

Spatial Distribution Characteristics of Soil Organic Matter in the Drawdown Zone of Guanting Reservoir (Postprint)

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Abstract

Soils in water-level fluctuation zones are formed under the combined effects of alternating aquatic-terrestrial habitats and complex geochemical processes, possessing unique physicochemical properties and ecological functions. Nutrient contents exhibit high temporal and spatial variability, and the distribution, migration, and transformation of soil organic matter are subject to complex influences. Focusing on the water-level fluctuation zone in the upstream Gui River section of the Guanting Reservoir watershed, a typical drawdown area of the fluctuation zone was selected to investigate the spatiotemporal distribution characteristics of soil organic matter content. The results indicate: 1) Soil organic matter content in the study area's water-level fluctuation zone is relatively low, ranging from 1.64–26 g/kg with a mean value of only 13.16 g/kg and a coefficient of variation reaching 50.59%. This demonstrates that due to the special hydrological conditions of seasonal wet-dry alternation in the fluctuation zone, soil nutrient distribution exhibits high spatial heterogeneity. The mean organic matter content in frequently flooded areas is 15.74 g/kg, higher than the 10.12 g/kg in long-term exposed areas, with a coefficient of variation of 41.38%, lower than the 54.98% in long-term exposed areas. This indicates that frequently flooded areas have stronger capacity for retaining soil nutrients, and periodic flooding conditions create similar habitat types in the nearshore area of the study zone, resulting in relatively smaller differences in soil organic matter content among different sampling points. 2) Under different plant communities, reed and cattail communities exhibit the highest soil organic matter content with a mean value of 17.08 g/kg; the lowest content occurs in the meso-xerophytic plant belt dominated by poplar and *Bothriochloa ischaemum*, with a mean value of 9.12 g/kg; followed by the hygrophytic plant belt with *Polygonum lapathifolium* and *Cirsium setosum* as dominant species, where soil organic matter content averages 15.49 g/kg. 3) Soil organic matter content varies significantly among different soil layers, with an overall decreasing trend

from the surface downward, showing significant differences between layers ($P < 0.05$). The C/N ratio of soils in the study area ranges from 1.64-18.95, with a mean value of 8.95. This indicates that the soil C/N ratio in the study area is relatively low, the degree of humification of organic matter is relatively high, and soil organic matter in long-term exposed areas is more prone to decomposition, with C accumulation rate being far slower than N. The vertical distribution of soil C/N ratio generally shows a trend of first increasing then decreasing, reaching its maximum at 30 cm depth, then gradually decreasing with increasing soil depth. 4) In the analysis of factors influencing soil organic matter distribution in the water-level fluctuation zone, soil organic matter shows a highly significant positive correlation with total phosphorus, with a correlation coefficient of 0.62 ($P < 0.01$); and significant positive correlations with total nitrogen and C/N ratio ($R = 0.57, 0.60; P < 0.05$). This demonstrates that total phosphorus, total nitrogen, C/N ratio, and organic matter in the study area clearly share the same trend of variation and mutually influence each other. Furthermore, soil organic matter shows a significant negative correlation with moisture content ($R = -0.51; P < 0.05$), indicating that soil moisture content has a significant impact on organic matter content in the study area. Among climatic factors, temperature has a significant influence on soil organic matter distribution in the study area, with a correlation coefficient of -0.51 ($P < 0.05$). Among vegetation factors, vegetation coverage shows a significant positive correlation with soil organic matter content, with a correlation coefficient of 0.64, indicating that vegetation factors are also one of the important factors influencing soil organic matter distribution.

Full Text

Preamble

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Spatial Distribution Characteristics of Organic Matter in the Water Level Fluctuation Zone of Guanting Reservoir

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Abstract

Soils in the water level fluctuation zone (WLFZ) develop unique physicochemical properties and ecological functions under the combined influence of alternating aquatic-terrestrial habitats and complex geochemical processes. Soil nutrient content exhibits high temporal and spatial variability, and the distribution, migration, and transformation of organic matter (OM) are subject to complex influences. This study investigated the temporal and spatial distribution characteristics of soil organic matter content in a typical WLFZ in the upper Guishui River reach of Guanting Reservoir. Results showed that WLFZ soils in Guanting Reservoir were relatively poor in organic matter, ranging from 1.64 to 26 g/kg with a mean of only 13.16 g/kg. The coefficient of variation reached 50.59%, indicating high spatial heterogeneity in soil nutrient distribution due to seasonal wet-dry alternation. The frequently flooded zone had an average organic matter content of 15.74 g/kg, significantly higher than the long-term exposed area (10.12 g/kg), with a lower coefficient of variation (41.38% vs. 54.98%), suggesting stronger nutrient retention capacity in flooded areas. Emergent plant communities (*Phragmites australis* and *Typha angustifolia*) showed the highest organic matter content (17.08 g/kg), followed by hygrophyte communities dominated by *Polygonum lapathifolium* and *Cirsium setosum* (15.49 g/kg), while mesoxerophytic communities dominated by *Populus simonii* and *Bothriochloa ischaemum* had the lowest content (9.12 g/kg). Organic matter decreased consistently from surface to deeper layers, with significant differences between layers ($P < 0.05$). The soil C/N ratio ranged from 1.64 to 18.95 with a mean of 8.95, indicating relatively low ratios, high humification degree, and greater potential for anaerobic decomposition to produce CH_4 and CO_2 . Vertically, C/N showed an initial increase followed by decrease, peaking at 30 cm depth. Correlation analysis revealed that soil organic matter was extremely significantly positively correlated with total phosphorus ($r = 0.62$, $P < 0.01$) and significantly positively correlated with total nitrogen and C/N ($r = 0.57$ and 0.60 , $P < 0.05$). Soil organic matter and moisture were significantly negatively correlated ($r = -0.51$, $P < 0.05$), while temperature significantly influenced organic matter distribution ($r = -0.508$, $P = 0.031$). Vegetation cover was also significantly positively correlated with soil organic matter content ($r = 0.64$, $P < 0.05$), confirming vegetation as an important factor affecting organic matter distribution.

Keywords: water level fluctuation zone; soil organic matter; spatial distribution; Guanting Reservoir

1. Study Area Overview

The WLFZ of the Guishui River section in Guanting Reservoir is located in Yanqing County, northwestern Beijing, within the Yeyahu Wetland Nature Reserve (115°46 16 -115°59 48 E, 40°22 04 -40°30 31 N). The region has a north temperate continental monsoon climate, representing a transitional zone between temperate and mid-temperate, semi-arid to semi-humid conditions. The multi-year average temperature is 8.9°C, with average precipitation of 463 mm concentrated in summer (accounting for 70% of annual rainfall). Groundwater depth around the reservoir fluctuates between 0-2 m. The main soil types are cinnamon soil and meadow swamp soil, with wet tidal soil distributed in local waterfront areas. Due to extensive agricultural land use on the north bank, sampling focused on the south bank where typical wetland landscapes are maintained with abundant wetland vegetation communities [Figure 1: see original paper].

2. Materials and Methods

2.1 Sample Collection and Preprocessing

To comprehensively investigate nutrient distribution and spatial heterogeneity in the Guanting Reservoir WLFZ, sampling transects were established based on spatial and temporal water level variation characteristics, dividing the zone into frequently flooded areas and long-term exposed areas. The south bank of the Guishui River section was selected as the primary sampling area due to its representative wetland landscape. Sampling was conducted during the dry season (October 2014) when water levels were low. Following the principle of “vertical water-land boundary and moisture gradient design” [31], sampling points were arranged perpendicular to the water-land interface from shore to highest water level, forming a sampling profile. Areas frequently inundated and dried were classified as frequently flooded zones, while higher elevation areas rarely inundated were classified as long-term exposed zones. At each point, soil samples were collected at 0-10, 10-20, 20-30, 30-40, and 40-50 cm depths using a soil auger. A total of 126 valid samples were collected at 50-100 m intervals, with simultaneous measurement of moisture, temperature, and conductivity using a soil parameter meter. Coordinates and site characteristics were recorded for each sampling point [Figure 2: see original paper]. Fresh soil samples were air-dried indoors, manually cleared of gravel and debris, then ground in a ceramic mortar for analysis.

2.2 Experimental Methods

Soil physicochemical analyses included organic matter, total nitrogen, total phosphorus, total salt content, pH, and moisture content, following the Forestry Industry Standards of the People's Republic of China [31]: LY/T1237-1999 for organic matter, LY/T1228-1999 for total nitrogen, LY/T1232-1999 for total phosphorus, LY/T1251-1999 for water-soluble salts, and LY/T1239-1999 for moisture content. Data were analyzed using SPSS 17.0 and Microsoft Excel 2007 for one-way ANOVA and correlation analysis.

3. Results and Analysis

3.1 Statistical Characteristics of Soil Nutrients

After outlier detection and removal, descriptive statistics were performed on 126 valid samples. Soil organic matter content in the WLFZ was relatively poor, ranging from 1.64 to 26.60 g/kg with a mean of 13.16 g/kg and median of 12.08 g/kg. The coefficient of variation was 50.59%, indicating high spatial heterogeneity due to seasonal wet-dry alternation. Total phosphorus and total nitrogen showed smaller variation coefficients (17.79% and 67.78%, respectively), while total salt content showed the highest variation (73.02%).

3.2 Organic Matter Distribution Under Different Moisture Gradients

The periodically flooded zone exhibited dramatic soil changes over short periods. Statistical analysis showed that the frequently flooded zone had organic matter ranging from 4.90 to 26.60 g/kg (mean: 15.74 g/kg), significantly higher than the long-term exposed zone (1.64–22.72 g/kg, mean: 10.12 g/kg). The coefficient of variation was lower in flooded areas (41.38%) compared to exposed areas (54.98%), indicating stronger nutrient retention capacity and more homogeneous habitat conditions in flooded zones.

3.3 Organic Matter Distribution Under Different Vegetation Communities

Vegetation communities enrich soil nutrients, while nutrient changes affect community distribution and succession. The study area exhibited rich wetland vegetation types showing distinct zonal distribution along moisture gradients. Emergent plant communities (*Phragmites australis* and *Typha angustifolia*) dominated the frequently flooded zone with the highest organic matter content (17.08 ± 6.45 g/kg). *Hygrophyt* communities (*Polygonum lapathifolium* and *Cirsium setosum*) were second highest (15.49 ± 6.23 g/kg), while mesoxerophytic communities (*Populus* and *Elymus dahuricus*) in the long-term exposed zone had the lowest content (9.12 ± 4.87 g/kg). Organic matter consistently decreased from surface to subsurface layers across all community types.

3.4 Organic Matter Distribution at Different Soil Depths

Analysis of soil layers (0-10, 10-20, 20-30, 30-40, 40-50 cm) showed significant differences between layers ($P < 0.05$), with a consistent decreasing trend from surface to depth. This pattern reflects the concentration of plant roots and organic residues near the surface. However, some communities showed special vertical distribution patterns: in *Populus simonii* stands, organic matter was lowest at the surface due to sparse understory vegetation and limited litter, but increased in deeper layers due to root exudates and residues, peaking at 30-40 cm before decreasing again. In herbaceous communities like *Elymus dahuricus*, organic matter was concentrated at the surface due to abundant litter and decreased sharply with depth due to shallow root systems [FIGURE:3, FIGURE:4].

3.5 Soil C/N Ratio Distribution Characteristics

The soil C/N ratio indicates the relationship between carbon and nitrogen transformation during microbial decomposition. The study area showed relatively low C/N ratios (1.64-18.95, mean: 8.95), suggesting high humification degree, easy mineralization of organic nitrogen, and high potential for anaerobic decomposition to produce CH_4 and CO_2 . Vertically, C/N increased initially then decreased, peaking at 30 cm depth.

3.5.1 Frequently Flooded Zone C/N Distribution In the frequently flooded zone, C/N ranged from 6.92 to 18.94 (mean: 9.65), peaking at 20-30 cm (11.02) before decreasing with depth. Under typical plant communities, *Phragmites australis* showed C/N peaking at 30-40 cm (12.07), while *Polygonum lapathifolium* peaked at 20-30 cm (11.30) [FIGURE:5, FIGURE:6, TABLE:5].

3.5.2 Long-term Exposed Zone C/N Distribution The long-term exposed zone had lower C/N (1.64-11.41, mean: 8.13), peaking at 30-40 cm (9.21). Vegetation included tall trees, shrubs, and herbs. Under *Populus simonii* and *Elymus dahuricus* communities, C/N showed more variable patterns, generally lower than in flooded zones [FIGURE:7, FIGURE:8, TABLE:6].

3.6 Factors Influencing Soil Organic Matter Distribution

3.6.1 Influence of Soil Physicochemical Properties Correlation analysis showed soil organic matter was extremely significantly positively correlated with total phosphorus ($r = 0.615$, $P < 0.01$) and significantly positively correlated with total nitrogen and C/N ($r = 0.572$ and 0.595 , $P < 0.05$). Organic matter and moisture were significantly negatively correlated ($r = -0.508$, $P < 0.05$), indicating that higher moisture promotes decomposition and reduces organic matter content [TABLE:7, TABLE:8].

3.6.2 Influence of Temperature Temperature significantly affects microbial and enzyme activity, with 25–35°C being optimal. Measured soil temperatures in the study area ranged from 15.2 to 22.3°C (mean: 17.83°C). Temperature was significantly negatively correlated with organic matter ($r = -0.508$, $P = 0.031$), with the linear relationship $y = -0.18x + 20.68$ ($R^2 = 0.257$). Long-term exposed zones had slightly higher temperatures than flooded zones, leading to faster decomposition rates.

3.6.3 Influence of Vegetation Coverage Using linear spectral mixture model analysis of remote sensing imagery, vegetation coverage was extracted and correlated with surface soil organic matter content. Results showed a significant positive correlation ($r = 0.64$, $P < 0.05$), confirming vegetation coverage as an important factor influencing organic matter distribution [FIGURE:9, FIGURE:10].

4. Conclusion and Discussion

This study investigated the spatial and temporal distribution characteristics of soil organic matter in the Guishui River WLFZ of Guanting Reservoir. Key findings include:

1. **Low organic matter with high heterogeneity:** Soil organic matter ranged from 1.64–26 g/kg (mean: 13.16 g/kg) with a coefficient of variation of 50.59%, reflecting high spatial heterogeneity due to seasonal wet-dry alternation.
2. **Flooding effects:** Frequently flooded zones had higher organic matter (15.74 g/kg) than long-term exposed zones (10.12 g/kg), with lower variation (41.38% vs. 54.98%), indicating stronger nutrient retention capacity and more homogeneous habitat conditions in flooded areas.
3. **Vegetation influence:** Emergent plant communities (*Phragmites australis* and *Typha angustifolia*) showed the highest organic matter (17.08 g/kg), followed by hygrophytes (15.49 g/kg), while mesoxerophytes had the lowest (9.12 g/kg).
4. **Vertical distribution:** Organic matter decreased significantly from surface to depth across all zones ($P < 0.05$), though some communities showed special patterns due to root distribution.
5. **C/N characteristics:** The low C/N ratio (mean: 8.95) indicated high humification degree and potential for anaerobic decomposition. C/N peaked at 30 cm depth, showing an initial increase then decrease with depth.
6. **Controlling factors:** Soil organic matter was significantly correlated with total phosphorus, total nitrogen, and C/N (positive), and with mois-

ture and temperature (negative). Vegetation coverage also significantly influenced organic matter distribution.

The WLFZ represents a critical ecotone with complex mechanisms of nutrient cycling and transformation. Further research is needed to fully understand the dynamic changes and cycling mechanisms of organic matter and other nutrients under the unique hydrological conditions of reservoir fluctuation zones.

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