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# Effect of domestic sewage on macro-micro physical and mechanical properties of soil

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**Abstract.** Domestic sewage can greatly affect the macro-micro physical-mechanical properties of building foundation soils. In order to investigate the effect of domestic sewage on physical and mechanical properties of soils, the physicochemical properties of three groups of different concentrations of domestic sewage contaminated soil were tested through indoor experiments. Combined with scanning electron microscopy, X-ray diffraction experiments, and grey relational analysis, the degree of influence of different concentrations of domestic sewage on the physicochemical properties of soil was compared and analyzed from multiple perspectives such as microstructure and mineral composition, revealing the influencing mechanism of soil pollution by domestic sewage. The results showed that under the immersion of contaminated water, the color of the soaking water turned black first and then yellow, and brownish yellow secretions appeared on the surface of the soil samples. The moisture content, specific gravity, density, and pore ratio index of the soil samples immersed in 50% and 100% domestic sewage decreased with the increase of sewage concentration, while the liquid limit of the soil samples changed in the opposite direction. The immersion time had little effect on the slope of the compression curve of the soil samples soaked in tap water. For the soil samples immersed in domestic sewage, the slope of the compression curve and the compression coefficient increased with the increase of domestic sewage concentration and immersion time, while the compression modulus showed the opposite trend. In the soil samples immersed in tap water, there were a large number of small particles and cementitious substances, and the structure was relatively dense. With the increase of domestic sewage concentration, the microstructure of the soil changed significantly, with the appearance of sigle particle structure, loose and disorderly arrangement of particles, increased and enlarged pores, gradual reduction of small particle substances and cementitious substances, and the soil structure transformed from compact to loose. The research findings can provide theoretical reference for contaminated geotechnical engineering.

**Keywords:** domestic sewage pollution soil; microstructure; mineral composition; hysical and mechanical properties

## 1. Introduction

Polluted soil refers to a type of soil in which ordinary soil undergoes chemical changes due to erosion by the three waste pollutants (waste, wastewater, and waste residue) generated during production and daily life processes (Zhang *et al.* 2015). With increasing industrialization and

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urbanization and dependence on agrochemicals, soil pollution has received increasing attention (Cai *et al.* 2015, Zhao *et al.* 2014). After the foundation soil is contaminated, geotechnical properties of contaminated soils may be significantly degraded due to physicochemical interactions between contaminant constituents and the soil matrix (Sadighi *et al.* 2022), which may lead to ground collapse and building collapse, ultimately causing enormous economic losses and casualties. Due to reasons such as high population density and limited land availability, it is inevitable to carry out engineering construction on polluted soil. Therefore, it is necessary to study the issue of polluted soil in order to minimize unnecessary losses and casualties.

According to the composition of pollutants, polluted soil can be divided into four categories: organic pollutant-contaminated soil, inorganic pollutant-contaminated soil, biological pollutant-contaminated soil, and radioactive pollutant-contaminated soil (Hu 2020, Li *et al.* 2018, Zhang and Chen 2017). Currently, research on polluted soil mainly focuses on soil remediation and environmental management (Sridhar and Parimalarenganayaki 2024), with relatively limited engineering achievements (Zhu and Liu 2007). Most of the studies on polluted soil engineering properties are conducted through indoor experiments. For example, Safehian *et al.* (2018) conducted compaction tests, consolidation tests, direct shear tests, and unconfined compression tests on illite clay contaminated with different amounts of diesel, and concluded that the maximum dry density of the soil sample decreases and the optimum fluid content increases in the presence of diesel; when the soil is exposed to organic fluids, the compressibility of the soil increases; adding diesel reduces the cohesion, internal friction angle, and unconfined compressive strength of the soil. Vásquez-Nogal and Hernández-Mendoza (2022) studied the effects of arsenic contamination on the geotechnical properties of montmorillonite clay through indoor experiments, and the results showed that arsenate contamination reduces the pH value of the soil. In addition, Zha *et al.* (2021), Xia *et al.* (2023), and Portelinha *et al.* (2021) have also conducted research on different types of polluted soil and obtained corresponding conclusions. Li *et al.* (2022) tested the effects of lead ions on the basic engineering properties of loess through acidity and alkalinity tests and unconfined compressive strength tests, and found that as the concentration of lead ions increases, the alkalinity of the soil decreases and the acidity increases, the liquid limit and plastic limit are lower than those of the original soil, and the overall unconfined compressive strength shows an increasing trend. Wang *et al.* (2022) conducted research on the strength and microstructure characteristics of loess polluted by organic phosphorus pesticides, and the results showed that the unconfined compressive strength of the polluted loess decreases with the increase of pesticide content. By summarizing the research data on polluted soil, it is found that the majority of studies focus on a single type of pollution, with a single pollution source and relatively regular physical and mechanical properties of the polluted soil, making it easier to grasp its corrosion mechanism. However, domestic wastewater contains organic matter, microorganisms, heavy metals, and other complex components. Although this paper is just an exploratory study on the mechanical properties and microstructure of contaminated soil, the research results still have certain engineering guiding significance.

This paper investigated the physicochemical properties of soil contaminated with domestic wastewater at three different concentrations through indoor experimental testing. By combining scanning electron microscopy, X-ray diffraction, and grey correlation analysis, a comparative analysis was conducted to assess the extent of the impact of domestic wastewater with different concentrations on the physicochemical properties of the soil. The study revealed the mechanisms of domestic wastewater pollution in soil from multiple perspectives, including microstructure and mineral composition. This research provides valuable references for practical engineering in the context of soil contaminated by domestic wastewater.

## 2. Materials and methods

### *2.1 Water collection and preparation*

The water samples used in this experiment were collected from the domestic wastewater in the sewage well of a university in Heilongjiang Province and the tap water in the water supply system. The domestic wastewater was obtained from sewage discharged from student dormitories, faculty apartments, canteens, and other public places. The tap water was supplied by the Songbei District Water Plant and sourced from underground, with relatively high mineralization. The collected wastewater and tap water were sealed in beakers and immediately sent to the testing center for analysis. The chemical parameters of the domestic wastewater are shown in Table 1. Since the inorganic component content of tap water is somewhat different from that of domestic sewage, the extracted tap water cannot be directly tested. Chemical substances rich in nitrogen, sulfur, iron, magnesium, etc. (Huang 2021) need to be added during the preparation process to make the inorganic component of tap water close to that of domestic sewage. The final chemical index of tap water is shown in Table 2.

In this study, tap water (0% domestic sewage) was selected as the control group to provide a baseline situation without the impact of domestic sewage; 50% domestic sewage was selected to simulate moderate pollution, between the control group and high concentration; and 100% domestic sewage was selected to study the effect of sewage on soil at maximum concentration. The choice helps to observe the progressive effects of soil under different concentrations of domestic sewage pollution, and can study the possible changes in soil physical and chemical properties under extreme pollution conditions, thereby gaining a more comprehensive understanding of the impact of domestic sewage on soil or the environment. Therefore, the domestic sewage was configured (as shown in table 3) and the domestic sewage was divided into three groups, A, B, and C, with 15 beakers in each group, and labeled. In this experiment, the solution stored in the beakers of group A, group B and group C were tap water, 50% domestic sewage and 100% domestic sewage, respectively.

### *2.2 Soil sample preparation*

The soil samples used in this experiment were taken from a construction pit in Harbin, China (at a depth of 10.4 m underground), and the physical indexes of the original soil samples were shown in Table 4. The soil samples were black in color and had an odor of mud. They had a

Table 1 Chemical indicators of domestic sewage

| Index | pH | CODCr/mg·L-1 | TN/mg·L-1 | Water hardness | Ga/mg·L-1 |
|---|---|---|---|---|---|
| Value | 8.26 | 455 | 135.5 | 10.77 | 53.7 |
| Index | Mg/mg·L-1 | Fe/mg·L-1 | Cl-/mg·L-1 | SO42-/mg·L-1 | BOD/mg·L-1 |
| Value | 16.07 | 0.973 | 56.9 | 8.15 | 262 |

Note: CODcr: Chemical Oxygen Demand; TN: Total Nitrogen; BOD: Biochemical Oxygen Demand

Table 2 Chemical indicators of blended tap water

| Index | pH | CODCr/mg·L-1 | TN/mg·L-1 | Water hardness | Ga/mg·L-1 |
|---|---|---|---|---|---|
| Value | 8.3 | 0 | 2 | 10.9 | 53.1 |
| Index | Mg/mg·L-1 | Fe/mg·L-1 | Cl-/mg·L-1 | SO42-/mg·L-1 | BOD/mg·L-1 |
| Value | 16.17 | 0.85 | 57.6 | 8.02 | 0 |

Note: CODcr: Chemical Oxygen Demand; TN: Total Nitrogen; BOD: Biochemical Oxygen Demand

Table 3 Water sample configurations

| Water sample number | Tap water | 50% domestic sewage | 100% domestic sewage |
|---|---|---|---|
| Configured tap water | 100% | 50% | 0% |
| Domestic sewage | 0% | 50% | 100% |

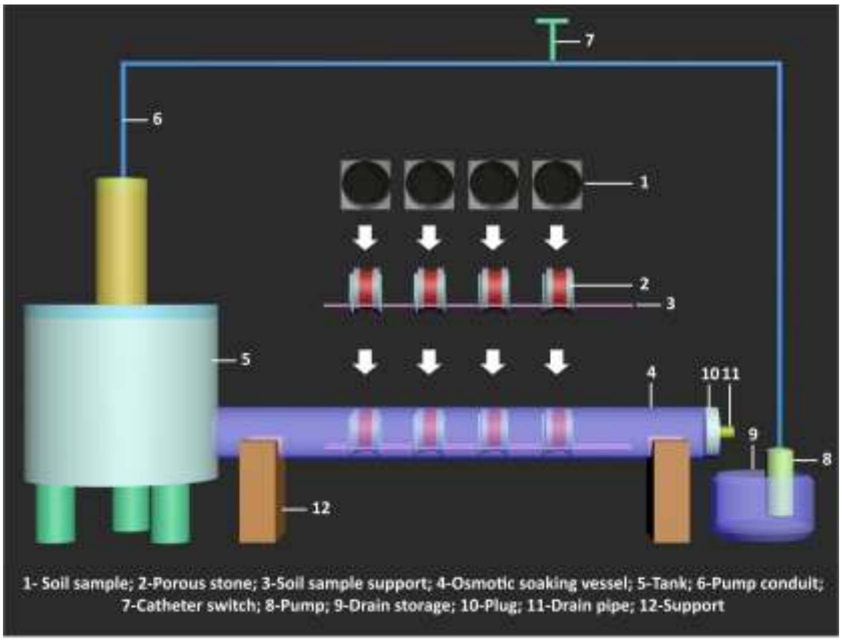


Fig. 1 Test instrument and penetration soaking method

relatively high moisture content. Laboratory tests confirmed that the soil was clay. After removing the disturbed topsoil, undisturbed soil samples were collected using a ring knife (the diameter is 61.8 mm and the height is 2 cm) and prepared accordingly. Once the collection was complete, the undisturbed soil samples were quickly sealed in plastic bags for preservation. Upon transferring the samples to the laboratory, they were carefully trimmed and both ends were covered with permeable stones and securely tied. After tying, the samples were placed on a homemade support system (Fig. 1). The support system, along with the soil samples, was then placed into a homemade cyclic permeameter. The plug on the right side of the apparatus was tightened, and the drain valve was closed. Next, water sample A was poured into the left water storage container and

Table 4 Indicators of physical properties of in-situ soils

| Index | moisture content /% | density /g·cm$^{-3}$ | specific gravity | liquid limit /% |
|---|---|---|---|---|
| Value | 39.58 | 1.79 | 2.64 | 43.9 |
| Index | plasticity limit /% | plasticity index | compression coefficient /MPa$^{-1}$ | porosity |
| Value | 23.3 | 20.6 | 0.41 | 1.06 |

covered. A small water pump was placed in the right water storage container, and the outlet of the pump was connected to the left water storage container using PVC pipes. After conducting a thorough inspection for air-tightness, the soil samples were subjected to a permeation soaking test. The drain valve and pump switch were opened, causing the solution to circulate continuously. Each group of samples consisted of three parallel samples, and the concentration of the solution was checked every 12 hours. Since the pollutants in domestic sewage will slowly accumulate in the soil, in order to accurately assess its impact on the soil, a longer test observation time will be set; when the soaking time is 20d, the morphology of both soil and water samples have produced large changes, so the samples will be observed in three time intervals, i.e., the total time of the soaking will be 20d, 40d, and 60d respectively, with a time interval of 20d.

After the immersion process, one of the parallel samples was taken for physical property testing, including water content, density, porosity, specific gravity, and liquid limit; the second parallel sample was used for compression tests on the soil sample; the third parallel sample was used for composition analysis and scanning electron microscopy (SEM) testing. In this study, the mineral composition of the soil sample was determined using X-ray diffraction (XRD) method. The soil samples were prepared by grinding, sieving, drying, making slides, and then allowing them to settle before the experiments commenced. The experimental data was obtained using a Bruker D8 Advance X-ray diffractometer. For the SEM testing, the soil samples were prepared with dimensions approximately. 5 cm in length, width, and height. The prepared samples were glued, polished, ink-jetted, and labeled (Wang *et al*. 2022), and then placed under a scanning electron microscope (SEM500) for testing.

### *2.3 Grey relational analysis method (GRA)*

The Grey relational analysis method quantitatively describes and compares the developmental trends of a system. Its basic idea is to determine the degree of similarity in geometric shapes between a reference data series and several comparative data series in order to assess their closeness of association and reflect the degree of correlation between curves. This study introduces the GRA method to analyze the influence of the physical properties of domestic sewage-contaminated soil on the compression coefficient.

The specific steps are as follows (Tang *et al*. 2020):

(1) Select the compression coefficient of soil samples soaked in different concentrations of domestic sewage as the reference sequence $X_0 = \left\{ X_0\left(k\right) \middle| k = 1, 2, \cdots, n \right\}$, since the soaking time of the soil sample was divided into 0 days, 20 days, 40 days, 60 days, the reference sequence was taken n as 4; with the corresponding physical properties of the soil samples as the comparative sequence $X_i = \left\{ X_i\left(k\right) \middle| k = 1, 2, \cdots, n; i = 1, 2, \cdots, m \right\}$, in the process of testing, the physical properties of soil sample tested include moisture content, density, gravity, porosity, liquid limit, and plastic limit,

totaling 6 types. Therefore, m is taken as 6.

(2) Normalize the indicator data. Since the experimental data does not show a clear upward or downward trend, the mean normalization formula is used:

$$\overline{X_0}(k) = \frac{X_0(k)}{\overline{X_0}} \tag{1}$$

$$\overline{X_i}(k) = \frac{X_i(k)}{\overline{X_i}} \tag{2}$$

In the equation, $\overline{X_0}(k)$ represents the average value of each point in the reference sequence, and $\overline{X_i}(k)$ represents the average value of each point in the comparison sequence, where $i = 1, 2, \cdots, m$.

(3) Calculate the difference between the reference and comparison sequences and their correlation coefficients $\zeta_i(k)$.

$$\Delta_i(k) = \left|\overline{X_0}(k) - \overline{X_i}(k)\right| \tag{3}$$

$$\zeta_i(k) = \frac{\Delta_{\min} + \rho\Delta_{\max}}{\Delta_{ik} + \rho\Delta_{\max}} \tag{4}$$

In the equation, $\Delta_i(k)$ represents the difference between the two sequences at point $k$; $\Delta_{\max}$ represents the maximum difference between two sequence levels; $\Delta_{\min}$ represents the minimum difference between two sequence levels; $\rho$ is the comparison coefficient, generally between 0 and 1. If $\rho$ is smaller, the difference between the correlation coefficients is bigger, and the differentiation ability is stronger; through reviewing the literature, it can be obtained that when $\rho$ takes 0.5, the gray correlation coefficient has a good performance, and it can accurately reflect the degree of correlation between the factors, so this paper takes $\rho$ as 0.5.

(4) Calculating correlation $r_i$.

$$r_i = \frac{1}{n}\sum_{k=1}^{n}\zeta_i(k) \tag{5}$$

The larger the value of the correlation degree, the greater the degree of correlation between the reference and comparison series. If it is greater than 0.6, the correlation is considered significant.

## 3. Results and analysis

### *3.1 Variation of sample morphology*

The undisturbed soil sample soaked in domestic wastewater undergoes changes in its appearance as the soaking time increases. As shown in Fig. 2(a), the undisturbed soil sample appears gray-black initially when soaked in tap water. With the increase in soaking time, the soil

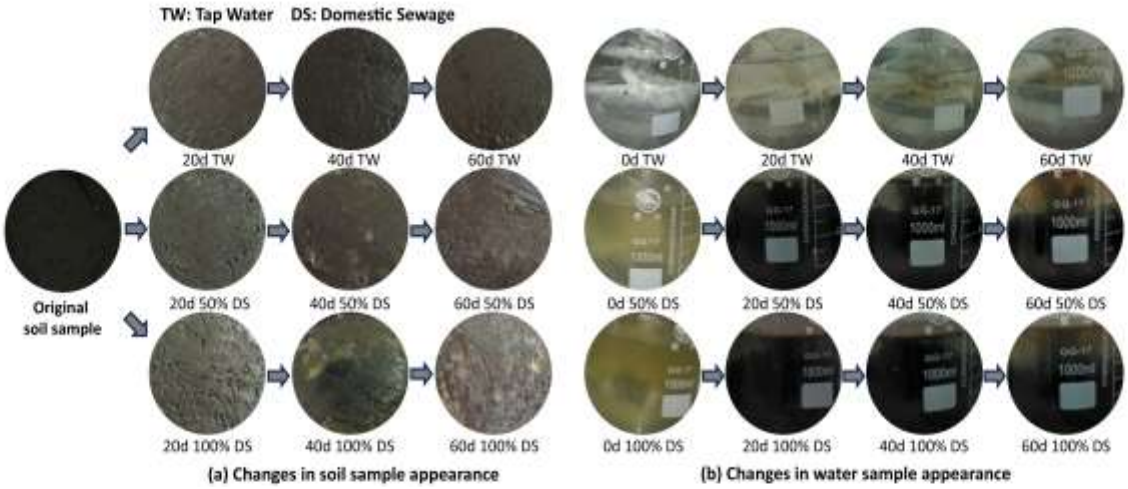


Fig. 2 Changes of sample morphology under different immersion conditions

sample gradually turns black and small bubbles start to appear on the surface. In the case of the soil sample soaked in 50% domestic wastewater, after 40 days of soaking, a small amount of biofilm attaches to the surface of the sample. The soil sample slightly expands and emits an unpleasant odor. For the soil sample soaked in 100% domestic wastewater, after 20 days of soaking, a minimal amount of biofilm starts to appear on the surface. As the soaking time increases, the biofilm gradually increases, and the soil becomes black. After 60 days of soaking, the soil sample appears slightly grayish-yellow and emits an unpleasant odor. As shown in Fig. 2(b), tap water is initially colorless and clear. However, with the increase in soaking time, the water sample turns yellow and slightly turbid. When the water sample is 50% domestic wastewater, it starts off as light yellow and turbid. With the increase in soaking time, the color of the water sample turns black and releases a foul-smelling gas. At 20 days of soaking, the water sample is darkest in color. Afterward, the black color gradually lightens and turns into yellow, while brownish-yellow suspended matter appears on the surface. As for 100% domestic wastewater, it appears yellow and turbid. With the increase in soaking time, the color of the water sample gradually turns black, and brownish-yellow suspended matter appears on the surface. After 20 days of soaking, the black color slowly fades into a lighter shade of yellow, and the amount of suspended matter on the surface increases.

### *3.2 Variation in physical properties of soil samples*

Fig. 3 presents the relationship curves between the moisture content, specific gravity, density, void ratio, liquid limit, and plastic limit of soil samples immersed in solutions containing different concentrations of domestic wastewater over time. The physical properties (moisture content, specific gravity, density, void ratio, plastic limit and liquid limit) of soil samples placed in 50% and 100% domestic wastewater decreased significantly with increasing soaking time compared to the unsoaked condition, and the test data increased or decreased in fluctuations. For the soil sample soaked in tap water, the moisture content, void ratio, liquid limit, and plastic limit exhibit a

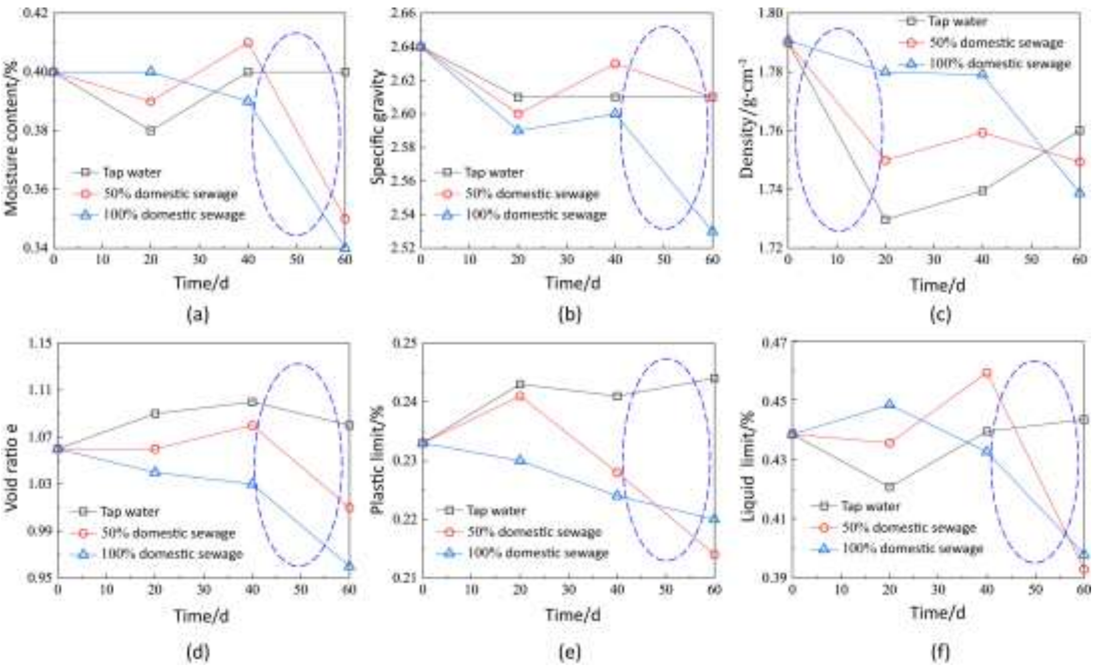


Fig. 3 Patterns of change in physical properties of soil samples

slight upward trend with the increase in soaking time, while the specific gravity and density show a downward trend. The dashed line section indicates that in the late soaking period, the change in physical properties of the soil sample exhibits a larger slope, except for density. It also indicates that the steeper the slope, the higher the concentration of domestic wastewater. The density of the soil sample undergoes significant changes initially during soaking, and the higher the concentration of domestic wastewater, the smaller the slope.

In vertical comparison, for a soaking time of 0~25 days, the higher the concentration of domestic wastewater, the higher the moisture content, density, and liquid limit of the soil sample, while the specific gravity, void ratio, and plasticity show the opposite trend. For a soaking time of 25~40 days, the soil sample soaked in 50% domestic wastewater has the highest moisture content, specific gravity, and liquid limit, whereas the sample soaked in 100% domestic wastewater has the lowest values in these aspects. Additionally, in this stage, the changing pattern of density, void ratio, and plastic limit is consistent with the previous stage. For a soaking time of 40~60 days, the changing pattern of the soil sample's physical properties mainly follows the principle that smaller values correspond to higher concentrations of domestic wastewater. The engineering properties of soil are closely related to factors such as mineral composition, structure, and particle composition (Jin *et al*. 2013, Wang *et al*. 2005, Zhang *et al*. 2023). The main reasons for the changes in the physical properties of the soil samples in this study are twofold. Firstly, after being infiltrated by domestic wastewater, soluble substances and inorganic colloids in the soil are dissolved in the domestic wastewater, leading to changes in the types of minerals in the soil and alterations in the soil structure. Secondly, domestic wastewater contains a considerable amount of organic matter, and during the experimental process, microorganisms decompose the organic matter and produce many intermediate products. As the biological processes progress, the soil structure is destroyed.

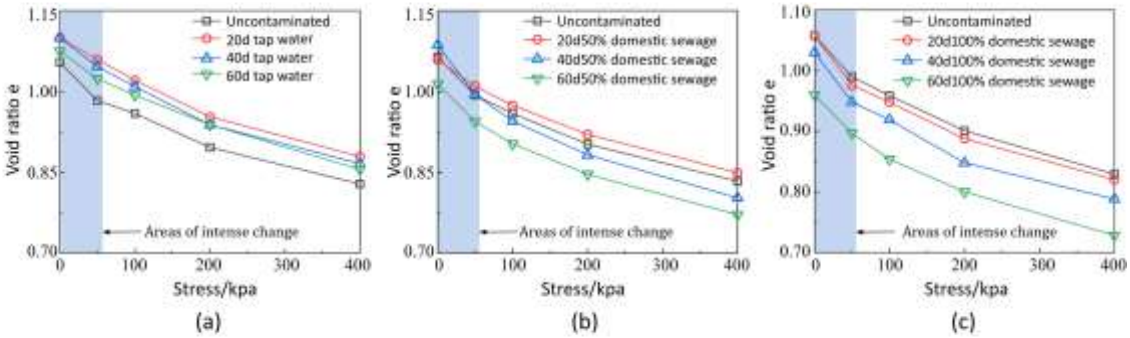


Fig. 4 Compression curves of soil contaminated with different concentrations of sewage

### *3.3 Variation in mechanical properties of soil samples*

The experiment was conducted on soil samples taken from solutions containing different concentrations of domestic wastewater and soaked for different immersion times. The soil samples were then placed in a consolidation apparatus for compression tests, and the compression curve is shown in Fig. 4. From Fig. 4, it can be seen that the compression curve of uncontaminated soil is relatively gentle when the load is within 0 ~25 kPa, reflecting that the main reason for the compression deformation of the soil is the decrease in pore volume of the soil. The free water and gas in the soil pores are gradually discharged during the compression process, while the structural continuity of the soil is not destroyed. At this time, the soil mainly undergoes elastic deformation. For the soil samples soaked in tap water, the immersion time has little effect on the slope of the compression curve. However, for the soil samples soaked in 50% and 100% domestic wastewater, the slope of the compression curve increases with the increase of immersion time. Moreover, the greater the concentration of domestic wastewater in which the soil sample is soaked, the steeper the slope of its compression curve.

Based on the compression curves of the soil samples, the compression indices (compression coefficient, compression modulus) deformation characteristics of soil contaminated by domestic wastewater were obtained. Fig. 5 shows the relationship between the compression indices of the soil samples and the immersion time and domestic wastewater concentration. In Fig. 5(a), as the immersion time of the soil samples increases, the compression coefficient also increases, indicating that the immersion time has a significant effect on the compression coefficient of the soil samples. In longitudinal comparison, when the immersion time exceeds approximately 30 days, the compression coefficient of the soil samples increases with the concentration of domestic wastewater. Conversely, when the immersion time is less than approximately 30 days, the opposite trend is observed. In Fig. 5(b), the compression modulus of the soil samples gradually decreases with the increase of immersion time. The curves of the compression modulus in 50% and 100% domestic wastewater are similar. When the immersion time is within the range of 0~20 days, the compression modulus of the soil samples at different concentrations is basically consistent, showing a decreasing trend. However, when the immersion time exceeds 20 days, the compression modulus becomes smaller with the increase of domestic wastewater concentration. Since only three water samples of tap water, 50% domestic sewage and 100% domestic sewage were tested in the experiment, the conclusions of the experiment may have some limitations, and the compression indexes of the soil polluted by domestic sewage in different concentrations may have

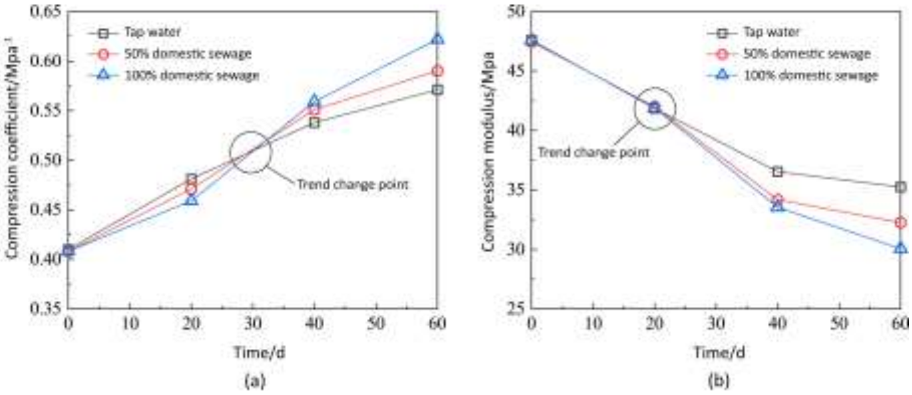


Fig. 5 Patterns of change in compression indicators

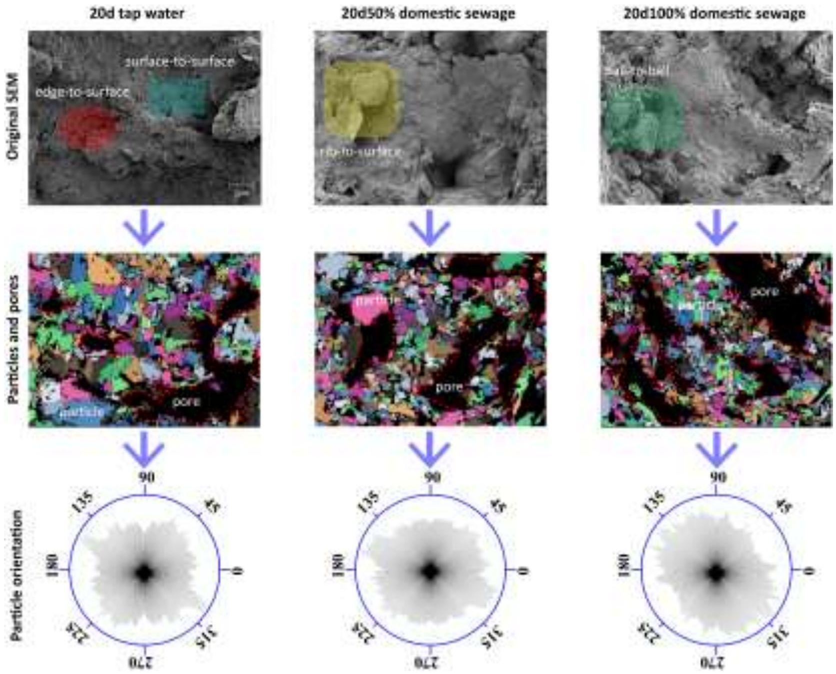


Fig. 6 Microstructure of soils contaminated with different concentrations of sewage

non-linear effects, resulting in potential changes in the results of different concentrations, but the compression coefficient of the soil samples gradually increased with the increase of soaking time, and the general trend of the compression modulus gradually decreased remained the same.

### *3.4 Variation in microstructure properties of soil samples*

The microscopic structure of soil contaminated by different concentrations of domestic wastewater after being magnified 3000 times for 20 days is shown in Fig. 6. From the figure, it can

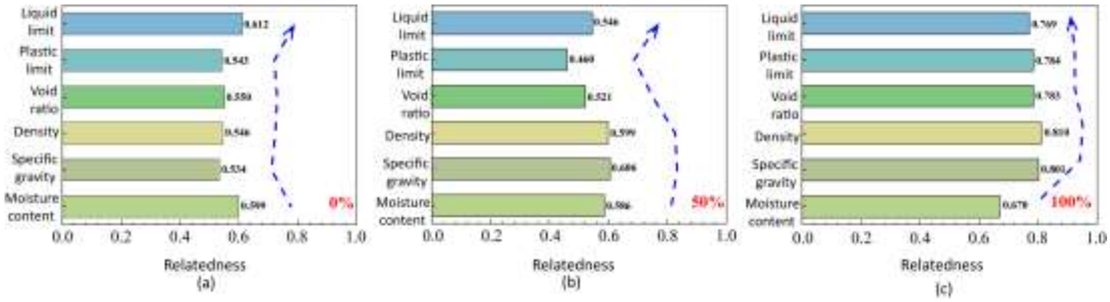


Fig. 7 Correlation between physical properties and compression coefficients of soil contaminated with concentrations of sewage

be observed that the soil sample soaked in tap water contains a large number of small particles and cementitious materials, making the soil structure compact and flocculent. There are no clear boundaries between particles, and the contacts are mainly surface-to-surface and edge-to-surface (Sun *et al*. 2020). The soil sample has few small pores, but the development and distribution of micropores and fine pores are obvious and widespread.

After soaking the soil samples in different concentrations of domestic wastewater, the microstructure of the soil undergoes significant changes with increasing domestic wastewater concentration. When the domestic wastewater concentration is 50%, the soil structure still remains flocculent, but the number of small particles decreases, and a small amount of single-grain structure appears, making the soil structure loose. The large pores in the soil increase and gradually enlarge, while some unstable scaffold pores appear, resulting in good pore connectivity and reduced cementitious materials. When the domestic wastewater concentration increases to 100%, the particle contours become more pronounced, the single-grain structure in the soil significantly increases, and the large particles are loosely arranged and randomly piled up. The pores become very prominent, and the soil is easily invaded by water when immersed, which in turn dissolves water-soluble minerals (Sun *et al*. 2022) in the soil. As a result, a large number of voids appear in the soil, making its structure very loose.

## 4. Discussion

### *4.1 Relationship between physical properties of soil samples and compressibility*

Based on the experimental results, the relationship between the physical properties and compression coefficient of soil contaminated by different concentrations of domestic wastewater can be obtained using the grey correlation analysis method (Fig. 7). From the figure, it can be observed that the correlation between the physical properties and compression coefficient of the soil samples soaked in tap water and 50% domestic wastewater is generally less than 0.6 (Xie *et al*. 2022), indicating that there is a certain relationship between the two but it is not significant. The correlation between the physical properties and compression coefficient of the soil samples soaked in 100% domestic wastewater is greater than 0.6 for all cases, indicating that there is a significant relationship between the variation in compression coefficient and the physical properties of the soil samples.

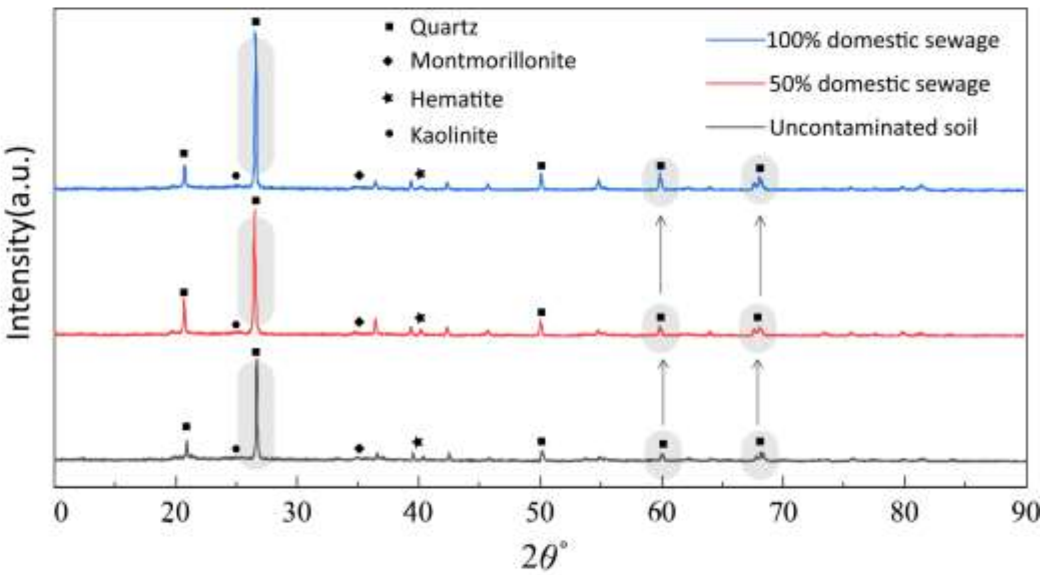


Fig. 8 Mineral composition of soil contaminated with concentrations of sewage

By comparing the magnitude of the correlations, it can be inferred that the density of the soil contaminated by 100% concentration of domestic wastewater has a greater impact on the compression coefficient compared to other physical properties. This is because the soil samples contain some soluble substances (secondary minerals). After being immersed, some of these soluble substances are dissolved and carried away by the circulating solution, resulting in a decrease in mass while the volume of the soil remains unchanged. At the same time, the pores in the soil increase, leading to an increase in the compression coefficient. Therefore, the density of the soil sample plays an important role in its compression coefficient.

In addition, as the concentration of domestic wastewater increases, the microbial content in the water also increases. The action of microorganisms generates a large amount of new substances, some of which react with the minerals in the soil sample to form new solid substances. These substances fill the pores in the soil sample and displace the water and gas in the pores. However, since the newly formed solid substances have insufficient strength, they cause instability in the new structure of the soil. Therefore, as the concentration of domestic wastewater increases during the immersion period, the physical properties of the soil contaminated by the wastewater undergo significant changes, ultimately leading to an increase in the compression coefficient. Thus, the higher the concentration of domestic wastewater during the immersion period, the larger the compression coefficient.

### *4.2 Effects of mineral composition on physicochemical properties of soil samples*

Useful information about different mineral phases in soil polluted with different concentrations of domestic sewage can be obtained through powder X-ray diffraction (Moretti *et al*. 2020). Therefore, an X-ray diffractometer was used to analyze the mineral composition of soil polluted with different concentrations of domestic sewage, and the results are shown in Fig. 8. It can be

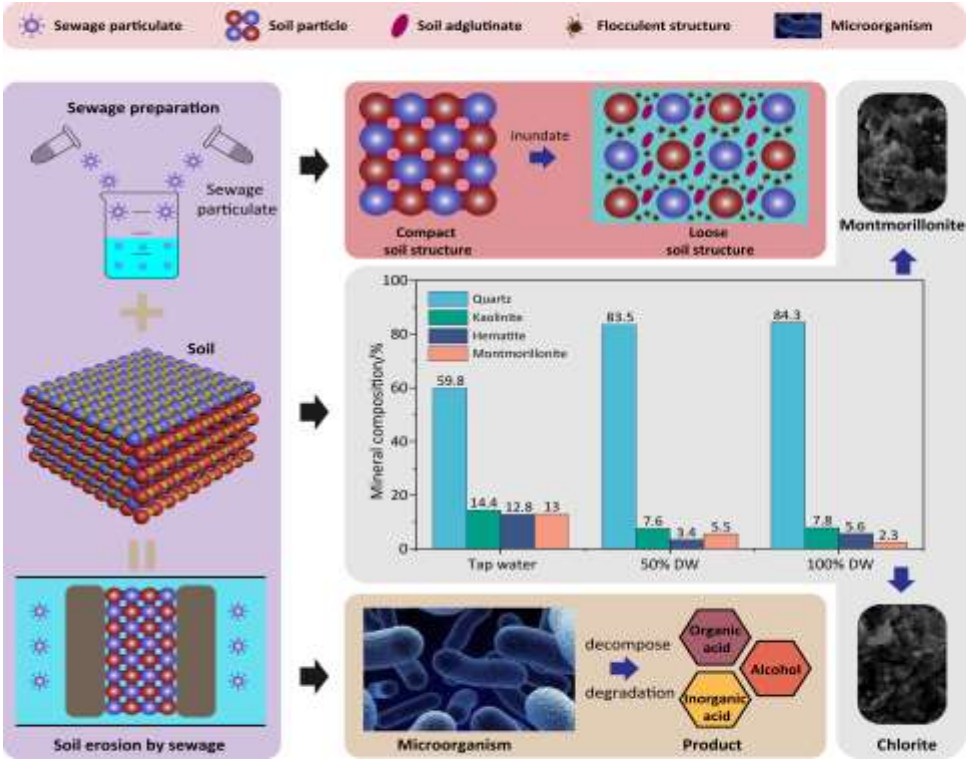


Fig. 9 Mechanisms of influence of domestic sewage contaminated soils

observed that the X-ray diffraction patterns of soil polluted with different concentrations of domestic sewage are basically similar, and the positions of the main diffraction peaks are essentially the same. The mineral composition in the soil samples is mainly quartz, with kaolinite and montmorillonite as pore fillers, and there is also a certain amount of hematite. Additionally, there are trace amounts of other mineral components in the soil samples. Among them, quartz has the highest content, and the quartz content in the soil samples soaked in domestic sewage shows a significant increase compared to the samples soaked in tap water. Furthermore, with the increase of domestic sewage concentration, the amount of quartz increase significantly decreases. The content of kaolinite, montmorillonite, and hematite is relatively low, but with the increase of domestic sewage concentration, their content all tend to decrease. Quartz is the most abundant mineral in the soil samples, and the higher the quartz content, the better the permeability and air permeability of the soil samples. This corresponds to the increase in pore size and quantity, as well as the loosening of soil structure, which ultimately changes the physical and chemical properties of the soil samples with the increase of domestic sewage concentration (increase in quartz content).

### *4.3 Influence mechanism of domestic sewage on soil*

The mechanism of soil pollution by domestic sewage is illustrated in Fig. 9. Prepared soil samples are immersed in domestic sewage, and with the increase of immersion time, pollutants infiltrate the soil and react chemically with certain substances in the soil to generate water-soluble compounds. Due to the leaching action of water, the water-soluble compounds and products generated from the original soil, as well as small particles and clay particles in the soil, are carried away by water flow, leaving behind insoluble substances and large particles, forming a soil structure with many pores. The content of soluble mineral components and inorganic colloids in domestic sewage increases, resulting in a transition from a compact to a loose soil structure. Comparing the composition of the soil before and after sewage erosion, it can be observed that the content of montmorillonite, hematite, kaolinite, and other minor minerals decreases compared to the original soil, primarily due to the decrease in column length of reflecting minerals (Hernández-Mendoza *et al*. 2021). The composition of the soil framework structure changes, which is the main factor causing changes in the fundamental physical and mechanical properties of the soil. During the immersion process, organic substances in domestic sewage undergo decomposition. Due to the low oxygen content in water, organic matter mainly undergoes hydrolysis and weak aerobic respiration, producing glucose and a small number of organic acids. When oxygen in domestic sewage is depleted, microorganisms begin anaerobic respiration, resulting in the production of a large number of organic acids and alcohols, making the solution acidic. As the concentration of domestic sewage increases, pH decreases (Karkush and Abdulkareem 2019), enhancing the solubility of water and dissolving mineral and colloidal substances in the soil, accelerating the destruction of the original soil structure.

## 5. Conclusions

This study investigates the impact of different concentrations of domestic sewage on the physicochemical properties of soil by comparing their physical and chemical properties. The effects are analyzed using scanning electron microscopy, X-ray diffraction, and grey relational analysis, revealing the mechanisms of soil pollution by domestic sewage from multiple perspectives including microstructure and mineral composition. The following conclusions are drawn:

- Under the immersion in polluted water, the color of the immersed water changes from black to yellow, and a brownish-yellow secretion appears on the surface of the soil sample. The water content, specific gravity, density, and pore ratio index of the soil sample immersed in 50% and 100% domestic sewage decrease with the increase in sewage concentration, while the liquid limit of the soil sample exhibits the opposite trend. The physical properties of the soil sample immersed in tap water remain stable within a certain range after immersion.
- The immersion time in tap water has little effect on the slope of the compression curve of the soil sample, whereas for the soil samples immersed in domestic sewage, the slope of the compression curve and compression coefficient increase with higher sewage concentration and longer immersion time, while the compression modulus exhibits the opposite trend.
- The soil sample immersed in tap water contains a large number of small particles and cementitious materials, indicating a compact structure. With the increase in domestic sewage concentration, the microstructure of the soil changes significantly. Single particle structures, loose particle arrangement, disorderly stacking, increased and enlarged pores, and a gradual decrease in small particles and cementitious materials are observed, resulting in a transition from a compact to a loose soil structure.
- Based on this study, further settlement and shear tests are needed to investigate the influence of domestic sewage on soil settlement and shear strength. Quantitative analysis of the

mechanisms of soil pollution by domestic sewage will provide theoretical reference for practical engineering applications.

The physical and mechanical properties of contaminated soil studied in this paper, such as water content and compressibility, have a great impact on the bearing capacity of engineering foundation, foundation and soil lateral supporting force. Contaminated soil by domestic sewage will change the physical and mechanical properties of soil, and these changes may lead to the safety and stability problems of engineering structures during long-term use, such as foundation settlement and structural deformation. Therefore, it is very important and necessary to study and analyze the soil polluted by domestic sewage.

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