**Evaluation of water quality and soil fertility in remediated farmland for protection of wetland ecology by planting different crops**

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## ABSTRACT

Enhancements in water quality and soil characteristics of wetlands can improve the ecological environment of the area and enrich its biodiversity. The present study examined the effects of five distinct crops (i.e.: colza oil, mustard, Chinese cabbage, wheat, barley) cultivated in ~~the~~ remediation plots, and evaluated their impact on water quality and soil fertility. The water quality within the remediated farmland was categorized as Class III (~~. A thorough investigation into the pollution index revealed that the region's water quality was classified as~~ moderately polluted). The soil ~~was~~ exhibited low total nitrogen and organic matter levels (the mean values were respectively 0.032% and 10.84 g/kg), and high readily ~~quick~~ available phosphorus and potassium concentration (the mean values were respectively 83.4 and 313.6 mg/kg). The soil fertility was comprehensively categorized as Class III. Subsequently, the different components of bird droppings in the soil were investigated~~, in which these substances of bird droppings and utilization of fertilizers might change~~ for their potential effects on ~~the~~ soil fertility. The present research demonstrated that the remediation of farmland had the potential to enhance the quality of water and soil fertility in wetland. This, in turn, might result in an increased number of migratory birds inhabiting the area.

**Keywords**: Remediated farmland; Wetland; Water quality; Soil fertility; Migratory birds

> **Comment [C1]:** What does it mean? Moderately fertile? The reader will not understand rating classes.

**INTRODUCTION**

Wetland ecosystems provide ~~an~~ ecological service~~s functions~~, such as purification of water, degradation of pollutants and protection of species that help sustain ecological equilibrium through the <u>resident</u> microorganisms, aquatic organisms, plants, and animals (Gu and Wu, 2023; Rowland, Hagger, and Lovelock, 2023; Zhi et al., 2023). ~~According to statistics, the g~~<u>G</u>lobal<u>ly,</u> wetland area~~s~~ ~~has~~ <u>have</u> shrunk by more than 35% due to degradation and destruction caused by both ~~the~~ climate change and human activities, including industrialization, urbanization and tourism development (Wang et al., 2024; Fedyń et al., 2023; Ferrarini, Celada, and Gustin, 2021). The Yancheng coastal wetland is populated by salt-tolerant plants (*Suaeda salsa*) and provides habitat for migratory birds (*Grus japonensis*) and elk. However, the wetland is also affected by species invasions, agricultural development, and human activities. There is an urgent need to restore the wetland to protect the habitat of rare birds and to promote biodiversity in the area (Wang et al., 2021a; McNeil et al., 2020).

A growing number of researchers are focusing on wetland conservation. They are proposing many methods of wetland remediation. The excessive growth of reeds ~~will~~ <u>in remediated wetlands may</u> reduce ~~the~~ desirable <u>wetland</u> function~~s of~~ ~~remediating wetlands~~. Researchers measured the growth differences of reeds ~~through~~ <u>in response to</u> flooding, mowing, and their combinations. The results showed that moderate flooding combined with treatment could effectively inhibit the excessive growth of reeds. (Park et al., 2024). The habitat of Chongming Dongtan Wetland was

optimized by implementing the semi-closed reclamation project, which ~~was~~ also controlled the invasion of *Spartina alterniflora*, an invasive saltmarsh grass. In addition, a macro-benthic ecological survey revealed that the macro-benthic density and biomass in the ecological enhancement project were significantly lower than those in the natural tidal flat (Huang et al., 2022). The remediation of coastal wetland had been used to create mosaic-type habitats that attracted more birds, improved biodiversity and provided a reference for remediating degraded ~~ecosystems in~~ coastal ecosystems (He et al., 2023). Yancheng Wetland is divided into a core area and a buffer area, the latter being larger and more affected by human activities, particularly agricultural expansion. To improve the migratory bird habitat in the degraded buffer zone of Yancheng Wetland, ecological remediation should be carried out (Ferreira et al., 2023; Barik, Saha, and Mazumda, 2022).

The early human activities that have been observed in this region have resulted in the continuous expansion of wetland buffer zones for cultivable farmland. Farmers have historically adopted pesticides and fertilizers with the aim of increasing farmland productivity. This has resulted in changes to the soil composition and water quality. The inland salt marshes were affected by degradation and soil desertification, ~~that was necessary~~ necessitating ~~to study the impact of~~research on wetland remediation strategies ~~on~~ to improve the soil quality of these marshes. By using remote sensing and wetland investigation methods, the differences in soil properties of different remediation stages of wetlands were investigated. The results showed that the remediation period had a significant impact on the total phosphorus content of the soil

90  (Zhao et al., 2024b). The implementation of the Floodplain Ecological Remediation

91  Project has led to the partial recovery of water quality, sediment and organisms in the

92  area (Roni et al., 2019). Consequently, the efficacy of wetland remediation initiatives

93  in enhancing water quality and augmenting plant diversity in affected regions is

94  indisputable. Moreover, these endeavors contribute to the establishment of a

95  conducive habitat for migratory birds and other fauna, thereby enhancing the local

96  ecological conditions.

97      The remediation of wetland farmland has been demonstrated to result in an

98  improvement in regional soil quality, including soil fertility, soil organic matter, and

99  others (Lu et al., 2024; Wu et al., 2023). In the scientific assessment of soil quality

100  with six different methods for sustainable vegetation eco-remediation in ~~engineering~~

101  engineered disturbed areas, the Zhao team evaluated the soil quality using the soil

102  quality index and found that the vegetation concrete ecological remediation slope (VC)

103  and frame beam fill soil slope (FB) methods had good remediation effects and were

104  conducive to ~~vegetation~~ ecological remediation (Zhao et al., 2024a). In order to

105  restore the functionality of the reservoir inundation regions' soil and ecological

106  environment, the Vietnamese government ~~had~~ conducted studies which monitored

107  topography, slope, inundation time, soil type and water quality. These studies

108  provided a theoretical foundation for subsequent remediation projects (Quang et al.,

109  2022). Consequently, it is imperative to consider the alteration of soil properties

110  during wetland farmland remediation to ensure the provision of nutrient-rich soil in

111  the area.

112   The Yancheng wetland serves as a transitional zone between the warm temperate

113   zone and the northern subtropical zone, which is mainly influenced by a marine and

114   continental climate, characterized by suitable temperature, abundant rainfall, and

115   sufficient light (Duan et al., 2020; Li et al., 2020). Every year, the wetland attracts a

116   large number of migratory birds, including several endangered and rare species such

117   as *Grus japonensis*, *Ciconia boyciana*, *Eurynorhynchus pygmaus*, and *Larus*

118   *saundersi*, which reside and winter in Yancheng (Wang et al, 2020b; Wang et al.,

119   2019). Due to its comprehensive ecological system, robust ecological regulation, and

120   high habitat value (Wang et al., 2020a), Yancheng Wetland ~~is~~ has been recognized ~~as~~

121   ~~a~~on the World Heritage List: Migratory Bird Sanctuaries along the Coast of the

122   Yellow Sea-Bohai Gulf of China (Phase I) beginning in 2019.

123   (https://whc.unesco.org/en/list/1606/). The ecological environment of the peripheral

124   buffer zone of the Yancheng Wetlands has been degraded by urbanization,

125   agricultural expansion and tourism development. In addition, the soil fertility has been

126   depleted, and water quality has deteriorated, affecting the ability of waterfowl to

127   forage and ~~build a~~reducing the area of suitable habitat. Therefore, it is imperative that

128   a restored habitat is implemented to improve soil fertility and water quality, safeguard

129   the ecological environment and promote ~~the~~biodiversity in the area.

130   The authors aim~~s~~ to study soil and water quality characteristics to simultaneously

131   strengthen wetland farm ecosystems and promote the diversity of migratory birds by

132   planting multiple crops on remediated farmland. The present study analyzed various

133   water quality parameters in fields cultivated with different crops during different

134　periods. The investigation further sought to ascertain the impact of migratory bird

135　droppings on the soil parameters ~~present~~ within the wetland farmland environment.

136　The authors conducted a comparative analysis of various physical and chemical soil

137　properties in fields where different crops were cultivated. The objective of the

138　research is to compare soil and water quality parameters under different remediation

139　treatment methods, with the aim of improving the remediation results of wetland

140　farmland in the protected area. The overarching objective of the program is to

141　increase the number and diversity of migratory birds.

142

143　**MATERIALS AND METHEDS**

144　**Study area**

145　　The study site is located in within the southern buffer region of the Yancheng

146　coastal wetland, which includes an area of agricultural reclamation between

147　33°30′N-33°32′N latitude and 120°30′E-120°33′E longitude (Fig. S1).

148　**Experimental design**

149　　Based on previous relevant studies, we adopted a randomized block design and

150　conducted different treatments after rice harvest to explore the effects of different

151　remediated farmland on rare birds and water quality of the soil (Liu et al., 2024). A

152　total of eight experiments were conducted, comprising the following treatments:

153　sowing colza oil, sowing mustard, sowing Chinese cabbage, sowing wheat, and

154　sowing barley after rice harvesting, respectively, artificial straw crushing, used as a

mulch, after rice harvesting, and no-tillage after rice ripening (with water replenishment, without water replenishment). The plot allocation of wetland farmland remediation area was displayed in Fig. 1. A total of eight ~~experiments~~ experimental plots were ~~conducted, and the distribution of crop was~~sampled as illustrated in the Table. 1.

The researchers sampled the soil ~~sampling~~ in the eight treatment plots and randomly selected two surrounding plots as controls ~~randomly~~. They used the 5-point sampling method consisting of three layers (0-20cm, 20-40cm, 40-60cm). In each plot, five random sampling points were established in a plum blossom formation, and samples were taken using a Φ70mm stainless steel soil drill. After sampling, samples from the same layer were combined to form representative soil samples for each area. The researchers collected bird droppings from eight different treated sites and pooled ~~identical sites with the same~~ bird droppings from each site as a single sample.

Water samples were collected from the outfalls and various drainage ditches within the rice field remediation project area. Samples were analyzed and monitored twice in late February (dry season) and late May (normal season). The processing carried out for each plot was as follows: C28: Chinese cabbage; C1: Wheat; C31: Barley; C10: Colza oil; C11: Mustard; C6: No tillage without water replenishment; C25: No tillage with water replenishment; C17: Without harvesting.

**Observations of birds**

During clear days (i.e. excluding periods of heavy rain, fog or strong winds), the presence or singing of species was recorded at both the experimental site (the

9

177 remediated region) and the control site (the plot where wheat was planted after rice

178 harvest) by two experienced observers. The foraging period of the birds in this region

179 was primarily concentrated during the overwintering period, which extended from late

180 November to February of the subsequent year.

181     Table. S1 provides a synopsis of the numerical data and taxonomic classification

182 of avian species observed at various locations and temporal points. The authors

183 conducted data analysis and found that the species and numbers of birds in the

184 farmland remediation area were higher than those in the control area. For detailed data

185 analysis and result comparisons, please refer to Liu's paper (Liu et al. 2024).

186 **Determination of water quality parameters**

187     The total nitrogen (TN) concentration was determined by means of an alkaline

188 potassium persulfate digestion process, followed by ultraviolet spectrophotometry

189 (wavelength 210 nm). The quantification of total phosphorus (TP) was conducted

190 through the utilization of an alkaline potassium persulfate digestion method,

191 complemented by molybdenum-antimony anti-colour spectrophotometry (at a

192 wavelength of 700 nm). Potassium permanganate was determined by acidification and

193 oxidation and then measured by ultraviolet spectrophotometry at 525 nm. The

194 determination of $BOD_5$ was accomplished through the implementation of the

195 iodimetry and dichromate method. The mass of total suspended solids was measured

196 by drying at 105 ℃ (Zhang et al., 2024). The total salt content of the water samples

197 was conducted to ascertain their total salt content, following a process of evaporation.

198 The presence of sulphur compounds present in water was detected by methylene blue

199 spectrophotometry at a wavelength of 660 nm (Sad et al., 2015). The mercury, arsenic,

200 plumbum, and cadmium in water was determined by means of graphite furnace

201 atomic absorption spectrophotometry. The pH values were measured using a pH

202 meter (Li et al., 2024).

203 **Determination of soil fertility parameters**

204     Soil samples and bird droppings were collected and subsequently dried in an

205 indoor environment to eliminate any extraneous contaminants. Subsequently, larger

206 particles were subjected to grinding and sieving. The droppings were meticulously

207 extracted from the soil, debris, and foliage, and subsequently transferred into a

208 ziplock bag for low-temperature storage in order to facilitate the detection of

209 indicators such as organic matter, total nitrogen, total phosphorus, and total

210 potassium.

211     The organic matter content was determined by employing potassium dichromate

212 volumetric method and external heating methods (Anwar et al., 2024). The Kjeldahl

213 method with a continuous flow analyzer (Bran and Luebbe TRAACS Model 2000

214 Analyzer) was employed to determine total nitrogen, while spectrophotometry with

215 potassium persulfate oxidation molybdenum blue colorimetric method was utilized

216 for total phosphorus in both soil and bird droppings using colorimetry (Hou et al.,

217 2021). The alkali diffusion method was utilized to determine the amount of alkali

218 hydrolyzed nitrogen. The sodium bicarbonate method was utilized to measure

219 available phosphorus in real time. The hydrofluoric acid perchloric acid method was

220 utilized to estimate total potassium. The ammonium acetate extraction method was

221 utilized for the expeditious estimation of available potassium (Yang et al., 2022). The

222 alkali hydrolyzed nitrogen, available phosphorus, total potassium, total N and

223 available potassium were determined by elemental analyzer (Elementar, Vario Macro,

224 Germany).

225 **Evaluation method**

226 Comprehensive pollution index of water quality

227 ~~Select t~~The values of four factors, total nitrogen, total phosphorus, potassium

228 permanganate index, and BOD$_5$, ~~and~~ were input~~ted~~ ~~them~~ into the Nemerow pollution

229 index equation to calculate the comprehensive pollution index $p$-value.

$$p = \sqrt{\frac{(p_i^2 + p_{i\ max}^2)}{2}}$$

230 Where: $p_i$ was Average single pollution index, $p_i = \frac{1}{n}\sum\frac{C_i}{S_i}$, $C_i$ was measured

231 value, $S_i$ was standard values; $p_{i_{max}}$ was the maximum single index among all the

232 pollution factors.

233 Soil fertility by bird droppings accumulating

234 ~~The~~ A large amount of bird droppings could accumulate on the soil surface,

235 ~~thereby that~~which might change soil fertility. The improvement in soil fertility could

236 be estimated using the following formula:

$$M = B * N * W * t * \frac{C}{1000 * 1000}$$

237 Where: $M$ was the increased value of a fertility index (kg/hm$^2$); $B$ was the

238 number of birds feeding on the plot each day; $N$ was the average number of

239 defecations per day; $W$ was the dry weight per defecation (g); $t$ was the time spent

240 foraging on the plot (d); $C$ was the content (%) of a fertility index in bird droppings.

1000 was the area of the plot (hm$^2$). The model was ~~referred and~~ modified from the models ~~about estimation of~~used to estimate Tundra Swan droppings (Somura et al. 2015).

Comprehensive fertility and soil fertility grade

The following additive model was used to calculate and evaluate the comprehensive fertility index of the plot, and the soil fertility grade was evaluated according to the value $I$.

$$I = \sum F_i * W_i \; (i = 1,2,3, \ldots \ldots, n)$$

Where $I$ was the comprehensive fertility index of the plot, $F_i$ was the score value of the $i$ index, and $W_i$ was the weight of the $i$ index.

**Statistical analyses**

All data obtained in shake flask culture process were the mean of triplicate experiments. The statistical significances of differences in chemical and physical properties of water quality, soil and bird droppings were evaluated using a one-way analysis of variance (ANOVA) and Duncan's multiple range tests in SPSS version 16.0. A value of $P < 0.05$ was considered statistically significant.

**RESULTS**

**Effects of wetland farmland remediation project on water quality**

A total of eight distinct categories of remediation sites were selected for water quality measurement, with the objective of conducting a comparative analysis across

Comment [d2]: A clearer explanation is needed here. What are the different Fi components that you used? What values di you use for Wi and how did you choose th values for Wi?

different seasons, namely the dry and normal seasons. The pH of the water ~~was~~

ranged from 7.18 to 7.83 in Fig. 2A, which was ~~displayed~~ classified as being weakly

alkaline. Furthermore, a ~~little~~ small increase in pH value was observed during the dry

period when compared to the normal period. The mean concentration of total nitrogen

during the dry period was found to be greater than 1.50 mg/L, with a maximum

recorded 2.65 mg/L. And, the content of total nitrogen during dry season in C11, C6

and C25 was significantly higher than that during normal season (~~, in which the value~~

~~of~~ $p$ ~~was~~ < 0.05). As demonstrated in Fig. 2B, the mean content of total nitrogen

during the normal period was 0.97mg/L. The total phosphorus content during the dry

period exhibited a higher value (0.29 mg/L) in comparison to the normal period (0.14

mg/L). The maximum value recorded was 0.31mg/L, observed at sample point C31,

as illustrated in Fig. 2C.

The permanganate index and the biological oxygen demand ($BOD_5$) ~~were~~ was

utilized ~~as parameters~~ to detect organic and inorganic oxidizable matter pollution in

water. The mean average value of the potassium permanganate index during the dry

and normal periods was 5.54 and 4.98 mg/L, respectively. The maximum value

recorded was 7.1mg/L in C31, in which the concentration of potassium

permanganate during the dry period was significantly higher than that during normal

season ( $p < 0.05$, see Fig. 2D). It was observed that the $BOD_5$ at a concentration of

5.12 mg/L~~)~~ during the normal period was marginally higher than that ~~at a~~ the

concentration of 4.15 mg/L during the dry period. The maximum $BOD_5$

concentration recorded during the dry period was 6.24 mg/L ~~in~~ (Fig. 2E). The

283     content of $BOD_5$ during dry season in C28, C1 and C17 was significantly higher than

284     that during normal season (~~, in which the value of 0~~$p$ ~~was 0~~< 0.05).

285     Suspended solids were also indicative of turbidity levels in the water, with higher

286     concentration recorded during the dry period (22.24 mg/L). The mean concentration

287     of suspended matter during the normal period was found to be significantly lower

288     than that during the dry season except C1 ($p < 0.05$), with an average of 9.31 mg/L

289     as illustrated in Fig. 2F. The mean concentration of total salt during the dry period

290     (660 mg/L) significantly exceeded that of the normal period (393 mg/L) without C17.

291     ($p < 0.05$, Fig. 2G). The sulphide content of the water in the wetland farmland

292     remediation project area was found to be minimal, with concentration consistently

293     below 0.005 mg/L during both dry and normal periods. The remediation project area

294     exhibited minimal concentrations of heavy metals in the water with mercury, arsenic,

295     ~~plumbum~~ lead and cadmium not detected during both dry and normal periods~~, in~~

296     (~~-~~Table. 1 and 2).

297 **Analysis of bird droppings in the wetland farmland remediation project area**

298     ~~In the designated area of the wetland farmland remediation project, the~~

299     ~~experimenters undertook the collection of bird~~ Bird droppings, which were obtained

300     from six species in the farmland plots: *Grus japonensis*, wild duck, wild goose, swan,

301     *Ciconia boyciana* and *Grus grus*. The content of organic matter in the six collected

302     types of bird droppings ~~collected~~ ranged from 11.60% to 40.12%, with an average of

303     23.07%. The concentration of organic matter in wild duck and wild goose was found

304     to be 40.12% and 30.61%, respectively. Furthermore, the contents of total nitrogen,

total phosphorus and total potassium in bird droppings~~, respectively,~~ ranged from 0.025% to 0.703%, 0.032% to 0.852%, and 0.822% to 1.918%, respectively, and the corresponding average values were 0.246%, 0.366% and 1.173% in Fig. 3.

**Effects of wetland farmland remediation project on soil fertility**

pH and organic matter of soil

The pH value of the soil in the various plots of the wetland farmland remediation project is presented in Table. 3. The value of the treatment group was between 7.62-9.19, and that of the control group was between 8.60-8.96. All of the values were apparently alkaline, in accordance with the characteristics of the saline alkaline soil in this area. The range of soil organic matter in the various plots of the remediation project area was found to be between 1.14 and 18.80 g/kg, the mean value~~s~~ was 10.84 g/kg. The concentration of soil organic matter in the control area was found to be between 13.8 and 17.0 g/kg, the mean value~~s~~ was 15.13 g/kg. The Second National Soil Survey, in conjunction with the six-level classification standard of soil nutrients in China, indicated that the organic matter content in this area was at a low level comparing the mean values with the experimental group and control group. This finding was consistent with the characteristics of low organic matter in the coastal saline alkaline soil of Jiangsu.

Total nitrogen and alkali-hydrolyzed nitrogen of soil

The total nitrogen content of the soil in the remediation project area ranged from 0.007-0.132% (the mean value~~s were~~ was 0.032%), while in the control area it ranged from 0.020-0.055% (the mean value~~s were~~ was 0.045%). The total nitrogen content of

327 the soil in this project was found to be at a low level, which was basically consistent

328 with the characteristics of the organic matter content. The range of soil alkali

329 hydrolyzed nitrogen in different areas of the remediation project was between 31.2

330 and 94.3 mg/kg, demonstrating significant variability. In the control area, the range

331 was between 49.6 and 87.6 mg/kg.

332 Total phosphorus and quick available phosphorus of soil

333 The total soil phosphorus ($P_2O_5$) levels in the various plots within the

334 remediation project area ranged from 0.11-0.23% (the mean values were was 0.17%),

335 while the total soil phosphorus ($P_2O_5$) levels in the control area ranged from 0.13-0.20%

336 (the mean values were was 0.14%). The total phosphorus ($P_2O_5$) content of the soil in

337 this area was found to be at high level comparing the mean values with the

338 experimental group and control group. The subject of this study corresponded to the

339 characteristics of high phosphorus and low nitrogen soil in the Yancheng area.

340 The quick readily available of phosphorus in the soil was found to be the most

341 effective component measure of soil available phosphorus storage accessible for crops.

342 It was also determined to be an important index for evaluating the level of phosphorus

343 supply and soil fertility. The readily available soil phosphorus ($P_2O_5$) levels in the

344 various plots of the remediation project area exhibited significant variability, ranging

345 from 16.8 to 163.9 mg/kg (the mean values were was 83.4 mg/kg), while the levels in

346 the control area ranged from 22.4 to 106.8 mg/kg (the mean values were was 65.7

347 mg/kg). In general, the phosphorus levels in the soil in this area were found to be at

348 high ~~level~~ when comparing the mean values ~~with~~ of the experimental group ~~and~~ to the

349 control group.

350 Total potassium and quick available potassium of soil

351 The total potassium ($K_2O$) content of the soil in the various plots of the

352 remediation project area ranged from 0.59% to 1.65% (the mean value~~s~~ ~~were~~ was

353 1.11 %), exhibiting significant variability. In contrast, the total potassium content of

354 the soil in the control area ranged from 0.97% to 1.11% (the mean value~~s~~ ~~were~~ was

355 1.07 %). The total potassium content of the soil in this area ranged from Class IV to

356 Class II, with 44% of the samples classified as Class IV, 54% classified as Class III,

357 and 2 samples classified as Class II in Table. 4. Consequently, the total potassium

358 content of the soils in this area was found to be at an above average comparing the

359 mean values with the experimental group and control group.

360 The content of readily available potassium had been identified as a significant

361 indicator of soil potassium supply and soil fertility. The availability of potassium

362 ($K_2O$) in soil exhibited significant variability across different plots of the remediation

363 project, with value ranging from 92.1 to 474.0 mg/kg (the mean value~~s~~ ~~were~~ was

364 313.6 mg/kg). In the control area, soil available potassium levels ranged from 271.1 to

365 304.6 mg/kg (the mean value~~s~~ ~~were~~ was 285.4 mg/kg). As demonstrated in Table. 4,

366 the potassium content of soil in this area was found to be range from Class Ⅳ to

367 Class I. Specifically, 11% of the samples were classified as Class II, while a

368 ~~significant~~ substantial majority ~~of~~ (84%)  were classified as Class I. Consequently,

18

369  the potassium availability of the soils in this plot was found to be at high level

370  comparing the mean values with the experimental group and control group.

371  **DISCUSSION**

372  **Evaluation of water quality**

373      Water quality monitoring ~~was~~ can be defined as the process of monitoring and

374  measuring the types of pollutants in a water body, the concentration and change trend

375  of various pollutants, and evaluating the state of water quality. As Barcellos and de

376  Souza (2022), Hou et al. (2023) and Yang et al. (2022) had demonstrated, water

377  quality monitoring ~~had~~ has the potential to provide the fundamental data required for

378  effective environmental management and ecological remediation.

379      As stated in the Environmental Quality Standard for Surface Water in China (GB

380  3838-2002), the water quality of the diversion channel in the wetland farmland

381  remediation project in the dry season was classified as Class III. The mean value of

382  total nitrogen concentration (the main pollutant) was 1.81 mg/L~~, with the mean value~~

383  ~~of main pollutant~~. Furthermore, the mean value of total phosphorus concentration was

384  0.285 mg/L. The permanganate index and the $BOD_5$ were both classified as Class III

385  water, in which the mean value of permanganate index and the $BOD_5$ were

386  respectively 5.5 and 4.0 mg/L. The levels of sulphide (< 0.005) and heavy metals (<

387  1.0) were found to be relatively low. Consequently, they were all classified as Class I

388  water, with detection values given in ~~the~~ Table. 1. The water quality during the

389  normal water period was classified as Class III (Thai-Hoang et al., 2022). Additionally,

390  the total phosphorus, total nitrogen and permanganate index levels were all found to

19

be within the parameters of Class III water, the mean values were respectively 0.14,

0.96 and 5.0 mg/L. The levels of sulphide, mercury, ~~plumbum~~ lead and cadmium

were found to be relatively low and were thus classified as Class I water. In

comparison with the low-water period, the arsenic content in the normal-water period

exhibited a slightly increase, yet it remained at the level of Class I water ~~in the~~as

defined in Table. 2 (Zeng et al., 2020).

The single-factor evaluation results of the water quality monitoring indicated that

the main factors affecting the water quality in the wetland farmland remediation

project were total nitrogen, total phosphorus, potassium permanganate index and

$BOD_5$. The results of the monitoring of the other factors met the Chinese national

Class II water quality standards. Therefore, the values of total nitrogen, total

phosphorus, potassium permanganate index and $BOD_5$ factors were selected in the

Nemero Synthesis Index equation, the purpose of which was to calculate the $p$ value

of the comprehensive pollution index (An et al., 2022). Ultimately, based on a

comprehensive evaluation of various parameters, ~~the authors~~we conclude~~d~~ that the

water quality was classified as Class III.

**Evaluation of bird droppings on soil fertility**

The wetland farmland remediation initiative was conceived with the objective of

providing a substantial food supplement for migratory birds (Agger et al., 2024). The

rice field, which had been sown ~~planted~~ with wheat, colza oil, Chinese cabbage and

other food sources after harvest, was a favored foraging area for wintering migratory

birds such as *Grus japonensis* (Kuang et al., 2019). The surrounding ditches also

20

413    provided drinking water for migratory birds and attracted a significant number of

414    migratory birds, primarily geese, ducks, cranes, and herons (Cital et al., 2022).

415         The mean organic matter concentration of bird droppings (23.07%) was found to

416    be significantly higher than that of typical soil, as well as considerably higher than

417    that of the soil organic matter content (1.19%) in the area of the wetland farmland

418    remediation project. The accumulation of bird droppings in areas where birds

419    congregated might have some effect on the organic matter content of the soil (Min

420    and Choi, 2022). Concurrently, the mean concentrations of total nitrogen, total

421    phosphorus and total potassium in the wetland farmland remediation project area were

422    detected to be 0.031%, 0.077% and 0.847%, respectively. The mean concentrations of

423    total nitrogen and total phosphorus contents in the bird droppings were found to be

424    0.246% and 0.336%, which was respectively 7.9 times and 4.8 times higher than those

425    found in the soil of restored farmland. Furthermore, the mean total potassium

426    concentration in the bird droppings (1.173%) was determined to be 1.4 times higher

427    than that of the local soil. The results indicated that the bird droppings might have a

428    certain impact on the nitrogen, phosphorus and potassium content of the soil, thereby

429    changing the fertility of soil. Research had demonstrated that the nitrogen present in

430    bird droppings was capable of volatilizing with ease into the atmosphere, manifesting

431    as $NH_3$ in alkaline soil environments (Osada, 2020). Furthermore, the presence of

432    robust nitrification and denitrification removal pathways in saline alkaline soils had

433    been documented (Zhang et al., 2022). As Wang et al. (2021b) demonstrate that the of

434 phosphorus in bird droppings readily combined with calcium (Ca) in saline alkaline

435 soil to form stable Ca-P compounds.

436 It was estimated that approximately 50,000 birds appeared daily in the wetland

437 farmland remediation project area for approximately 15 days during the winter

438 foraging period (Liu et al., 2022). Subsequent to the termination of the foraging

439 period, an average of approximately 400 birds per day were recorded in the wetland

440 farmland remediation project plot from January to the end of February (a total of 120

441 days).

442 As demonstrated in Table. 5, the wetland farmland remediation project area had

443 shown an estimated increase in organic matter of approximately 6629.4 kg, total

444 nitrogen of approximately 97.1 kg, total phosphorus of approximately 75.3 kg, and

445 total potassium of approximately 294.5 kg based on estimated inputs from bird feces.

446 This increase could be attributed to the fertilization, decomposition of different crops,

447 and bird foraging and defecation in the designated area. The mean estimated increase

448 per km$^2$ was 2.88 kg, 0.042 kg, 0.033 kg, and 0.128 kg, respectively. The estimated

449 increase in organic matter was most significant, followed by total potassium, total

450 nitrogen and total phosphorus (Zhang et al., 2021). Despite the brevity of foraging

451 period following the harvest, the bird density was found to be significantly higher in

452 comparison to the non-foraging period (Brennan, 2020). The wetland farmland

453 remediation project had been shown to provide foraging habitat for birds, the

454 droppings of birds might have acause changes in the properties of the soil (Makenova

455 et al., 2024).

22

**Evaluation of soil fertility**

Comprehensive fertility indexes of soil

~~It was an irrefutable that s~~Soil ~~constituted~~ constitutes the fundamental basis of crop production, with soil fertility representing a comprehensive reflection of all aspects of soil properties. ~~This was~~Fertility is typically understood as the ability of the soil to provide and ~~coordinate~~ beneficial nutrient conditions and environmental conditions for crop production (Ma et al., 2020; Kumar, Sindhu and Kumar, 2025). The level of soil fertility ~~had~~ has a direct impact on the growth of crops, which in turn ~~had~~ has a significant effect on the growth and development of soil animals, plants, microorganisms, and even migratory birds associated with crops. Consequently, it ~~was~~ is imperative to meticulously examine the fundamental physical and chemical properties of soil and soil fertility within the designated area of wetland farmland remediation projects (Gettys and Moore, 2018; Xie, Cui, and Zhang, 2019).

~~In a large amount of scientific research work, the c~~Comprehensive standards ~~might~~ were ~~be~~ consulted in the analysis of sample plots to derive a comprehensive nutrient index. Such ~~as~~ an index could be utilized to ascertain the ~~actual~~ overall fertility of the soil (Sun, Fan and Zhang, 2025). In the present research, the total nitrogen, alkaline hydrolyzed nitrogen, available phosphorus, and available potassium of the soil were selected for assessment and assigned values. The results were presented in Table. 6. The soil fertility in the designated wetland farmland remediation project area was found to be of medium quality, primarily due to a significant deficiency in soil nitrogen content. Subsequent agricultural management

478 and fertilization processes ~~were~~ are recommended to appropriately increase the input

479 of organic and nitrogen fertilizers, whilst concomitantly controlling input of

480 phosphate and potassium fertilizers (Zheng et al., 2022).

481 As posited by Ma et al., (2020), the analysis of ~~extent~~ existing literature

482 suggested that the process of forming a substantial quantity of Ca-P and accumulating

483 it within the soil was facilitated by the absorption of exogenous phosphorus (as a

484 fertilizer) in an alkaline environment proximate to the sea. Furthermore, the presence

485 of significant avian populations within the region suggests the potential for partial

486 phosphorus input via bird excrement (Jauffrais et al., 2015; Zhang et al., 2021; see

487 also Table 5). Because plants absorbed relatively little phosphorus, phosphorus

488 accumulated in the soil of this region due to the absence of any alternative means of

489 removal. However, the predominant source of nitrogen was from biological processes

490 associated with plant life, yet the region's plant population was sparse. Furthermore,

491 the presence of robust nitrification and denitrification removal pathways in the soil

492 has been demonstrated, resulting in the observation of relatively low nitrogen content

493 in the region's soil (Li, Zhang and Shi, 2023).

494 Fertility distribution of soil

495 As demonstrated in Fig. 4, a comparison was made of ~~the~~ soil nutrients ~~content~~

496 ~~of soil~~ in the ~~area designated~~ wetland farmland remediation project area and the

497 control area. All nutrient indices were subjected to transformation in order to facilitate

498 cartographic representation and comparative analysis. pH, organic matter, total

499 nitrogen, alkaline hydrolyzed nitrogen, ~~quick~~ available potassium and total potassium

500  were all found to be less than those in the control area, while the total phosphorus and

501  ~~quick~~ available phosphorus were both found to be little greater than the levels in the

502  control area. Meanwhile, the content of total nitrogen in the farmland remediation

503  project area was significantly higher than that in control area ($p < 0.05$). Given the

504  similarity in soil material, the observed difference might be primarily attributable to

505  the varying absorption capabilities of the plants and the effect of rainwater runoff

506  (Schurkamp, Lishawa and Ohsowski, 2024). Furthermore, the substantial avian

507  congregation observed within the wetland farmland remediation area might prove to

508  be a factor in the process of soil phosphorus changing within this particular

509  ecosystem.

510  The vertical distributions of nutrients within the wetland farmland remediation

511  area had been demonstrated in Fig. 5. There were significant differences in the

512  organic matter, total nitrogen, and ~~quick~~ available phosphorus among different soil

513  layers ($p < 0.05$). As shown in Fig. 5, with the exception of pH, the content of other

514  soil fertility indices was high in the surface layer and low in the bottom layer, thereby

515  indicating that soil fertility was predominantly concentrated in the surface layer

516  (Zamorano et al., 2018). As the soil layer deepened, there was a gradual decrease in

517  soil fertility, which may be primarily attributable to the input of exogenous fertilizer

518  (including fertilizer and bird droppings) (An et al., 2025). The pH exhibited a low

519  value in the surface layer and a high value in the bottom layer, this phenomenon was

520  attributed to the downward leaching of $Cl^-$ and $OH^-$ in saline alkaline soil by rainfall

521  (Pipil, Haritash and Reddy, 2022). Therefore, considering multiple parameters and

522  multiple layers of soil, the soil is classified as Class III.

523  **Prospects and Suggestions**

524  The present study revealed that by planting different crops, the local water

525  quality and soil properties could be improved, which would attract more winter

526  migratory birds to the Yancheng Wetland, providing a guarantee for the ecological

527  protection of the Yancheng Wetland. Based on this research, we would investigate

528  whether the feeding and defecation behaviors of birds really have an enhancing effect

529  on the soil fertility in this area in the future. If so, which parameters would be

530  positively affected? Furthermore, in the wetland farmland remediation project, the

531  water quality was classified as category III. The main pollutants were total nitrogen

532  and $BOD_5$. The sources of these main pollutants were should be further investigated.

533  In the subsequent soil improvement process, it was recommended to further

534  enhance soil desalination, dealkalization, water replenishment; increase organic

535  matter (organic fertilizers); and appropriately retain some plant residues and fallen

536  materials. At the same time, it was further reduced reducing human interference to

537  would improve the food sources for overwintering birds. Furthermore, based on the

538  characteristics of the local soil fertility, it was suggested that the fertilization method

539  should be appropriately changed in future planting, fertilization and field management.

540  The focus should be on supplementing nitrogen fertilizer and organic matter, while

541  the application of phosphate and potassium fertilizers could be appropriately

542  controlled.

26

**CONCLUSION**

543

544     The present paper demonstrated that the implementation of the wetland farmland

545     remediation initiative results in a number of notable environmental benefits. These

546     benefits included the enhancement of water quality and soil fertility within the

547     wetland ecosystem, the improvement of the surrounding ecological environment, an

548     increase in the number of migratory birds that chose to reside in the area, and an

549     overall enhancement of the capacity of the Yancheng Wetland for the protection of

550     rare bird species. The water pollutants present in the remediation area at different

551     periods were primarily total nitrogen and BOD$_5$, which were Classified as ~~III~~

552     ~~categories~~ category III and belonged to the state of moderate pollution ~~by~~ in the

553     wetland farmland remediation area. The soil comprehensive fertility index of the

554     wetland farmland remediation area was medium, primarily exhibiting the

555     characteristics of low nitrogen, low organic matter, high phosphorus and high

556     potassium. The organic matter, nitrogen, phosphorus and potassium levels in the soil

557     might be enhanced by the fertilizers and bird droppings. The soil fertility was

558     comprehensively categorized as Class III. Following a comprehensive analysis of the

559     water quality and soil fertility in this area, it was recommended that changes be made

560     to the fertilization and field management practices. The suggested modification to the

561     fertilization method for the future planting included the addition of nitrogen and

562     organic matter, in addition to the precise regulation of phosphate and potassium

563     fertilization. Subsequent wetland farmland remediation projects ~~had~~ can continue~~d~~ to

564     enhance the water quality and soil quality, whilst simultaneously enriching the

565    biodiversity of the area and attracting an increasing number of wintering migratory

566    birds to the wetland.

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The authors declare that they have no competing interests.

**Authorship contributions**

**Changqing Liu**: Methodology, Formal analysis, Writing - review & editing, Funding acquisition. **Zhongxiang Sun**: Investigation, Formal analysis. **Hongyang Wang**: Investigation, Methodology. **Tianwen Chen**: Investigation, Formal analysis. **Lina Deng**: Writing – review & editing, Formal analysis. **Li Zhang**: Writing – review & editing, Funding acquisition. **Huixing Liang**: Investigation, Formal analysis. **Yuxiang Shen**: Writing – review & editing, Formal analysis. **Hongshan Li**: Resources, Conceptualization, Supervision, Funding acquisition. **Hai Cheng**: Investigation, Methodology, Formal analysis.

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**Table legends**

**Table. 1** The water quality monitoring and statistics of single factor results in dry

season (sulfide: mg/L; mercury, arsenic, plumbum, cadmium: μg/L).

**Table. 2** The water quality monitoring and statistics of single factor results in normal

season (sulfide: mg/L; mercury, arsenic, plumbum, cadmium: μg/L).

**Table. 3** Basic physical and chemical properties of soil fertility in eight different

fields in the wetland farmland remediation project.

**Table. 4** Classification standard and results of soil nutrient content.

**Table. 5** Improvement of soil fertility by bird droppings in the wetland farmland

remediation project area.

**Table. 6** Comprehensive fertility indexes of soil in the wetland farmland remediation

project area and control area.


**Figure legends**

**Fig. 1** The plot allocation of wetland farmland remediation area.

**Fig. 2** Analysis of main physical and chemical characteristics of water in different

season. C28: Chinese cabbage; C1: Wheat; C31: Barley; C10: Colza oil; C11:

Mustard; C6: No tillage without water replenishment; C25: No tillage with water

replenishment; C17: Without harvesting. *: $p \leq 0.05$; ns: $p > 0.05$.

806     **Fig. 3** Analysis of nutrient composition of bird droppings.

807     **Fig. 4** Comparison of soil nutrients between the wetland farmland remediation project

808     area and control area. *: $p \leq 0.05$; ns: $p > 0.05$.

809     **Fig. 5** The vertical distribution of soil nutrients in the wetland farmland remediation

810     project area. *: $p \leq 0.05$; ns: $p > 0.05$.