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Transport Characteristics of Soil Salinity in Saline – alkali Land under Water Storage and Drainage Conditions

Juan LI[1,2,3], **Jichang HAN**[1,3 *]

1. Shaanxi Land Engineering Construction Group, Xi'an 710075, China; 2. College of Forestry, Northwest A&F University, Yangling 712100, China; 3. Key Laboratory of Degraded and Unused Land Consolidation Engineering, the Ministry of Land and Resources of China, Xi'an 710075, China

Abstract To test the variation and transport of soil salinity in saline – alkali land under water storage and drainage treatments, an experimental model was established in Fuping, Shaanxi Province, 2009. The variation of soil salinity during 0 – 160 cm soil depth under the two treatments was determined and analyzed. Results showed that the average soil water content under water storage treatment was 4.47% higher than that under drainage treatment, which means that the water storage treatment could help to improve soil moisture to satisfy the crop's growth needs. The profile distribution of soil soluble solids (TDS), anion (Cl^-, HCO_3^-, SO_4^{2-}) and cation (Ca^{2+}, Na^+, K^+) content and the variation of soil pH were also measured and analyzed. PCA (Principal Component Analysis) was used to explore the relationship between the soil salinity and its ions, which showed that the water storage treatment could significantly decrease the surface salinity of soil and accelerate the desalination of topsoils, and finally, the soil quality was improved significantly, demonstrating that the water storage treatment has a remarkable effect on soil salinity management.

Key words Saline – alkali land, Storage, Drainage, Soil salinity, Salt ions

1 Introduction

With the increasingly acute conflicts between world's population growth and land demand, how to reasonably use limited land resources and increase land resources has become a top issue of concern around the world[1 – 3]. Currently, the saline – alkali land has great potential for development and utilization, and how to control soil salinization is one of the serious problems facing agriculture today[4 – 9]. In agricultural production, the saline soil is low-yielding soil, and it is a obstacle to building high-yielding fields. There is the threat of secondary soil salinization in the modern irrigation project[10]. The comprehensive control methods for saline-alkali land at home and abroad include physical, irrigational, chemical and biological improvement and other technologies and methods. In China, irrigational improvement is often used (namely using fresh water to restrain salt content and draining for desalinization of soil, and the drainage-based approach has reduced the salinity. Traditional saline-alkali land control has high operating costs, and leads to a waste of water, which to a certain extent can pollute downstream water bodies[11 – 16]. Lubotan, at the junction of Fuping County and Pucheng County in Shaanxi Province, is the low-lying land and the severe saline-alkali land formed naturally and artificially. Han Jichang *et al.*[17] report that the traditional saline-alkali land control is based on storage and it is necessary to establish the irrigation and drainage system, and propose a new model of "shifting drainage to storage, water-land coexistence, harmonious ecology" for the saline-alkali land control based on Comprehensive Control Project for Lubotan in Shaanxi Province. Under conditions of water storage and water drainage, we set the simulation experiment in the experimental base of Fuping County to analyze changes in soil salinity under different treatments and changes in salinity and anion and cation in different depth of soil, conduct comprehensive study of various treatments and perform the correlation analysis between salt ions, in order to provide a scientific basis for the rational development and utilization of saline-alkali land and harmonious ecological control.

2 Materials and methods

2.1 Overview of experimental station The experimental base is in Chuyuan Village, Ducun Town, Fuping County, Weinan City, Shaanxi Province. The area features a warm temperate semi-humid climate, with the average annual rainfall of 472.97 mm. The rainfall in June-September accounts for 49% of the annual rainfall. The annual evaporation is 1000 – 1300 mm, the frost-free period is 225 d, and the annual average temperature is 13.4 ℃. The summer maximum temperature is 41.8 ℃, and the winter minimum temperature is –22 ℃. The total annual energy radiation is 123.9 – 127.8 kca/cm^2.

2.2 Experimental design The experiment was implemented in October 2009. In order to simulate the land situation of Lubotan experimental area, we make the experimental device by ourselves. It has the size of 23.0 m × 1.5 m × 2.0 m, and is made by brick concrete. The experimental device includes two parts, namely water storage part and experimental soil bin. One end is the tank filled with water, and the middle section is soil bin. The geotextile is placed between water and soil to prevent soil into the water. In order to ensure the experimental results, various interfaces are installed to do waterproofing. The experimental treatments include water storage treatment and water drainage treatment. Water stor-

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* Corresponding author. E-mail: kele502514@163.com

age treatment is to put some water into the ditch and use the dispersion effect between water and soil to control soil salinity transport; water drainage treatment is to use flood irrigation and take advantage of the convection effect between water and soil to drain for desalinization of soil. The same amount of water is used for water storage and water drainage treatments, and the transport and changes of salinity under different treatments are shown in Fig. 1. The soil sample is the saline-alkali soil in Lubotan, and soil is taken at 30 – 40 cm intervals. After crushing, grinding, air drying and sieving (5 mm), the soil samples are put into the experimental soil bin. According to the test data on soil in the experimental area from Test Center of Northwest A&F University in 2009, the average content of soil organic matter, total salt, pH value, Cl^-, HCO_3^- and SO_4^{2-} is 0.70%, 9.33, 0.37%, 0.08% and 0.06%, respectively.

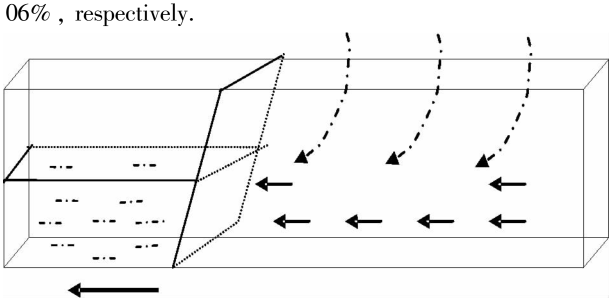

Fig. 1 The soil salinity transport under water storage and water drainage treatments

2.3 Determination items and methods After the cotton harvest in September 2013, in the above two treatments, 6 sampling points were selected from each experimental plot, and the soil auger was used to collect 0 – 160 cm soil with sampling interval of 20 cm. By laboratory experiment, the various indicators of 0 – 160 cm soil were analyzed. Determination indicators and methods are shown in Table 1.

Table 1 Determination indicators and methods

Determination items	Methods
Water content	Drying method
Total salt content	Evaporation method
pH value	pH meter
Calcium ion	EDTA complexometric titration method
Chloride ion	AgN03 titration method
Sulfate ion	Alizarin red method
Bicarbonate ion	Double-tracer neutralization method
Sodium ion, potassium ion	Flame photometer

2.4 Calculation and statistical analysis Excel 2007 and DPS 7.05 software are used for statistical analysis, and Duncan's new multiple range method is used for multiple comparisons.

3 Results and analysis

3.1 Comparison of 0 – 160 cm soil moisture between water storage and drainage treatments In June 2013, we conducted irrigation for water storage and drainage treatments with consistent irrigation rate. In October 2013, the 0 – 160 cm soil moisture was measured during the cotton harvest. The soil water storage capacity under water storage and drainage treatments in the autumn idle period is shown in Fig. 2(a). The 0 – 160 cm soil moisture shows the same trend under water storage and water drainage treatments; in the 0 – 60 cm soil layer, soil moisture decreases while in the 60 – 160 cm soil layer, soil moisture increases. The 0 – 160 cm soil soil moisture on the average under water storage treatment is 4.47% higher that under water drainage treatment, and there are no significant differences between treatments. The experimental results show that after a long period of water transport, evaporation and use, the soil moisture under water storage treatment is slightly higher than that under water drainage treatment, and the field soil compaction does not easily occur.

3.2 Analysis of mass fraction of TDS Under water storage and drainage treatments, the profile distribution of TDS (Total Dissolved Solids) in 0 – 160 cm cotton field soil is shown in Fig. 2(b). The mass fraction of TDS in soil under water storage treatment is significantly higher than that under water drainage treatment, there are no significant changes with the increase of soil depth, and there are no significant differences between treatments. The average mass fraction of TDS in 0 – 160 cm soil under water storage and drainage treatments is 0.906 and 0.487 g/kg, respectively. In the 0 – 40, 40 – 100, 100 – 160 cm soil, the mass fraction of TDS in soil is smallest in the upper layer, and shows an increasing trend; in the 100 – 160 cm soil, the mass fraction of TDS in soil is largest, 14.98% and 15.59% higher than that in the 0 – 40 cm soil, respectively. This is related to the soil water transport under the two treatments. Under water storage treatment, the water usually enters into soil from the middle part of soil, and moves with soil salinity up and down. Under water drainage treatment, the water enters into soil from surface, and the saline-alkali soil surface is prone to compaction, so soil salinity mainly moves down with the water. The experimental data show that different water storage and drainage treatments can effectively reduce soil salinity possibly at soil depth of less than 60 cm.

3.3 Analysis of main salt ions in soil

3.3.1 Anions. Under different treatments, the profile distribution of average mass fraction of main anions in 0 – 160 cm cotton field soil is shown in Fig. 2(c). In 0 – 160 cm soil, the average mass fraction of HCO_3^- in soil under water storage and water drainage treatments is 0.019 and 0.018 g/kg, respectively; the average is highest in the lower layer and lowest in the upper layer. There are no significant differences between treatments ($P < 0.05$). The mass fraction of SO_4^{2-} and Cl^- shows a similar trend, and the mass fraction under water storage treatment is significantly less than that under water drainage treatment. In 60 – 100 cm soil layer, the average mass fraction of Cl^- in soil under water storage treatment is smallest, and the average mass fraction of SO_4^{2-} in soil under water storage treatment is 55.87% lower than that under water drainage treatment. The experimental data show that the desalination effect is obvious in the middle soil under water storage treatment.

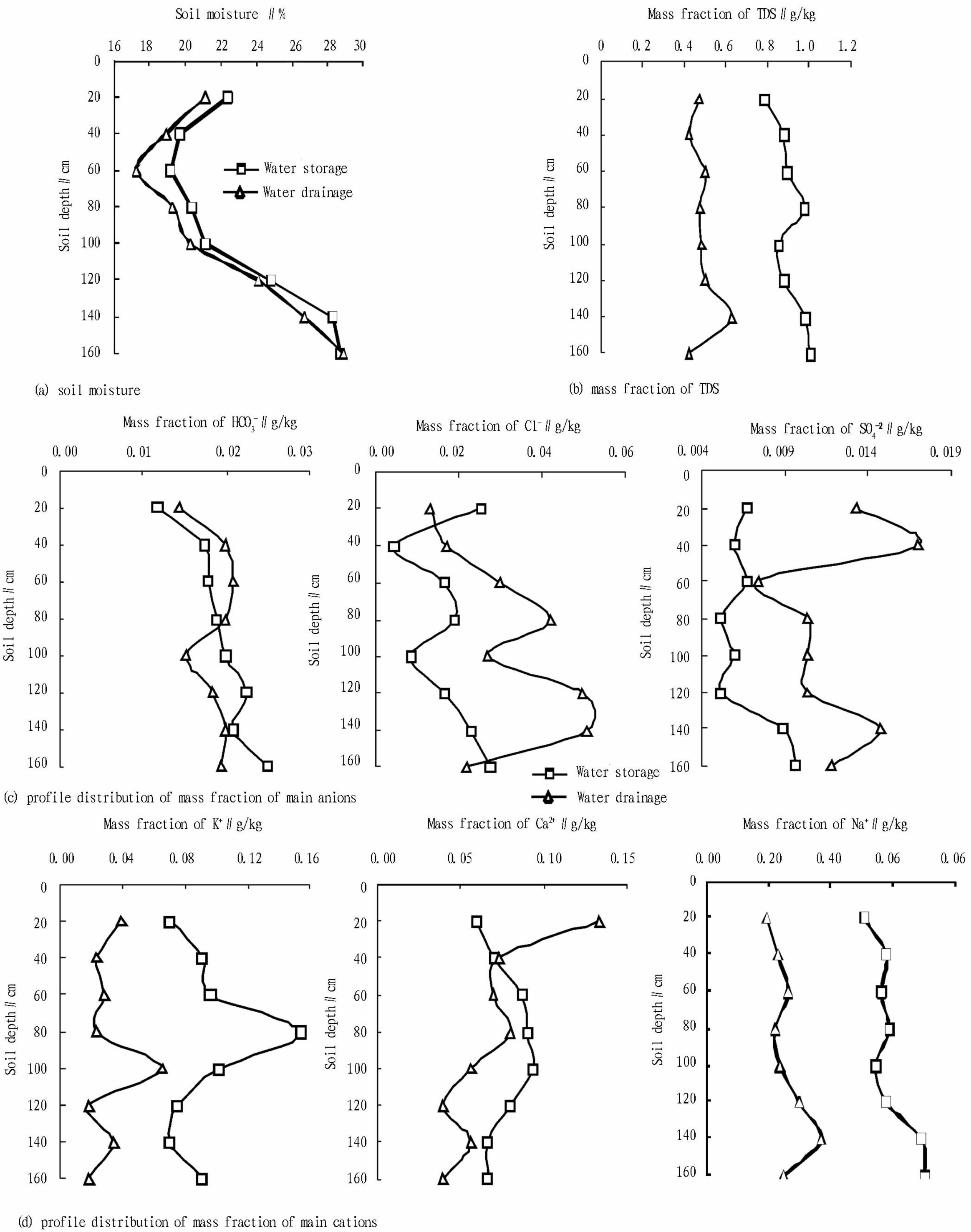

Fig. 2 The 0 – 160 cm soil under water storage and water drainage treatments

3.3.2 Cations. Under different treatments, the profile distribution of average mass fraction of main cations in 0 – 160 cm cotton field soil is shown in Fig. 2(d). Under water storage and water drainage treatments, the average mass fraction of Ca^{2+}, K^+ and Na^+ in 0 – 160 cm soil shows the same trend, and the average mass fraction under water storage treatment is higher than that under water drainage treatment. There are no significant differences between treatments or various soil layers ($P<0.05$). The lowest average mass fraction of K^+ is in 120 – 160 cm soil, and it is lower under water drainage treatment. Under water storage and water drainage treatments, the average mass fraction of Ca^{2+} in soil is 0.077 and 0.069 g/kg, respectively. In 0 – 160 cm soil, the average mass fraction distribution of Na^+ in soil under water storage and water drainage treatments is similar to that of HCO_3^-, and it is highest in the lower layer and lowest in the upper layer. Potassium is the major crop nutrient, and the mass fraction of K^+ in soil is high under water storage treatment, which can effectively improve the crop nutrient.

3.4 Analysis of soil pH Under water storage and drainage treatments, the changes in pH of various layers of soil are shown in Table 2. The soil pH under water storage treatment is less than that under water drainage treatment. In the 0 – 40 cm soil layer, the average soil pH under water storage treatment is 12.41% less than that under water drainage treatment. It can be seen from Table 4 that under different treatments, the soil pH is high in the middle and lower layer but low in the upper layer, but it has no effect on the growth of alkali-resistant cotton, and there are no significant differences between treatments, indicating that the two treatments have a little effect on soil pH. Compared with traditional water drainage treatment, the water storage treatment can effectively reduce the pH value of the soil layer.

Table 2 Soil pH value comparison under water storage and drainage treatments

Soil depth	Water storage treatment			Water drainage treatment		
cm	Mean	Minimum	Maximum	Mean	Minimum	Maximum
20	8.92	8.59	9.48	9.69	9.42	10.11
40	8.99	8.67	9.62	9.82	9.57	9.95
60	8.96	8.67	9.36	9.86	9.48	10.09
80	8.91	8.65	9.29	9.99	9.66	10.12
100	9.02	8.68	9.21	9.81	9.49	10.07
120	9.03	8.71	9.49	9.83	9.62	10.15
140	8.52	8.58	8.81	10.09	9.52	10.18
160	8.77	8.72	8.85	9.94	9.82	10.15

3.5 Soil salinity and major ions To further analyze the reason for differences in soil salinity distribution and test the changes in soil salinity under water storage and drainage treatments, we perform the statistical analysis of soil salinity and its composition. The main statistical characteristics of salinity and its composition under different treatments are shown in Table 3. It can be found that soil salinity is mainly based on bicarbonate and sulphate. The multiple linear regression analysis of salt ions and total salt shows that the correlation coefficient (R^2) between total salt and only two ions (HCO_3^- and Na^+) is high, reaching 0.9661.

Table 3 Descriptive statistics of soil salinity and main ions Unit: g/kg

	Water storage treatment		Water drainage treatment	
	Mean	Standard deviation	Mean	Standard deviation
Total salt	5.519	1.212	8.507	3.110
Cl^-	0.007	0.001	0.012	0.001
HCO_3^-	0.019	0.001	0.018	0.003
SO_4^{2-}	0.018	0.005	0.032	0.014
Ca^{2+}	0.077	0.005	0.069	0.014
K^+	0.094	0.054	0.031	0.023
Na^+	0.595	0.128	0.259	0.129

As can be seen from Table 4, the correlation coefficient between cations and anions is relatively large. Therefore, we use principal component analysis to extract common factors. Table 5 is the component matrix of the first three main common factors.

Table 4 Correlation matrix between main ions

	Cl^-	HCO_3^-	SO_4^{2-}	Ca^{2+}	K^+	Na^+
Cl^-	1.000	−0.174	0.690	−0.410	−0.716	−0.807
HCO_3^-	−0.174	1.000	−0.142	0.587	0.343	0.447
SO_4^{2-}	0.690	−0.142	1.000	0.141	−0.040	−0.286
Ca^{2+}	−0.410	0.587	0.141	1.000	0.707	0.724
K^+	−0.716	0.343	−0.040	0.707	1.000	0.892
Na^+	−0.807	0.447	−0.286	0.724	0.892	1.000

Table 5 Component matrix

	Na^+	Cl^-	K^+	Ca^{2+}	SO_4^{2-}	HCO_3^-
Common factor 1	0.9637	−0.8362	0.8948	0.7870	−0.3453	0.5614
Common factor 2	−0.0025	0.5154	0.1632	0.5126	0.8742	0.3310
Common factor 3	−0.1299	0.1610	−0.3331	0.0317	−0.3334	0.7441

Table 5 shows that common factor 1 mainly depends on the contribution of Na^+, K^+ and Ca^{2+}, and is largely affected by Cl^-, while common factor 2 mainly depends on the contribution of Cl^-, Ca^{2+} and SO_4^{2-}, indicating that the local salinity is mainly based on bicarbonate and sulphate, but the main ions affecting difference in the salinity distribution are Na^+ and Cl^-. By comparing the three main common factors under water storage and drainage treatments, it is found that for the 60 – 100 cm soil, salt may gather and there may be salinity enrichment and secondary salinization.

4 Conclusions and discussions

Traditional draining for desalinization of soil is to pour fresh water to dissolve various states of salt in soil, and emphasizes the role of washing and convection[18], while water storage for desalinization of soil is to give play to the diffusion effect. To test the change in saline-alkali land soil salinity and salinity transport under water storage and drainage treatments, we established the experimental model in Fuping County of Shaanxi Province in 2009, to analyze the salinity change in 0 – 160 cm soil under two treatments. The experimental results show that the soil moisture under water storage treatment is significantly higher than under water drainage treatment, and soil is not likely to be compacted, which is conducive to crop growth. It is consistent with the findings of Han Jichang[19]. The salinity decrease under water storage treatment is mainly due to the diffusion effect; the salinity decrease under water drainage treatment is mainly due to the convection effect. The salinity, pH and ion concentration of soil decreases when compared with the initial stage of experiment, indicating that water storage treatment has better desalination effect than water drainage treatment. The main salt ions affecting the soil salinity distribution under water storage and drainage treatments are Na^+ and Cl^-, and the mass fraction of Na^+ in soil under water storage treatment is high, which is not conducive to the improvement of soil structure and crop growth, similar to the findings of Zai Songmei *et al.*[20]. Water storage treatment is mainly based on water level of impounding reservoir, changing concentration and dynamic balance between water and soil salinity, to achieve accelerated circular leaching of salt on saline-alkali soil, reducing the secondary pollution and hazards to soil and water, so it has good application prospect[9]. The domestic studies on saline-alkali land control mostly focus on the comparison of different control measures and ecological restoration effect of saline-alkali land[21-22]. For the study on soil salinity change under water storage and drainage treatments, the foreign studies on saline-alkali land control mainly focus on the control of water drainage and agricultural non-point source pollution[23-25], and it lacks water storage treatment. Sun Bo *et al.*[26] make the experiment on soil-water salt transport, and conduct an in-depth analysis of salt whereabouts after the salinity reduction under water storage conditions. The study of Han Jichang *et al.*[27-28] shows that after water storage, the soil organic matter content increases, and the soil quality is improved significantly. This experimental study has not yet finished, because it only involves 0 – 160 cm soil, it lacks water salinity monitoring and subsoil indicator research under water storage treatment, and the quantitative analysis of various experimental factors is not deep. Through the study of this experimental model, we'll monitor water and salt dynamic system and conduct a long-term analysis of water and soil distribution, transport and soil quality in order to gradually improve the research results.

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(i) Taking natural feature as primary and social feature as auxiliary. Natural feature and social feature are basic parts of intrinsic features of different marine areas. When dividing marine functional zones, the precondition is based on similar natural features of a specific marine area and difference of different marine areas, while the social feature is auxiliary factor of dividing marine functional zones. If there is no certain natural feature in certain marine area, the marine area is not provided with certain marine functions and thus it is not appropriate to include this area into such functional zones.

(ii) Orientating towards scientific development. It is recommended to control or limit scale of construction use of marine areas, make overall arrangement of industrial use of marine areas, properly optimize distribution of marine primary, secondary and tertiary industries, and save various marine resources in accordance with demands of social and economic development.

(iii) Focusing on protecting fishery. At present, fishery use of marine areas accounts for 60% of marine resource allocation[10]. Fishery resources and ecological environment are foundation of fishery production. Therefore, it is required to ensure no occupation of traditional fishery marine areas, maintain sustainable development of fishery, and ensure increase of fishermen's income and safety and stability of fishery zones.

(iv) Taking environmental protection as precondition. Functional zoning should comprehensively consider protection of marine environment and prevention and control of land based pollution, protect marine ecosystem such as bays, estuaries, island, coastal wetland, and strengthen marine environmental protection and ecological construction.

(v) Making overall arrangement of land and marine areas. Coastline is precious resource of marine areas and must be strictly protected. It is required to make overall arrangement of marine space development and marine area development.

(vi) The national security is the key. Marine rights and interests concern survival of the nation. Thus, it is required to guarantee security of national defense and demand of military use of marine areas and surrounding areas, safeguard marine rights and interests of China.

3 Conclusions

In conclusion, marine functional zoning should establish scientific functional zoning classification system and indicator system, conform to local existing resource development plans, and keep sustainability and continuity of marine resource development. In addition, it is required to take into consideration actual demands and actual technological level of marine development and use, effectively combine present situation and future development trend, and formulate practical and feasible measures for present and future marine resource allocation.

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