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Assessment of Soil Quality of Tidal Marshes in Shanghai City

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Abstract We take three types of tidal marshes in Shanghai City as the study object: tidal marshes in mainland, tidal marshes in the rim of islands, and shoal in Yangtze estuary. On the basis of assessing nutrient quality and environmental quality, respectively, we use soil quality index (SQI) to assess the soil quality of tidal flats, meanwhile formulate the quality grading standards, and analyze the current situation and characteristics of it. The results show that except the north of Hangzhou Bay, Nanhui and Jiuduansha with low soil nutrient quality, there are not obvious differences in soil nutrient quality between other regions; the heavy metal pollution of tidal marshes in mainland is more serious than that of tidal marshes in the rim of islands; in terms of the comprehensive soil quality index, the regions are sequenced as follows: Jiuduansha wetland > Chongming Dongtan wetland > Nanhui tidal flat > tidal flat on the periphery of Chongming Island > tidal flat on the periphery of Hengsha Island > Pudong tidal flat > Baoshan tidal flat > tidal flat on the periphery of Changxing Island > tidal flat in the north of Hangzhou Bay. Among them, Jiuduansha wetland and Chongming Dongtan wetland have the best soil quality, belonging to class III, followed by Nanhui tidal flat, tidal flat on the periphery of Chongming Island and tidal flat on the periphery of Hengsha Island, belonging to class IV; tidal flat on the periphery of Changxing Island, Pudong tidal flat, Baoshan tidal flat and tidal flat in the north of Hangzhou Bay belong to class V.

Key words Soil nutrient quality, Soil environmental quality, Soil quality index, Tidal marshes in Shanghai City

Tidal marshes, the largest wetland type in Shanghai City, provide material production, nutrient cycling, climate regulation, biodiversity maintenance and other important ecosystem services for economic and social development of Shanghai and the Yangtze River Delta area[1-2]. Meanwhile, the tidal marshes in the Yangtze River Estuary are also the important ecologically fragile areas, having been threatened by enclosure, trawling, biological invasion and many other factors, so that the ecosystem structure and function is damaged[3]. The soil is regarded as the important component of tidal marshes, whose quality is the basis for tidal flats ecosystem to sustain productivity and maintain the vitality[4], having a direct impact on the ecological health, risk and safety of tidal marshes[5]. There are few reports on the research of soil quality assessment on tidal marshes in Shanghai City. This article conducts assessment on the soil quality of tidal marshes in Shanghai City, conducive to the scientific protection and rational use of tidal marshes ecosystem, providing protection for sustainable development of Shanghai City.

The phenomenon of higher content of heavy metal in soil than the natural background value becomes increasingly common, and the researches on assessment and treatment of heavy metal pollution are becoming increasingly deep[6], but how to combine soil heavy metal and soil nutrient quality for comprehensive measuring, has not been reported. Therefore, based on the summarization of previous evaluation methods, coupled with soil nutrient quality and environmental quality, this paper uses soil quality index (SQI) to conduct comprehensive evaluation on the soil quality of tidal marshes in Shanghai City, to provide support for guiding the management and conservation measures on tidal marshes.

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1 Materials and methods

1.1 Overview of the study area Shanghai City (120°51′ - 122°12′E, 30°40′ - 31°53′N) is located in the Yangtze Delta Estuary area, an important estuarine salt marsh distribution area in China. The study area covers three types of tidal marshes in Shanghai City: tidal marshes in mainland, tidal marshes in the rim of islands, and shoal in Yangtze estuary (Table 1).

1.2 Sample collection and testing Using GPS precise positioning, the sampling was conducted in September to October, 2011, identifying 19 sampling points including all tidal marshes in Shanghai City (Fig. 1). According to the vegetation and elevation of tidal flats in each sampling point, corresponding quadrats were laid, respectively; each quadrat is mixed with 0 - 20 cm surface soil within 10 m diameter.

The soil bulk density was measured using circular knife method. In each quadrat, the circular knife with inner diameter and height of 5 cm was used to sample the 0 - 5 cm surface soil, and the bottom of circular knife was lifted using a smooth sheet metal to ensure that the water will not leak through the soil pore. Then after being sealed in a bag, the soil sample was brought to the lab, dried at 60 ℃, and weighed. The soil bulk density was derived through the conversion formula.

IQ 150 portable pH temperature measurement apparatus was used for direct measurement, and HI1053 stylus glass composite electrode was used to measure pH. As for the TN measurement, the soil sample dried and ground was sieved by the mesh sieve with 100 beads; carbon and nitrogen analyzer Thermo Flash EA1112 was used to get total nitrogen content of 50 mg of soil sifted. TP uses HNO3 - HClO4 - HF for dissolution, ICP - AES for measurement. Soil organic matter was determined by potassium dichromate volumetric method, and oil was determined by infrared spectrophotometry. Meanwhile, USEPA6010C - 2007 method was used to measure the soil heavy metal As, Cd, Cr, Cu, Ni, Pb, Zn, while heavy metal

Hg was measured by GB/T17136 – 1997 method[7].

1.3 Soil quality assessment The meaning of soil quality is very rich, and the quality of soil nutrient and soil environment are the most important two factors, therefore, we should combine the quality of soil nutrient and environment for comprehensive evaluation when assessing the soil quality[8].

Table 1 Distribution of tidal marshes in Shanghai City

Type	Name	Distribution	Note
Tidal marshes in mainland	Tidal flat in the north of Hangzhou Bay	West from Jinsiniangqiao, east to Huijiao in Nanhui	Including Tongsha Shazui
	Nanhui tidal flat	Pudong International Airport to Huijiao	
Pudong tidal flat	Wusong Port to Pudong International Airport		
	Baoshan tidal flat	Liuhe Port to Wusong Port	
Tidal marshes in the rim of islands	Chongming Dongtan wetland	North from Baxiao, south to Xijiagang	Including Sheshan Island
	Tidal flat on the periphery of Chongming Island	In addition to Dongtan, the northern, western and southern tidal flats of Chongming Island	North including Huangguasha, south including Biandansha
	Tidal flat on the periphery of Changxing Island	The northern and western tidal flats of Changxing Island	
	Including Qingcaosha, Zhongyangsha and Xinliushahesha		
	Tidal flat on the periphery of Hengsha Island	The eastern tidal flats of Hengsha Island	Including Hengsha shoal, Baitiaozisha
Shoal in Yangtze estuary River	Jiuduansha	Between Hengsha Island and Chuansha, 14 km from Pudong International Airport	Including Jiangya Nansha

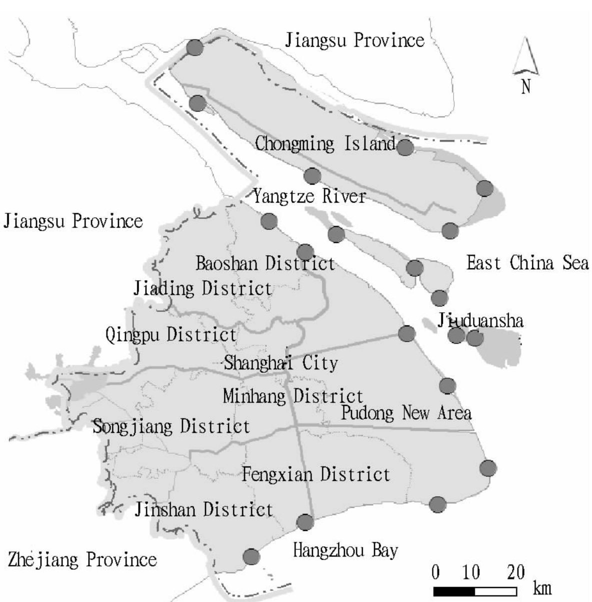

Fig. 1 Distribution of sampling points in the study area

1.3.1 Nutrient quality evaluation method. We select five factors (soil pH, organic matter, total nitrogen, total phosphorus, total carbon) as the assessment indicators, and the fuzzy membership function model as the evaluation method[9]. To avoid the subjective influence, we use the correlation coefficient method to determine the weight of evaluation factors[10]. Due to the lack of comparability between evaluation indicators, we use the membership function to conduct normalization processing. Based on the results of previous studies, we determine the undertopedge function as the membership function of soil organic matter, total nitrogen, total phosphorus, and total carbon[11]. The function is $I(X)$:

$$I(X) = \begin{cases} 1.0 & X \geqslant X_2 \\ \dfrac{0.9(x - x_1)}{x_2 - x_1} & X_2 \leqslant X < X_2 \\ 0.1 & X_2 \end{cases} \quad (1)$$

Based on the actual situation of the study area and the national soil nutrient grading standards[12], we determine the turning point of the soil organic matter, total nitrogen, total phosphorus, X_1, X_2; X_1, X_2 of total carbon are determined based on the predecessors' research on the carbon content of tidal flats soil in Shanghai City[13]. The values of turning point of membership function, X_1, X_2, are shown in Table 2.

Table 2 The values of turning point of membership function of various soil nutrient indicators

Evaluation indicators	Organic matter g/kg	Total nitrogen g/kg	Total phosphorus g/kg	Total carbon g/kg
X_1	6	0.5	0.4	10
X_2	40	2	2	50

Given that pH value has an optimally suitable range for the soil function (such as productivity), we select the parabolic membership function as the membership function of soil pH of tidal flats in Shanghai City[14], and its expression is as follows:

$$\mu(x)=\begin{cases}1 & b_1\leqslant x\leqslant b_2\\ \dfrac{x-a_1}{b_1-a_2} & a_1<x<b_1\\ \dfrac{a_2-x}{a_2-b_2} & b_2<x<a_2\\ 0 & x\leqslant a_1 \text{ or } x\geqslant a_2\end{cases} \quad (2)$$

In this study, the values of a_1, a_2, a_3, a_4 in the pH evaluation model are based on Shanghai green soil quality standards (4.5, 8.5, 6.5, 7.8)[15].

The calculation expression of composite indicator value of soil nutrient is as follows:

$$IFI=\sum W_i\times I_i \quad (3)$$

where IFI is the composite indicator value of soil nutrient, between 0 and 1 (the higher the value, the better the quality of soil nutrient); W_i, I_i are the weight value and membership value of evaluation indicators.

1.3.2 Soil environmental quality assessment. According to the national soil environmental quality standards[16], we select the heavy metal As, Cd, Cr, Cu, Ni, Pb, Zn, Hg, and petroleum as the evaluation indicators. The selection of heavy metal evaluation criteria is based on the natural background values of soil environmental quality standard (GB5618 – 1995); petroleum evaluation is based on the reference value of total petroleum hydrocarbon in soil in Environmental Pollutant Standard in the Netherlands. The single factor pollution index Pi and Nemerow pollution index PN are used for assessment.

Single factor evaluation formula is as follows:

$$P_i=\begin{cases}C_i/C_1 & 0<C_i\leqslant C_1\\ 1+(C_i-C_1)/(C_2-C_1) & C_1<C_i\leqslant C_2\\ 2+(C_i-C_2)/(C_3-C_2) & C_2<C_i\leqslant C_3\end{cases} \quad (4)$$

where P_i is the single factor index of pollutant i; C_i is the measured value of pollutant i; C_1, C_2, C_3 are the first, second and third level standard values in the national soil environmental quality standards, respectively.

The integrated soil environmental quality is assessed using Nemerow pollution index, and the formula is as follows:

$$P_N=\sqrt{\frac{(pi_{ave})^2+(pi_{max})^2}{2}} \quad (5)$$

where P_N is Nemerow pollution index; Pi_{ave} is the average value of single factor pollution index; Pi_{max} is the maximum value of single factor pollution index.

1.3.3 Comprehensive evaluation method of soil quality. Given the lack of comprehensive evaluation methods and related standards of soil quality at home and abroad, this paper uses the formula designed by Zhang Wangshou et al[7] in 2010 for assessment. The formula takes the positive contribution of soil nutrient to integrated soil quality and the negative effects of soil heavy metal on integrated soil quality as the fundamental basis. Based on the minimum nutrient law, the SQI index is used to assess integrated soil quality, and five assessment levels are divided, as shown in Table 3.

$$SQI=\begin{cases}0 & PI_{ave}>1\\ \sqrt{(SFI_{min}{}^2+SFI_{ave}{}^2)/(PI_{max}{}^2+PI_{ave}{}^2)} & 0.4<PI_{ave}\leqslant 1\\ 1.5\sqrt{SFI_{min}{}^2+SFI_{ave}{}^2} & PI_{ave}\leqslant 0.4\end{cases} \quad (6)$$

where SQI is comprehensive soil quality index; PI is the single factor pollution index of soil heavy metal; SFI is the single factor index of soil nutrient, SFI = Measured value of soil nutrient/Nutrient indicators.

Table 3 Assessment grading criteria of soil quality index (SQI)

Level	SQI	The level of integrated soil quality
I	SQI≥0.8	Extremely high
II	0.6≤SQI≤0.8	High
III	0.5≤SQI≤0.6	Medium
IV	0.4≤SQI≤0.5	Low
V	SQI≤0.4	Extremely low

2 Results

2.1 Assessment of soil nutrient quality During evaluation of soil nutrients, in order to avoid the influence of human factors on the outcome, the weight coefficients of various evaluation factors are determined according to the correlation coefficient method, and the correlation coefficient between various evaluation factors is analyzed using SPSS19.0. Through further calculating the proportion of mean of the correlation coefficient between evaluation indicators to the sum of mean of the correlation coefficient between all evaluation indicators, we can derive the weight of each evaluation indicator, as shown in Table 4. In terms of the size of weight coefficients, the descending order is as follows: TC > pH > TN > TP > organic matter. The determining of the weight coefficients shows that TC, pH and TN have great impact in the assessment of soil nutrient quality in the study area.

Table 4 The average correlation coefficients and weight coefficients of the evaluation indicators

Evaluation indicators	Average correlation coefficient (rave)	Weight coefficient (rave/∑rave)
pH	0.655 6	0.235 5
TN	0.614 8	0.220 8
TP	0.504 6	0.181 3
TC	0.664 2	0.238 5
Organic matter	0.344 8	0.123 9

Based on the above data and the evaluation method described in **1.3.1**, we derive the evaluation value of soil nutrient in the study area, as shown in Table 5.

Table 5 shows that the evaluation value of Pudong tidal flat is the highest, reaching 0.583 6, followed by tidal flat on the periphery of Hengsha Island with the value of 0.577 9; the evaluation value of tidal flat in the north of Hangzhou Bay is the lowest, reaching 0.385 5. In terms of the variation range, there is great fluctuation in the evaluation value of nutrient quality of Jiuduansha, and small fluctuation in the evaluation value of Baoshan tidal flat. Through the study of coefficient of variation, we find that there are great differences in the nutrient quality of Jiuduansha, while the nutrient quality of Baoshan tidal flat is even.

Table 5 Evaluation index of soil nutrient quality of tidal marshes in Shanghai City

Assessment areas	The variation range of soil nutrient index IFI//%	Mean	Standard deviation	Coefficient of variation
Tidal flat in the north of Hangzhou Bay	22.46 – 45.80	0.385 5	0.095 3	0.247 2
Nanhui tidal flat	28.94 – 55.45	0.444 7	0.138 8	0.311 0
Pudong tidal flat	53.11 – 68.55	0.583 6	0.066 0	0.113 0
Baoshan tidal flat	48.52 – 57.42	0.514 8	0.038 0	0.073 8
Chongming Dongtan wetland	34.39 – 71.28	0.554 4	0.155 9	0.281 2
Tidal flat on the periphery of Chongming Island	31.09 – 61.24	0.506 6	0.094 4	0.186 3
Tidal flat on the periphery of Changxing Island	43.73 – 71.20	0.534 2	0.129 6	0.242 6
Tidal flat on the periphery of Hengsha Island	48.98 – 70.57	0.577 9	0.113 3	0.196 0
Jiuduansha	16.97 – 65.64	0.421 5	0.156 5	0.371 4

In terms of the nutrient quality, the assessment areas are sequenced in descending order as follows: Pudong tidal flat > tidal flat on the periphery of Hengsha Island > Chongming Dongtan wetland > tidal flat on the periphery of Changxing Island > Baoshan tidal flat > tidal flat on the periphery of Chongming Island > Nanhui tidal flat > Jiuduansha > tidal flat in the north of Hangzhou Bay.

2.2 Soil environmental quality assessment The single factor pollution index of soil heavy metal of tidal flats in Shanghai City and Nemerow index are shown in Table 7. The soil environmental quality in the study area is good, and the mean of single factor pollution index of soil heavy metal in all sampling points is less than 1. However, the single factor pollution index of soil heavy metal Cd is greater than 1, more than the natural background value, indicating that there is the risk of contamination of heavy metal Cd in the study area, so Cd should be classified as the heavy metal to the primarily controlled. The single factor pollution index of soil heavy metal Cu is greater than 1, in Hangzhou Bay tidal flat, Hengsha Island tidal flat, and tidal flat on the periphery of Changxing Island, indicating that there is the contamination of heavy metal Cu in the soil of these regions. The single factor pollution index of soil heavy metal Zn in Baoshan tidal flat is 1.099, indicating that there is slight contamination. The Nemerow pollution index in all sampling points is greater than 0.7, indicating that the soil environmental quality in the study area is not completely at the level of cleanness and safety. The Nemerow index of soil is less than 1 in Nanhui tidal flat, Chongming Dongtan wetland and Jiuduansha wetland, indicating that the soil in the three regions is still clean, but it reaches the level of warning line. The Nemerow index of the soil is greater than 1, in Hangzhou Bay tidal flat, Pudong tidal flat, Baoshan tidal flat, tidal flat on the periphery of Chongming Island, Hengsha Island tidal flat, and tidal flat on the periphery of Changxing Island, indicating that the soil in the study area is lightly polluted.

In addition, it can be seen from the table that the Nemerow pollution index of tidal flat on the periphery of Changxing Island is the highest, reaching 1.493 1, while the Nemerow pollution index of Jiuduansha wetland is the lowest, reaching 0. 781 8. In terms of the size of Nemerow pollution index (PN), the tidal flat is sequenced as follows: tidal flat on the periphery of Changxing Island > tidal flat in the north of Hangzhou Bay > tidal flat on the periphery of Chongming Island > Baoshan tidal flat > Pudong tidal flat > tidal flat on the periphery of Hengsha Island > Nanhui tidal flat > Chongming Dongtan wetland > Jiuduansha wetland.

Table 6 The single factor pollution index of heavy metal and Nemerow index in the study area

Heavy metal pollution index	Tidal flat in the north of Hangzhou Bay	Nanhui tidal flat	Pudong tidal flat	Baoshan tidal flat	Chongming Dongtan	Tidal flat on the periphery of Chongming Island	Tidal flat on the periphery of Changxing Island	Tidal flat on the periphery of Hengsha Island	Jiuduansha
PI(Cd)	1.162 5	1.137 5	1.450 0	1.650 0	1.825 0	1.750 0	1.950 0	1.600 0	1.175 0
PI(Hg)	0.173 3	0.124 7	0.273 3	0.400 7	0.418 0	0.352 0	0.389 3	0.276 7	0.308 7
PI(As)	0.294 7	0.308 0	0.436 7	0.342 7	0.688 0	0.520 0	0.472 7	0.498 0	0.242 0
PI(Cu)	0.404 0	0.599 7	0.776 9	0.931 7	1.027 7	0.851 4	1.016 2	1.005 4	0.463 1
PI(Pb)	0.210 9	0.332 6	0.498 6	0.471 7	0.802 0	0.574 3	0.593 1	0.588 0	0.298 6
PI(Cr)	0.290 9	0.398 8	0.504 1	0.503 1	0.694 2	0.556 7	0.533 4	0.547 7	0.410 7
PI(Zn)	0.351 0	0.524 4	0.704 1	1.099 0	0.931 3	0.760 0	0.778 3	0.757 1	0.462 6
PI(Ni)	0.388 0	0.567 5	0.706 5	0.695 0	0.926 0	0.770 0	0.747 5	0.986 8	0.547 0
PI ave	0.409 4	0.499 2	0.668 8	0.761 7	0.914 0	0.766 8	0.810 1	0.782 5	0.488 5
PN	0.870 2	0.876 4	1.129 1	1.285 0	1.443 3	1.351 0	1.493 1	1.259 4	0.781 8

2.3 Comprehensive assessment of soil quality The soil nutrient and environmental quality in the study area are combined for research. Using SQI formula for the comprehensive assessment of soil quality, we derive the SQI values in the study area, as shown in Table 7: tidal flat in the north of Hangzhou Bay, 0.286 4; Nanhui tidal flat, 0.457; Pudong tidal flat, 0.388 1; Baoshan tidal flat, 0.367 4; Chongming Dongtan wetland, 0.511 9; tidal flat on the periphery of Chongming Island, 0.444 7; tidal flat on the periphery of Changxing Island, 0.332 4; tidal flat on the periphery of Hengsha Island, 0.420 8; Jiuduansha wetland, 0.521 6.

In terms of integrated soil quality, the tidal flat is sequenced as follows: Jiuduansha wetland > Chongming Dongtan wetland > Nanhui tidal flat > tidal flat on the periphery of Chongming Island > tidal flat on the periphery of Hengsha Island > Pudong tidal flat > Baoshan tidal flat > tidal flat on the periphery of Changxing Island > tidal flat in the north of Hangzhou Bay.

2.4 Comparison of evaluation results Soil nutrient quality, environmental quality and comprehensive quality evaluation results are shown in Fig. 2. By conducting a comparative analysis of them (Fig. 3), we see that SQI index method combines soil nutrient quality and heavy metal pollution, comprehensively reflecting the status quo of soil quality. With the increase of PN, SQI overall tends to decrease, and the fluctuations clearly show that there is good synergy between IFI and SQI. Theoretically, SQI will increase with the increase of IFI, but from the figure, we find that this relationship is not very clear, because SQI is the combining effect of IFI and PN. In the study, the role of PN is relatively more significant.

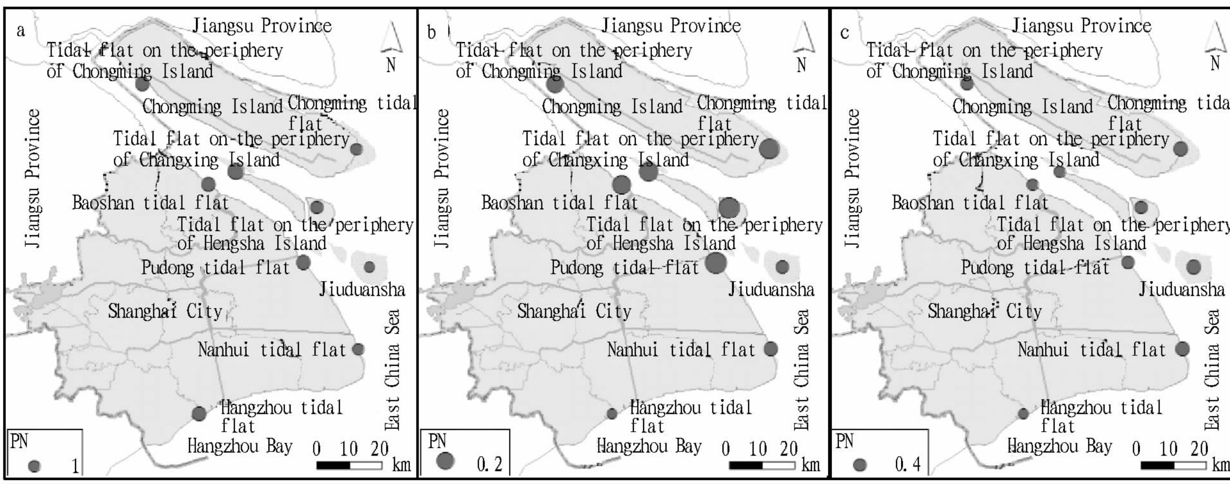

Fig. 2 The soil quality evaluation results in the study area: (a) PN; (b) IFI; (c) SQI

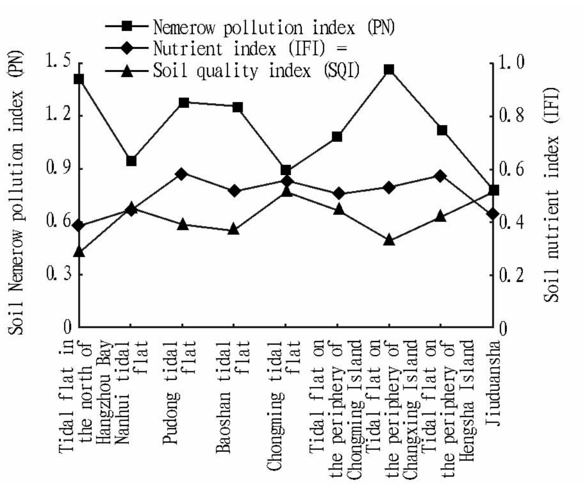

Fig. 3 Comparative analysis of the three soil evaluation results of tidal flats in Shanghai City

3 Discussions

The comprehensive evaluation of surface soil quality of tidal marshes in Shanghai City is based on the assessment grading standard of soil quality index developed in this paper. The results show that the soil quality of tidal flats in Shanghai City is at moderately low level. The mean of soil quality index is 0.414 5, the variation range is 0.286 4 – 0.521 6, and the coefficient of variation is 19.03%, indicating that the soil quality of tidal flats in Shanghai City is affected by various factors. These factors include tidal flat economic activities, tidal flat enclosure, biological invasion, tidal flat pollution, etc. Human dependence on tidal flats to carry out economic activities not only causes pollution, but also destroys the tidal flat biological habitat, making the habitat of tidal flats change greatly. Enclosure is currently one of the greatest factors influencing the tidal marsh resources in Shanghai City. Enclosure will directly lead to substantial decline in the areas of tidal flats, and natural vegetation destruction. The artificial wetland created after enclosing tideland for cultivation can not entirely replace the natural wetland's waterfowl habitat functions; it breaks the natural succession law of the original wetland, and changes the maintenance mechanism of biodiversity. The invasion and expansion of Spartina is currently the most serious and most urgent stress factor influencing tidal marshes in Shanghai City, reducing the original high quality biological habitat. At the same time, Spartina strengthens the tidal marshes' material flow based on detritus system in Shanghai City, and may change the tidal marshes' substance output to the ocean and the atmosphere[17].

The tidal marsh in Shanghai City with the highest soil quality index is Jiuduansha wetland (0.521 6), because Jiuduansha wetland is submerged when there is astronomical tide, still rarely populated by the permanent residents except for a small number of fishermen engaged in low-intensity fishing. Consequently, it is rarely disturbed by human activities, with inconspicuous pollution, and its Nemerow pollution index is the lowest. The soil quality index of tidal marshes in the rim of islands is higher than the soil quality index of tidal marshes in mainland (except tidal flat on the periphery of Changxing Island), which is related to the developed industry, frequent fishing and marine cargo activities around tidal marshes in mainland. The discharge of industrial wastewater containing heavy metals such as mercury, as well as the vehicle exhaust containing cadmium and lead, will cause some pollution to soil. There are ports in tidal flat in the north of Hangzhou Bay, Baoshan tidal flat and Pudong tidal flat, so a large number of vessels cause severe oil pollution. The CSSC Jiangnan Heavy Industry Co., Ltd. is located in tidal flat on the periphery of Changxing Island, which brings great pressure on the environmental capacity of tidal flat on the periphery of Changxing Island. At the same time, through on-site sampling, we find that in tidal flat on the periphery of Changxing Island, Hengsha Island tidal flat and the southern tidal flat of Chongming Island, some cattle farmers raise the cattle in the tidal flats, so that a large number of cattle, cattle feeding and trampling have a certain impact on the soil of tidal flats. Studies show that grazing activities affect the migration and transformation of soil moisture content and soluble salt of tidal flats, so that part of soluble salts in the soil of tidal flats are accumulated in the surface soil of tidal flats, increasing pH value and soil salinization of tidal flats. And grazing decreases the organic matter, NH4 + − N, and total phosphorus in the soil of tidal flats[18], which is consistent with the conclusions of this study, therefore, the soil quality of tidal flat on the periphery of Changxing Island is not good.

In addition, reclaiming fields from the sea plays an important role in development of Shanghai City. Since 1950, the Shanghai municipal government has organized a lot of manpower and resources to enclose the tidal flats at the mouth of the Yangtze River. The tidal flats enclosed are mainly distributed Chongming Island, tidal flat on the periphery of Changxing Island, north of Hengsha Island, south bank of the Yangtze River estuary, Pudong tidal flat, and the northern Hangzhou Bay. After excessive reclamation, the width of tidal flats narrows, and the natural vegetation is destroyed, resulting in soil degradation of tidal flats[19].

4 Conclusions

(i) Using the method of SQI to assess the soil quality of tidal marshes in Shanghai City can better reflect the actual situation of soil quality. The index also takes into account the effects of value of evaluation indicator, weight of evaluation indicator, interaction between evaluation indicators, and the minimum factor limiting rate on the soil quality, in line with reality.

(ii) This study selects organic matter, total nitrogen, total phosphorus, total carbon and pH as the soil nutrient indicators; selects 8 heavy metals and petroleum as the soil environmental quality indicators, able to well reflect the information of integrated soil quality.

(iii) The soil quality grading standard of tidal marshes in Shanghai City is drew up, to divide the soil quality in the study area into five levels (extremely low, V; low, IV; medium, III; high, II; extremely high). The soil quality of tidal marshes in Shanghai City is at the medium-low level. Jiuduansha wetland and Chongming Dongtan wetland have the best soil quality (III), followed by Nanhui, the periphery of Chongming Island, and tidal flat on the periphery of Hengsha Island (IV); the soil quality is poor in tidal flat on the periphery of Changxing Island, Pudong tidal flat, Baoshan tidal flat, and tidal flat in the north of Hangzhou Bay (V). Therefore, we should pay attention to this and take appropriate management measures.

(iv) It is worth mentioning that the soil nutrient indicators selected in this study do not take into account available phosphorus, available potassium and other basic physical and chemical properties, so there are limitations in the evaluation results of soil nutrient quality. Meanwhile, the integration of data on part of sampling points in data analysis can fully reflect the situation of soil quality, but it lacks representativeness, so there is a need of further research work.

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est stand of perennial *Pinus elliottii* are 27 402.62 yuan, 5 480.52 yuan, 16 089.13 yuan and 3 217.83 yuan, respectively; the net income, average annual net income, net present value and average annual net present value of forest not tapped are −889.34 yuan, −177.87 yuan, −3 165.91 yuan and −633.18 yuan. NPV focuses on the total benefits of project's all investment, while IRR is actually the efficiency of investment achieved by the project, emphasizing recovering the funds in the shortest time. Under normal circumstances, the acceptance and judgment of both to the project are consistent[6], so are the test results. NPV and IRR of forest stand tapped show acceptance, while NPV and IRR of forest stand not tapped show rejection. NPV and IRR can evaluate the economic benefit of forest investment project from different aspects.

Therefore, under the same site conditions and same operating level, the early tapping of man-made *Pinus elliottii* forest not only timely recovers investment and shorten the production cycle, but also has high profitability (IRR of 39.2%, far higher than the social discount rate of 12% issued by National Planning Commission and the Ministry of Construction in 1994[7]), which is of important guiding significance to production units and individuals' selection of investment projects.

Table 6 The cash flow and economic evaluation of the experimental forest in different processing ways yuan/hm^2

Processing		1st year	2nd year	3rd year	4th year	5th year	NPV	IRR
Tapped	Flowing out	7 697.00	2 807	1 050	1 050	31 713.08	16 089.13	39.2%
	Flowing into					84 323.70		
Not tapped	Flowing out	7 697.00	2 807	1 050	1 050	10 868.74	−3 165.91	−2.2%
	Flowing into					35 187.36		

4 Conclusions

First, the forest growth cycle is long and the benefit recovery is slow, which is a major feature of forestry production. How to shorten the production cycle, improve capital efficiency and maximize profits is the issue that forestry production companies and individuals are most concerned about. The economic benefit analysis of tapping stand of perennial man-made *Pinus elliottii* forest shows that without increasing forest planting investment and extending the growth cycle of trees, the early tapping of *Pinus elliottii* forest stand at the same operating level can obtain high economic benefit, and speed up the recovery speed of funds, which is of certain guiding significance to changing the the traditional production and management mode of forestry, and at the same time, providing a reference for China's rapid construction of turpentine material forest.

Second, for a long time, the traditional tapping of pine species is generally conducted after ten years since the tree is planted[2], the operating cycle is long, so most of the production units and forest growers choose fast-growing eucalyptus with short growing cycle. From the analysis results in this article, the investment costs of perennial man-made *Pinus elliottii* forest tapped are low, with significant economic benefits; even after tapping, it can keep sustainable management, with long profitability cycle. At the same time, early tapping can promote demand for labor, and improve rural and farmers' income.

Third, the early tapping of *Pinus elliottii* has an impact on the tree growth, so that trunk diameter, tree height, forest stand stocking volume and other indicators decline. although the healing ability of *Pinus elliottii* is strong after the tapping[2], further researches are yet to be carried out on how to keep the economic benefit and sustainable use of forest resources, establish the best production business model, to truly achieve rational sustainable tapping.

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