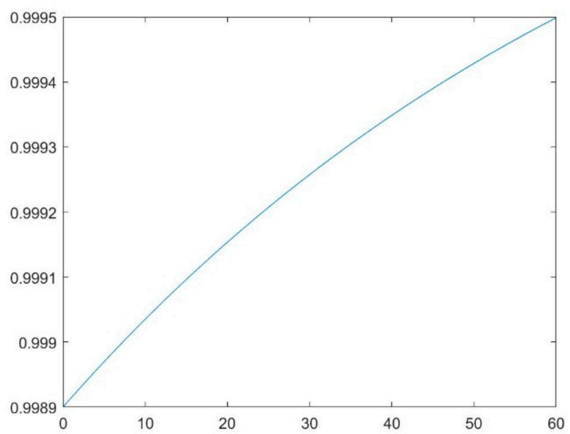

Figure 6. The recovery curve of the extractive industry.

From Formula (18) we can see that when the recovery of extractive industry production takes 60 days, the accumulated output value of the sector is USD 0.66 million (Figure 7). Based on this, we can calculate the value of accumulated output loss in other industries. The total accumulated output loss in the entire economic system is the sum of the accumulated output loss in various industries. If the recovery period is changed to 30 days, 90 days, 120 days, 180 days and 360 days respectively, the cumulative output loss values of the extractive industry under each recovery period are as shown in Table 13.

Analyzing the recovery period of the excavation industry in Figure 6, it can be seen that the early recovery period of the industry is relatively fast, while the later period tends to be stable. In general, the proportion of the extractive industry loss is within a proper range. With the improvement of the contingency plans of the relevant sectors and the further escalation of preventive measures, we can expect that the recovery period after storm surges will be further shortened and economic loss will be reduced accordingly.

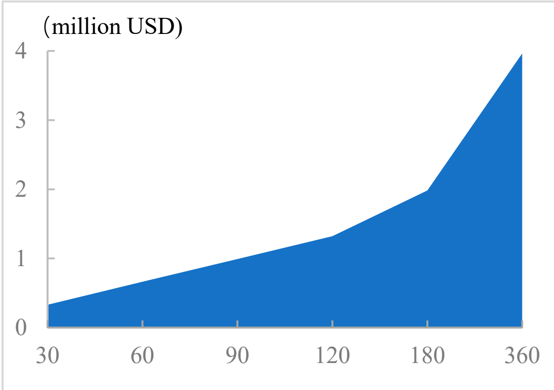

Figure 7. The accumulated output loss value.

Table 13. The excavation industry's accumulated output loss under different recovery periods.

Recovery Period/Days	30	60	90	120	180	360
The industrial economic system recovery rate	0.0307	0.0154	0.0102	0.0077	0.0051	0.0026
Accumulated output loss value (unit: million USD)	0.3308	0.6624	0.9911	1.3214	1.9821	3.9642

On the one hand, with the extension of the recovery period, the recovery rate of the industrial economic system gradually decreases, and the decrease is weakening. This indicates that the recovery rate of the sector has gradually reduced, but as the recovery period is extended, the recovery rate decline will decrease. This is because while the recovery period is extended, the amount of economic recovery per unit of time is not fixed, we can easily find this conclusion through the recovery curve. On the other hand, the accumulated output loss value increases gradually with the extension of the recovery period. This is because the recovery period is prolonged and the recovery is slowing down. The sector is unable to produce its normal production, thus exacerbating economic loss. Therefore, after a storm surge, the relevant sectors should take timely measures to coordinate the damaged sector and reduce the recovery period to effectively reduce the storm surge economic loss.

5. Discussion

The calculation of indirect economic loss due to natural disasters usually uses the empirical coefficient method which is simple and easy to operate. However, due to its strong subjectivity, it is unable to conduct a comprehensive quantitative study and thus cannot accurately reflect the loss estimation. The foreign models of indirect economic loss estimation due to natural disasters mainly include the system dynamics model, econometric model, input-output model, production function model, general equilibrium model, etc.

At present, the measurement of indirect economic loss is not unified, the statistics and related research on indirect economic loss are insufficient. Therefore, the related research on the indirect economic loss due to storm surges is still in the stage of exploration, and a comprehensive evaluation system is not formed. This paper introduces the sector input-output approach to calculate indirect economic loss.

Wassily W. Leontief believes that "the characteristic and advantage of input-output analysis is that it can systematically analyze and study the relationship between different sectors of a complex economy quantitatively." At present, input-output analysis is mainly used in structural analysis, economic prediction and economic benefit analysis [64].

Compared with other methods, the input-output model is more suitable for the assessment of indirect economic losses caused by marine disasters. Firstly, the input-output table reflects the local actual input-output volume, the data is true and consistent with the actual situation, and the application precision of the model is high. Secondly, the input-output model can comprehensively reflect the influence relationship among various industries in the national economic system, which is convenient for the comparison between industries, and the model results are more convenient to obtain. Finally, through the input-output table of different product sectors, the analysis can achieve the purpose of the study, and the calculation difficulty of the model is low.

The dynamic input-output model focuses on the economic dynamic model of structural change of economic sectors, including the time-varying factors. It focuses on the analysis of the quantitative relationship between the total amount and composition of investment in the forward period of the national economy and the scale and structure of product production in various economic sectors in the follow-up period, which reflects not only the total amount change but also the structural change.

The static I-O model reflects the economic quantitative relationship in a specific period, excluding the influence of time factors. The dynamic model is established based on the static model. While retaining the basic quantitative relationship in the static model, the basic task of the dynamic model is to connect the different periods of the national economy through the model, and the link in the formation of fixed capital. The analysis of the quantity, structure and effect of fixed capital formation is the key to establishing the dynamic input-output model.

A dynamic input-output model is established based on the static model. When calculating storm surge disaster loss using a dynamic model with the changes in time, the effect of resilience should be taken into consideration. This is the primary difference between the static model and the dynamic model. Taking the extractive industry as an example, the influence of resilience on loss assessment results is analyzed.

In the situation of a storm surge, the indirect economic loss in the extractive industry will be affected by both the recovery of the extractive industry and the recovery of the economic system. The rapidity and redundancy of the system determine the speed and process of the recovery force of the extractive industry, while external factors determine the size of indirect economic loss. Economic resilience refers to the ability of various industrial sectors in the economic system to adjust and restore balance after the external shock. Given the impact of resilience, when there is a shortage of demand or supply of the extractive industry, each industry sector can mitigate potential loss through alternative resources. In the dynamic input-output model, economic resilience refers to the decline in the input of the extractive industry required by the unit output due to the alternative enhancement of resources.

The dynamic input-output model makes up for the static input-output model's limitation that it cannot reflect the change with time, but only reflect the economic and social sectors in the short-term related links, without long-term relationships. However, the application of the input-output model requires certain assumptions, that the input-output relationship between the various sectors of the national economy remains the same. These assumptions are often not well satisfied in real life, which will have an impact on the assessment of indirect loss.

6. Conclusions

Storm surges have become one of the most important natural disasters to economic development. Once a storm surge takes place, there will be a huge economic loss, and how to estimate the loss has become an important problem plaguing the relevant researchers.

In this paper, according to the national statistical bureau's classification criteria for the three industries, the storm surge disaster input and output sectors were merged into 10 industrial sectors, with the consideration of the storm surge hazard assessment index system, and the characteristics of storm surge disaster loss. The 10 sectors' input-output table of storm surge disaster loss was designed. Based on the year 2007, the total output loss of agriculture and the indirect economic loss in various sectors were obtained from 2007 to 2011 in Guangdong Province. Based on 2012, the total output loss of agricultural output from 2012 to 2016 and the indirect economic losses of various sectors were obtained. The conclusion was that the storm economy has the greatest impact on the agricultural sector and has conversely little impact on the social and public services sector, the health education service sector and the construction sector.

Based on the static input-output model, considering the time factor, the dynamic input-output model of storm surge disaster assessment was constructed. As it had the largest proportion of total output loss, the extractive industry was selected as the object to calculate cumulative output loss value under different recovery periods (30 days, 90 days, 120 days, 180 days, 360 days). The dynamic model loss value of the extractive industry was compared with the static input-output model. The results showed that the longer the production recovery period is, the greater the output loss value is, and the total output loss value of the dynamic input-output model is smaller than that of the static model.

The dynamic input-output model is a development of the static model, revealing the quantitative relationship and causality of the change in the development process. The concrete comparison result is as follows: In the case of the different recovery periods in Table 13, it shows that the accumulated output loss in the industry is proportional to the recovery period of production and becomes larger as the recovery period becomes longer. The total output loss calculated by the static input-output model is larger than that of the dynamic input-output model. This is because the industrial loss rate of the static model is the instantaneous value, which is obtained from the industrial loss rate by multiplying the industrial output value (recovery period is one year). Dynamic model loss is obtained from the loss rate by multiplying the industrial output value by a cumulative number of days from the recovery period, so the total loss is relatively small.

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Appendix A. Highlights

- The 10 sectors' input-output table of storm surge disaster loss was designed.
- The indirect economic loss due to storm surges between 2007–2017 was determined by calculating the direct and indirect consumption coefficients.
- Based on the static input-output model, considering the time factor, the dynamic input-output model of storm surge disaster assessment was constructed.
- Cumulative output loss value was calculated under different recovery periods (30 days, 90 days, 120 days, 180 days, 360 days).
- The dynamic model loss value of the industry was compared with the static input-output model.

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