Correlation Between Occurrence Environment and the Cause of Deterioration at Ancient Earthen Ruins: A Case Study at Shenna Ruins, Qinghai, China

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Research Article

Keywords: earthen ruins, Shenna ruins, geotechnical technique, Correlation, occurrence environment, deterioration

Posted Date: December 13th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-1144811/v1

Abstract

The earthen ruins are precious historical imprints left over from ancient human life and production, and have important cultural values. Chinese ancient ruins are widely distributed, large in number, and numerous in types. Most of the unearthed ruins are large in scale, immovable, and closely related to the surrounding environment. This paper takes the Shenna ruins as the research object, realizes the investigation of the occurrence environment of the ruins through geotechnical survey technology, and explores the reasons for the deterioration of the soil at the ruins of Shenna through the research of the correlation between the occurrence environment and typical diseases. On the basis of traditional cultural relics survey, the geological, environmental characteristics and geotechnical engineering conditions of the ruins were identified, analyzed, and evaluated through survey methods. Combined with indoor experimental analysis, it was found that the main reason for the deterioration of Shenna ruins was the migration of water and salt in the soil caused by seasonal precipitation, and combined with the geotechnical investigation results, the possibility of groundwater damage in this area is eliminated, which provides a research basis for the preventive treatment of water environment in the future protection and restoration of the Shenna ruins, and provided very useful technical application reference and research idea for such earthen ruins protection in Northwest China.

Introduction

The earthen ruins are precious historical imprints left over from ancient human life and production, and have important cultural values. Chinese ancient ruins are widely distributed, large in number, and numerous in types. Most of the unearthed ruins are large in scale, immovable, and closely related to the surrounding environment [1–7].

Through a large number of field investigations and literature reports, it is found that soil sites are threatened by erosion, alkali, wind erosion, surface weathering, rain erosion, cracking and collapse, and salt damage plays an important role in these diseases. The occurrence of soil salt damage is related to many factors, such as salt content, type of salt, water content, soil environment and so on. In long-term practice, researchers have found a close relationship between salt and water in soil sites. Salt only dissolves in water and moves with water migration, resulting in void structure destruction in the process of recrystallization, so that various types of salt diseases can occur [20–23]. Salt migration caused by water migration is the fundamental cause of salt damage.

Salt damage is a very important reason for earthen sites deterioration. However, there are many reasons for salt damage in soil sites. What we pay attention to is the fundamental cause that causes the development of soil salt damage and accelerates the damage of soil salt damage. The water factor in the site environment is the fundamental reason that causes the soluble salt in soil to harm the safety of the site. At the same time, the sources of water factors in the occurrence environment are extremely complex, therefore, the diseases of earthen ruins are greatly affected by the geological, especially hydrological and environmental factors in which they are located, and the protection of the ruins shall fundamentally find scientific solutions to the relationship between the occurrence environment and the causes of the deterioration. The protection of earthen ruins is one of the most difficult in the protection of cultural relics.

The Shenna ruin is located in the Chengbei District, Xining City, Qinghai Province, China. In 2006, the State Council announced it as the sixth batch of national key cultural relics protection units. The ruin is located on a secondary terrace at the intersection of Huangshui and its tributary Beichuan River. The terrace is narrow from east to west and long from north to south. It is a long strip with low south and high north, covering an area of about 100,000 square meters. Its archaeological value is firstly manifested in that it was a hub on the corridor of cultural exchange between the Hexi Corridor and the Western Regions 4000 years ago, names the Qijia culture, which is an archaeological culture of special value in the upper reaches of the Yellow River and an important source of Chinese civilization. It is mainly distributed in the eastern part of Gansu to the west to zhangye and Qinghai Lake area within a range of nearly 1000 kilometers, across Gansu, Ningxia, Qinghai, Inner Mongolia and other four provinces and the communication function of this route during the Qijia cultural period was the main road for the spread of Eastern and Western culture in that period; secondly, the Qijia culture where the Shenna ruin is located is an era of transformation and revolution, mainly based on Qijia culture, with a small amount of Majiayao type, Banshan type and Kayue culture, therefore, it is a representative settlement in this era of transformation and revolution. In 1992 and 2016, the Qinghai Provincial Institute of Cultural Relics and Archaeology conducted archaeological exploration and excavation of 2000 square meters of it, and the excavated area was 2 meters thick, and discovered 171 houses, 358 ash pits, and 19 tombs, it is the site of a Qiang settlement about 3500 years ago, and the relics are very rich.

Geotechnical engineering survey [8–10] is the foundation of the earthen ruins protection engineering design. It is mainly used to identify, analyze, and evaluate the geological, environmental characteristics and geotechnical conditions of the ruins based on the requirements of the earthen ruins protection project and on the basis of traditional cultural relics surveys through a combination of innovative survey and methods. Therefore, this paper takes the Shenna ruins as the research object, and realizes the investigation of the occurrence environment of the ruins through geotechnical survey technology. Through the correlation research of the occurrence environment and typical diseases, the reasons for the soil deterioration [11–13] of the Shenna site are explored.

1 Survey Area

As Fig. 1 is shown, the survey scope of this project is the Shenna Ruins Exposure Zone, which covers an area of 1620 square meters. It is divided into Zone I and Zone II according to the location of the site. Zone I mainly includes 5 excavation pits (No. 1~5). Zone I includes 1 excavation pit (No. 6).

2 Survey And Research Methods

Geotechnical engineering survey is the foundation of the earthen ruins protection engineering design, and the description of the methods mentioned in "Geotechnical and mechanical parameter statistics and values" are carried out in accordance with the provisions of "Code for Geotechnical Engineering Investigation" GB50021-2001, "Technical Code for Geotechnical Engineering Investigation" (YS5202-2004) and "Standard for Geotechnical Test Method" (GB/T50123-2019).

Base on the fully collecting and investigating archaeological excavation data, combined with the geographical characteristics of the occurrence environment of the Shenna ruins, it is carried out using a combination of drone aerial photography, on-site measurement, disease surveying and mapping, sampling and indoor testing. It is mainly drilling, including engineering geological survey [14] and mapping, in-situ testing, sample collection, indoor test survey and other exploration and testing methods combined with comprehensive survey methods to expose the adverse geological effects of the Shenna ruins and assess the stability of the ruins, detailed surveys and investigations are carried out on the types, scales and scope of the existing diseases. The research on the relationship between the occurrence environment and the causes of the typical diseases of the ruins and the evaluation of the development trend of the diseases have laid a research foundation for the research on the governance and protection of the ruins diseases.

2.1 Sampling and Testing Methods for Geotechnical Investigation

The principle of minimum intervention should be adopted, the exploration holes for taking soil samples and conducting in-situ tests along the ruins area shall not be less than 1/2 of the total number of exploration holes, the number of sampling holes shall not be less than 1/3, and a certain number of exploration drilling holes shall be arranged. According to the above principles, the 4 exploration points (4 boreholes) are arranged in a grid according to the surrounding lines and corners of the greenhouse. The number of effective mechanical parameters that meet the coefficient of variation of the main engineering geological layers within the survey depth is not less than 4 groups, for the drill sampling, the mud wall is used for drilling below the water level, the loess thin-walled soil extractor is used for static pressure soil extraction above the water level, and the original sample below the water level is taken from the drilling tool. The in-situ exploration test of the ruins during the investigation can complete the standard penetration test and heavy dynamic cone penetration test in situ, as well as the conventional test of soil samples, collapsibility test, self-weight collapsibility test, permeability test, soil corrosion analysis of the ruins, and rock compressive strength analysis test etc.

Tab. 1 Summary Sheet of Workload Completed in Exploration

Items	Content	Unit	Workload
Disease photo shooting	UAV aerial photography	Piece	100
	Camera shot	Piece	120
Surveying and mapping	Field measurement	Working day	20
	Disease mapping and measurement	m^2	1620
Exploration point measurement and release	4	Point	4
Well drilling	4	m/hole	82m/4
Sampling	31	Group	31
Indoor test	31	Group	31

2.1.1 Permeability Coefficient

This time, the five locations were selected for the double-loop method to determine the permeability coefficient of the vadose zone. The test points were all located at the periphery of the Shenna ruins. The test method was to clear the test points and press the concentric iron rings with the outer ring diameter of 50 cm and the inner ring diameter of 25 cm into the soil body 10cm, the ring wall is in close contact with the soil layer, and the inner ring is covered with 2~3cm filter coarse sand. During the test, water is added to the ring space between the inner ring and the outer ring to keep the water level at 10cm. The infiltration water volume of the inner ring is used as the flow rate for calculating the permeability coefficient, and the permeability coefficient of the vadose zone is calculated by the water seepage formula.

Formula:$K=QL/\{F(H_k+Z+l)\}$

Among them: K-permeability coefficient m/d, Q-stable infiltration water volume m³, F-inner ring water area m^2, H_k =-capillary pressure, L-infiltration depth.

when the water column is equal to 10cm, the head gradient can be considered close to 1. (K=V)

2.1.2 Statistics and Value of Geotechnical Physical and Mechanical Parameters

The physical and mechanical properties of each layer are counted according to the layered rock and soil, and the obvious discrete data caused by the unevenness or interlayer of the rock and soil layer is eliminated.

2.1.3 Indoor Test Analysis

The samples from the east side (SN-A), west side (SN-B), south side (SN-C), and north side (SN-D) of the excavated area were taken from the bottom, middle and upper parts of the excavated area. The moisture content, element composition and salinity of the ruins soil body were analyzed and tested.

pH meter: select three paintings with different sunlight intensity, water erosion degree, and different locations to use a non-destructive acid tester (Sartorious PB-10, Sartorious Scientific Instruments Co., Ltd., China) to test the pH of the paper. The samples are all measured at three different points.

Moisture content: in accordance with the national standard SL237-003-1999 test method

Microscopic morphology and element composition: the inspections of SEM, XRF were carried out with the collected samples from the east side (SN-A), west side (SN-B), south side (SN-C), and north side (SN-D) of the Shenna Ruins.

SEM: The crispy silt obtained at the Shenna ruins is kept in its original form under low vacuum for electron microscope observation. Scanning electron microscope (SU3500, Hitachi High-Tech Co., Ltd.) is used to analyze the microscopic morphology and element composition and distribution of paper and pigments for testing, the gold spraying time of the sample is 80s, the test condition is in vacuum mode, and the scanning voltage is 5-15KV.

XRF: use XRF-1800 X-ray fluorescence spectrometer produced by Shimadzu Corporation of Japan for analysis, X-ray tube target: rhodium target (Rh), X-ray tube voltage: 40KV, X-ray tube current: 95mA, power: 3KW. Grind the sample soil in a mortar and fully dry it to a constant quality in a vacuum drying oven at 105 degrees Celsius, and it is used for analysis after sieving the sample soil.

2.1.4 Salt Analysis

Researching the types and content of soil salt is of great significance to understanding the occurrence of diseases in soil ruins. The primary minerals in the soil undergo slow weathering under the action of the external environment to generate a large number of secondary minerals, and there are a large amount of soluble salt in the generated secondary minerals, which crystallize under the action of soil moisture. The dynamic changes of crystallization-dissolution-crystallization, along with such changes, the soil has produced a series of changes in physical properties, and the effects of different contents and different types of salt are very different.

Ion chromatographic analysis: ICS-1500 ion chromatograph (Dion Corporation, USA), the collected samples are dried at 105 degrees Celsius after the impurities are removed, ground and sieved, and 0.1000g soil sample is accurately weighed to dissolve in 10mL ultrapure water (18.2mΩ/cm), put the beaker in an ultrasonic cleaner and sonicate for 30min, then pour the soil solution into a 25mL centrifuge tube, centrifuge at 8000r/min for 10min, the ion chromatography test solution was prepared by filtration with the 45μm filter head. Anion analysis: Dionex IonPac AG9 guard column and IonPacAS9-HC anion separation column, eluent is 12.0 mmol/L Na2CO$_3$, flow rate is 1.0 mL/min, AMMS ▯ anion suppressor, injection volume is 10 μL. Cation analysis: Dionex IonPac CG12 guard column and IonPac CS12A-HC cation separation column, eluent is 20.0 mmol/L methanesulfonic acid, flow rate is 1.0 mL/min, CSRS-300 electrochemical suppressor, injection volume is 10 μL.

Conductivity analysis: Dry the soil sample at 105 degrees Celsius and pass it through a 20-mesh sieve. Weigh 10g of the soil sample into a 100 ml beaker, and then add 50 ml of ultrapure water to the beaker (water-soil ratio is 5:1). Oscillate on a shaker for 3 minutes and let it stand for 30 minutes, put a small amount of soil suspension in a small beaker, and conduct a conductivity test according to the conductivity meter operating procedure.

3 Results And Discussion

Through investigation and research on the topography, stratum and lithology characteristics of the ruins, geological structure, groundwater and surface water, and unfavorable geological phenomena, the results show as follows:

3.1 Topography, Geomorphology and Geological Structure

The Shenna Ruins are located in the north of Xiaoqiao Village, Chengbei District, Xining City, Qinghai Province, they start from a shady slope in the north, to Fenmugou in the south, to Luangou in the west, and the Ningzhang Highway underneath the eastern platform. The entire ruins are long from north to south and narrow from east to west, the terrain in the area has small undulations. The geomorphic unit is the second terrace at the intersection of Huangshui and its tributary Beichuan River. According to the research results of "Northwestern Region Stability Evaluation Map" ("Northwestern Region Engineering Geology Map Manual"), the area where Shenna Ruins are located has no signs of structural development, and it is a relatively stable block with no active faults in the area, and the strata of the ruins is stable.

3.2 Meteorology and Hydrology

The ruins are within the range of the Huangshui River, the distance is 0.6km away from the Huangshui River. The flood season of the Huangshui River is from May to September, and the main flood season is from July to August. The survey period is a dry period, according to the survey data of the area where the ruins are located, the aquifer is the unpressurized pore water in the Quaternary medium dense round gravel layer, the absolute elevation of the stable groundwater level is 2338.01~2338.79m, the average elevation is 2338.4m, and the stable water level buried depth is 32.8 ~33.2m, with an average depth of 33.0m, the amount of groundwater is large, and it is mainly recharged by atmospheric precipitation and upstream flow, the flow direction is from southwest to northeast, and groundwater replenishes river water. According to the data, the water level varies between 0.50-1.00m during the wet and dry seasons. The permeability coefficient of the aquifer is 30.0m/d. Within the depth of 25m in the Shenna ruins area, the influence of groundwater may not be considered.

In addition, the area where the Shenna Ruins are located has a continental climate of arid and semi-arid plateau, with high altitude, low air pressure, small precipitation, large evaporation, long freezing period, short frost-free period, large daily temperature difference, strong ultraviolet rays. The annual average temperature is 2.6~5.3℃, the annual frost-free period is 140~150 days, and the annual average precipitation is 527.6mm (as is shown in Fig.2). The maximum rainfall per hour is 47.7mm, the average evaporation for many years is 900~3000mm, and the average humidity for many years is 61%. Therefore, it can be inferred that the precipitation factor of the site's occurrence environment will be the key water environment source.

3.3 Soil Geotechnical Characteristics and Permeability

Within the survey depth of this ruins area, it is Quaternary Upper Pleistocene (Q3al-pl) alluvial deposits. The foundation soil is divided into 3 layers from top to bottom: the surface is plain fill, the upper part is collapsible loess, and the lower part is non-collapsible loess, and the lithological characteristics of each layer are as follows:

① Plain fill (Q4ml): earthy yellow, yellow-brown. The main ingredient is silt. It contains plant roots and is widely distributed in the field. The thickness is 1.10～1.50m, and the average is 1.33m, the bottom elevation is 2272.85～2273.20m, and the average is 2273.08m, the depth of the bottom is 1.10～1.50m, and the average is 1.33m.

② Collapsible loess (Q32al-pl): yellowish brown, brownish yellow. It is mainly in brown-yellow tones, the soil is mainly composed of powder particles, and the content of powder particles accounts for more than 60%. The root system of the upper plant is well-developed, with wormholes and large pores. The 3mm soil strip is easy to break when rubbed by hand, and it has a slightly sandy texture when pinched by hand. The soil is relatively uniform, slightly dense to medium dense, slightly wet to wet. The shaking response is moderate, the dry strength is low, and the toughness is low. The layer is distributed stably and the field is generally distributed, with a thickness of 16.00～17.95m, an average of 17.50m, an elevation of the bottom of the layer 2255.25～2257.05m, an average of 2256.40m, and a buried depth of 17.50～19.25m, an average of 18.00m.

③ Non-collapsible loess (Q32al-pl): brownish yellow. The particle size component is mainly composed of powder particles, which are easily broken by hand rubbing into 3mm soil strips. There is a sticky feeling of sand when pinched by hand. The powder particles account for more than 50%. It is slightly wet to wet, the density is slightly dense and medium dense, the soil is relatively uniform, the lower part contains sand and gravel, and the structure is relatively loose. The shaking response is moderate, the dry strength is low, and the toughness is low. The field is generally distributed, and the maximum exposure depth is 2.75m, which is not exposed.

Tab. 2 List of Permeability Coefficient of the Shenna ruins

Test location	Permeability coefficient (cm/s)	Test section lithology	Permeability evaluation
4m to the south Area	6.60×10^{-4}	Fill soil	Weakly
10m to the south Area	4.37×10^{-4}	Fill soil	Weakly
3m to the north Area	6.39×10^{-4}	Fill soil	Weakly
10m to the north Area	3.08×10^{-4}	Fill soil	Weakly
5m to the west Area	4.17×10^{-4}	Fill soil	Weakly

As the list of permeability coefficient of the Shenna ruins indicted that the ruins are located on the secondary terrace, and the soil permeability coefficient of the soil at the ruins is found to be weak, the groundwater has a negligible impact on the ruins and combined with the hydrological data, we can preliminarily exclude the possibility of groundwater damage in the area where the site is located, and speculate that the wet environment and water damage of the site are mainly from seasonal precipitation. It provides a research basis for the preventive management of water environment in the later period of the site.

3.4 Evaluation of Soil Corrosion and Soluble Salt

According to the exploration hole in the field area, each section of the soil is taken to analyze the soluble salt, according to the evaluation clause of the ruins soil corrosion in the "Geotechnical Engineering Survey Code" (GB50021-2001) (2009 Edition). According to the environmental conditions of the ruins, the corrosiveness of ruins is evaluated.

As the Fig. 4 is shown, the pH value of the soil is 8.4-8.5, the content of SO_4^{2} in the soil is 360.00-600.00mg/kg, the content of HCO^{3-} in the soil is 360.00-430.00 mg/kg, the content of Cl in the soil is 230.00-400.00mg/kg. It can be seen from the contents of various soluble salts in the figure 4 that there are a lot of soluble salts in different sampling locations of the site, and the total salt content is as high as 17%-23%. The environmental type of the ruins is considered as Category III, and the soil on the ruins is slightly corrosive.

3.5 Microstructure of the Ruins and Soluble Salt Analysis

From the SEM morphology (Fig.5), it can be clearly observed that there is a large amount of soluble salt in the interstitial soil particles on the surface of the crisp powder. When a large amount of soluble salt precipitates on the surface of the ruins, the ruins will have whitening and lose its original appearance and cause alkali disease [15-17]. These slightly soluble and soluble salts filled between the soil particles, under the influence of the external temperature and humidity and the moisture inside the earthen ruins, on the one hand, through physical action, that is, the soluble salt in the pores can repeatedly crystallize-dissolve-recrystallize, the process of continuous squeezing of the pores of the surrounding soil can result in the destruction of the surface structure of the earthen ruins and the shedding of crisp powder.

On the other hand, through chemical action, that is, water and carbon dioxide in the air and some acid gases have complex chemical reactions with the salt in the soil and soil minerals, which change the original stable material composition, resulting in changes and reductions in the soil structure, and the agglomeration force of the soil causes the crumbs to fall off the surface under the action of air flow and gravity. However, salt is a very important reason for earthen sites deterioration which is only dissolves in water and moves with water migration, resulting in the process of recrystallization. Salt migration caused by water migration is the fundamental cause of salt damage. Therefore, it is of great significance and value to explore the water factors in the environment of ruins.

Tab. 2 the mineral composition analysis results of the soil samples at Shenna ruin

XRF sample	SiO_2%	CaO%	Al_2O_3%	K_2O%	SO_3%	Na_2O%
SN-A	46.82	19.13	10.35	5.23	2.83	3.14
SN-B	51.01	18.23	10.16	5.03	2.42	2.84
SN-C	50.62	17.63	9.83	3.98	3.05	2.53
SN-D	49.18	16.75	10.18	4.23	2.52	2.34
EDX sample	Si%	Ca%	Al%	K%	S%	Na%
SN-A	48.02	19.45	11.45	7.63	3.06	2.75
SN-B	53.30	17.32	11.23	7.32	2.87	2.53
SN-C	51.89	17.62	10.52	4.82	3.13	2.21
SN-D	52.76	17.93	11.28	5.84	2.93	2.07

In addition, from the comparison of the mineral composition analysis results of the soil samples (as Tab.2 is shown), it shows that the crispy soil sample on the surface of the Shenna ruins contains gypsum, which further shows that the soluble salt on the surface of the soil at the Shenna ruins is mainly $CaSO_4$ [18-20]. It and NaCl are the main salts that cause soil salinization and will destroy the structure of the soil. Among them, the sulfate in the soil expands with the change of temperature, which makes the soil soft. Gypsum not only makes the soil soft, but also forms gypsum ($CaSO_4 \cdot 2H_2O$) after hydration of anhydrite ($CaSO_4$), which expands in volume during the hydration process, causing soil loosening and into crisp powder. In the sulfate crystal structure, the complex anion SO_4^{2-} has a large radius (2.95Å), when combined with the small radius cations Ca^{2+} (1.05Å) and Na^+ (0.98 Å), it is easy to surround the cation with a layer of water molecules to form a more stable water-containing sulfate. When they precipitate from the interstitial solution of the earthen ruins, the large gaps become smaller, and the small gaps expand and squeeze the adjacent particles, and the void structure is destroyed. For example: gypsum ($CaSO4•2H_2O$) not only makes the soil soft, but also anhydrite ($CaSO_4$) will form gypsum after hydration, which expands by 60% during the hydration process, which is a kind of the important exothermic reaction causing volume change, which results in soil loosening and crispy powder. Thenardite (Na_2SO_4) becomes mirabilite ($Na_2SO_4•10H_2O$) after hydration and crystallization, and its volume expansion is 3.1 times of the original.

Tab. 3 Ions content of the soluble salt and conductivity in different sampling location at Shenna ruins

Sampling location	Ions content of the soluble salt （$g•kg^{-1}$）		conductivity（ms/cm）	
	crisp powder area	uncrisp powder area	crisp powder area	uncrisp powder area
SN-A	17.41	4.54	5.82	1.43
SN-B	11.77	4.21	5.28	1.74
SN-C	14.23	3.17	5.23	1.52
SN-D	18.14	3.62	6.85	1.63

The salt content of the soil in different areas of the ruins was compared (as Tab. 3 is shown), the research found that the salt content of the exfoliated soil in the crispy powder area was much greater than that in the non-crispy powder area, which indicates that under the combined action of evaporation and capillary action, the salt migrates from the inside of the ruins to the surface of the ruins and continuously accumulates on the surface of the ruins. The surface salt is periodically dissolved and crystallized under the combined action of environmental temperature and humidity and moisture in the ruins. It continuously exerts force on the soil, and the long-term force leads to the destruction of the soil skeleton, weakening the agglomeration force of the soil, and finally falling off the surface of the ruins under the dual effects of air flow and gravity attraction.

The ion content of soil in different sampling location at Shenna ruins (Tab.3) shows that the highest conductivity of the soil in the crispy powder area reached 6.85 ms/cm, while the highest conductivity in the non-crispy powder position was only 1.74 ms/cm, indicating that the leaching solution of the soil of the crispy powder area contained a large amount of soluble salt ions, but there are few free ions in the leaching solution of the non-crispy powder soil, and the test results of electrical conductivity are consistent with the test results of soluble salt content, which once again shows that there is a large amount of soluble salt in the soil in the area where the crisp powder occurs at the ruins.

Tab. 4 Ion content of soil in different sampling location at Shenna ruins（$mg·L^{-1}$）

Sampling location	Anion			Cation			
	Cl^-	NO_3^-	SO_4^{2-}	Na^+	K^+	Mg^{2+}	Ca^{2+}
SN-A	11.0287	11.2244	157.9967	41.0894	1.1840	35.0987	158.3572
SN-B	19.8219	12.5318	129.5034	50.3222	1.2381	34.5045	192.5225
SN-C	19.5310	8.4453	187.5635	67.5365	1.0326	29.5300	224.2424
SN-D	25.3951	9.4610	184.6944	48.9909	0.9904	26.9119	142.8778

It can be seen from the Tab.4, it shows that the content of SO_4^{2-} in the anions in each test area of the ruins is relatively high, and the content of Ca^{2+} and Na^+ in the cations is relatively high. This is mutually corroborated by the elemental analysis results of soluble salts. It can be inferred that the soluble salts $CaSO_4^{2-}$ and $Na_2SO_4^{2-}$ caused the crispy powder and salt precipitation of the soil at the ruins. In addition, a certain amount of NO^{3-} in the ruins may be related to the high content of organic matter in the ruins. It is speculated that the organic nitrogen in the soil is converted into inorganic salt form through the nitrification of microorganisms. The chloride and magnesium salts obtained by ion chromatography also proved our inference.

3.6 Correlation Between Occurrence Environment and the Cause of Deterioration

In 1995, a temporary protection shed was built in the excavation area of the Shenna ruins. The protection shed covered the important foundations of the first excavated ruins and played an important role in protecting cultural relics. The key protected areas such as the Shenna ruins excavation area are in a semi-enclosed "indoor" environment. Because the ruins are located in northwestern China, the Xining City has more rain in summer than in other seasons, and water vapor constantly gushes out of the ground, as a result, the internal humidity of the ruins is relatively high in summer and the ventilation facilities are simple, they only rely on the top window for ventilation, and the ventilation facilities cannot effectively improve the ventilation conditions in the ruins. Therefore, the occurrence environment of the ruins in the temporary protection greenhouse is characterized by high humidity and heat in summer, and dry in autumn and winter, and the soluble salt in the soil moves with the water to cause salt precipitation, crispy powder and other diseases of the soil ruins.

More importantly, the Shenna ruins are in a special environment, and shallow surface water is still active in the ruins. Therefore, the soluble salt in the soil continuously migrates and accumulates to the surface soil layer of the ruins along with the movement of shallow water [19]. In fact, the harm of soluble salt to the ruins is obvious, especially in winter, the annual average temperature of the area is 2.6~5.3℃, the temperature difference between day and night is large, and the annual minimum temperature is around minus 20 degrees, the freezing and thawing expansion is severe in winter, when the water content of the soil is high, the freezing and thawing expansion will inevitably occur, which will also cause the expansion of the soil and make the surface powdery [22]. At the same time, due to the differences in the mineral components contained in the soil itself, different minerals have different thermal expansion coefficients, under the conditions of rapid temperature changes, differential expansion occurs, which makes the structure of the soil loose and its strength decreases.

Among them, the main reasons for the shedding of pit wall pieces of the ruins are preliminarily inferred as follows: □The excavation of the pit resulted in the destruction of the pit wall structure, the stability and balance being broken, and the partial shedding of the pit wall soil, □The upper soil of the pit wall is mainly filled with soil and the structure is loose. When the excavation pit is excavated, this part of the soil is very easy to fall off or even collapse, □ The splitting action of the plant root system accelerates the fall of the pit wall fill. On the other hand, the ruins survey results found that there were many cracks in the soil at the ruins, including vertical penetration cracks, zigzag diagonal cracks, and longitudinal cracks on the top surface. The length of the crack is generally 0.5~4.1m, the opening is 1~40mm, and there is no filling inside. The cracks cut the ruins and partially penetrated each other, reducing the overall strength of the excavated pit wall, and even led to the collapse of the pit wall.

The cracks are the conditions for the occurrence of collapse, the main reasons for the cracks are as follows: □Unloading influence: During the archaeological excavation, the balance of the preservation of the site was broken. From the excavation to the construction and protection of the exhibition hall, due to the unloading effect, multiple cracks were formed in the pit wall. □Shrinkage and cracking: After the excavation of the soil beam, the internal water evaporates and loses continuously, causing the soil to shrink and crack. Cracking first produces tiny cracks, under the influence of various factors such as external man-made disturbances and salt content, the tiny cracks continue to develop into wide cracks, the further extension of wide cracks creates local dangerous soils, in the absence of timely measures, it can easily cause diseases such as soil collapse. □The effect of temperature difference: the temperature is an indispensable factor for the occurrence, development and aggravation of various diseases. Although there is a protection hall, the indoor temperature difference still exists, which provides extremely favorable conditions for the occurrence, development and aggravation of various diseases, the cracks and flaky peeling are inseparable from the effect of temperature. During the development of cracks, the temperature difference plays an indispensable role, in the development of flaky denudation, it is the difference in temperature that causes the shrinkage of the mud skin, which lays a good material foundation for the later denudation, the difference caused the migration of salt and the uneven shrinkage and looseness of the rammed soil at the ruins, which provided a prerequisite for the further development of this disease. □ Man-made disturbance: The ruins survey found that the top of the soil barrier beam was the working channel for the on-site archaeological staff, walking back and forth caused the load on the top of the soil barrier beam to increase, and at the same time caused certain disturbances, which made the soil barrier beam easier to produce smoothness, in addition, man-made disturbances also have a certain influence on the development of the cracks in the soil beam crack, the combined action of multiple factors results in the development and extension of the cracks. □The role of herb vegetation: the splitting effect of plant growth on the wall of the pit will also accelerate the development of the original cracks or produce new cracks. The existence of various cracks on the wall of the pit provides a good channel for the leakage of water. Due to the lack of drainage system in the field, rainwater seeps along the cracks, increasing the static earth pressure of the rock and soil on the wall of the pit, causing cracks, Various cracks reduced the overall stability of the pit wall, and reduced the ability of the pit wall to withstand dynamic loads such as earthquakes and strong wind, The staggered combination of various cracks on the pit wall develops, cutting the pit wall to form a dangerous block, which accelerates the destruction of the pit wall.

To sum up, the main reason for the salt damage of the Shenna ruins to cause the soil crispy powder is due to the volume change caused by the repeated dissolution shrinkage-crystal expansion-dissolution shrinkage process of the soluble salts $CaSO_4^{2-}$ and $Na_2SO_4^{2-}$ in the soil of the ruins body, and the crystallization pressure directly destroys the aggregate structure of the soil, increases the distance between soil particles, reduces the agglomeration of the soil, and causes the phenomenon of soil crispy powder. In view of the weak influence of groundwater at the Shenna ruins on the ruins, the excavation area and other key protected areas were in a semi-enclosed "indoor" environment, the high salt content soil has the strong hydrophilicity and has a strong ability to absorb moisture in the air and the seasonal precipitation caused the water movement in the ruins, the soluble salt migrate with the water is the main reason that caused the salt damage and crisp powder in the soil.

4 Conclusion

Availability of data and materials

The datasets used and/or analysis results obtained in the current study are available from the corresponding author on request.

Funding

The authors gratefully acknowledge the financial support by the National Natural Science Foundation of China (No. 22102094), Social Science Fund project of Shaanxi Province (No. 2021G008), the Fundamental Research Funds for the Central Universities (GK 202103061, GK 202103058) and the Key Research and Development Program of Shaanxi Province, China (No. 2021SF-457).

Authors' Contributions

Conceptualization, Juan li Wang, Xiao lian Chao, Yu hu Li and Jing Cao, Data curation, Yan Rong, Ying Zhang, Xiao lian Chao, Xue Feng, Jing li Yu and Jian Liu, Formal analysis, Bing jie Mai and Jing Cao, Funding acquisition, Juan li Wang, Yan Rong, Bing jie Mai and Jing Cao, Investigation, Juan li Wang, Yan Rong, Ying Zhang, Xiao lian Chao, Xue Feng, Jing li Yu and Jian Liu, Methodology, Juan li Wang, Jian Liu, Bing jie Mai and Yu hu Li, Project administration, Yu hu Li, Resources, Jian Liu, Writing – original draft, Juan li Wang, Writing – review & editing, Jing Cao. Yu hu Li, Bing jie Mai and Jing Cao have contributed equally to this work.

Conflict of interests

The authors declare that they have no conflicts of interest related to this work. We declare that we do not have any commercial or associative interest that represents a conflict of interest in connection with this work submitted.

Declarations

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Figures

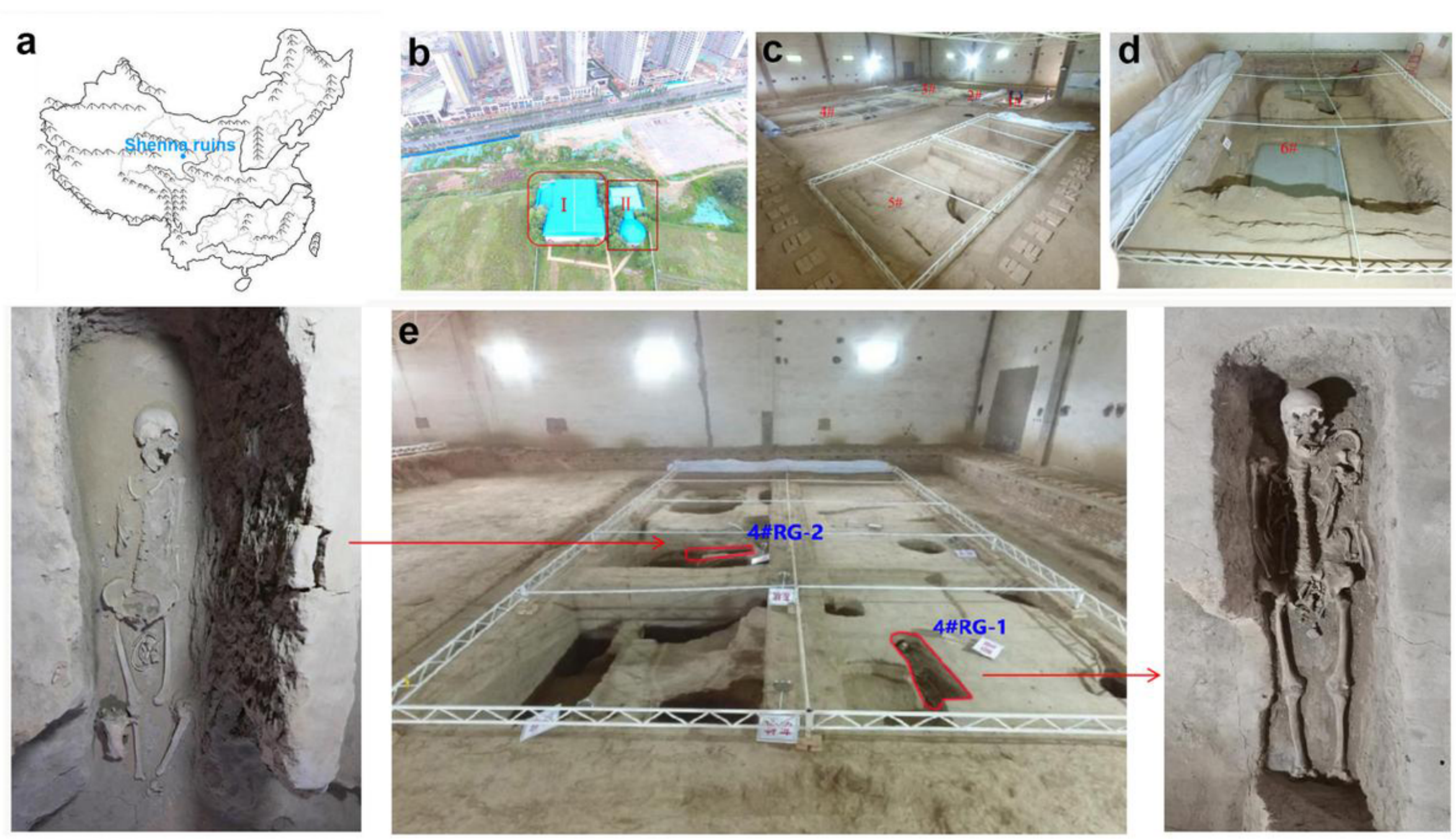

Figure 1

Survey Area of Shenna ruins, China (a Location map of Shenna ruins b Exposure Zone I, c excavation pits 1-5 in Exposure Zone I, d xcavation pits 6 in Exposure Zone II, e the unearthed human bones in Exposure Zone I)

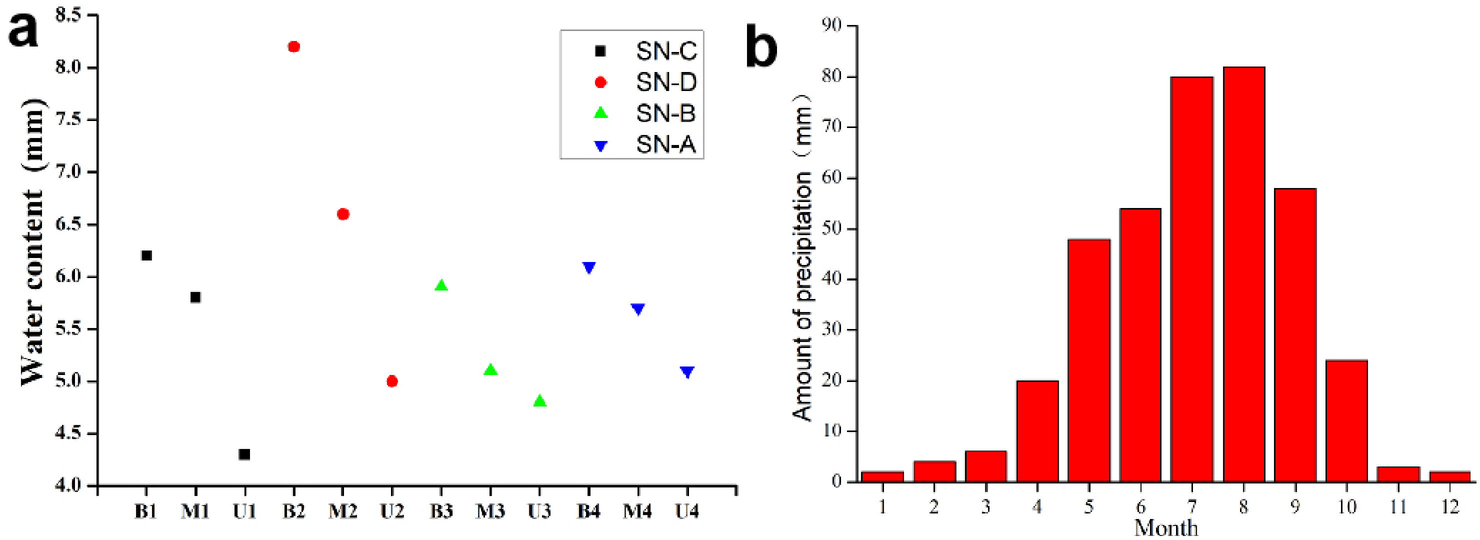

Figure 2

Soil moisture content of the Shenna ruins (a) and linear equation of perennial precipitation of Xining, Qinghai(b)

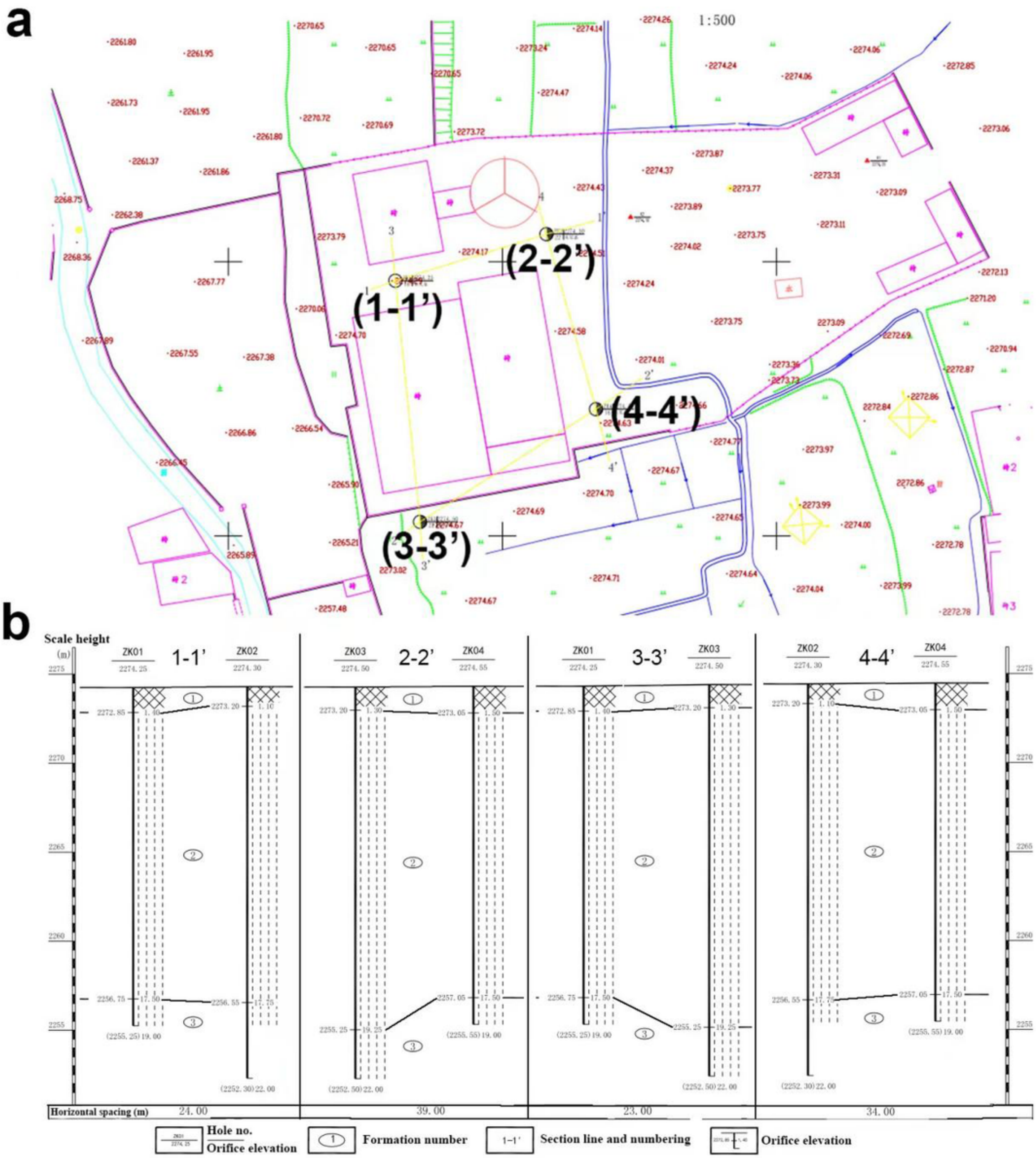

Figure 3

The borehole locations in the ruins (a) and the Simplified geological stratigraphy observed (b) in the borehole(1-4).

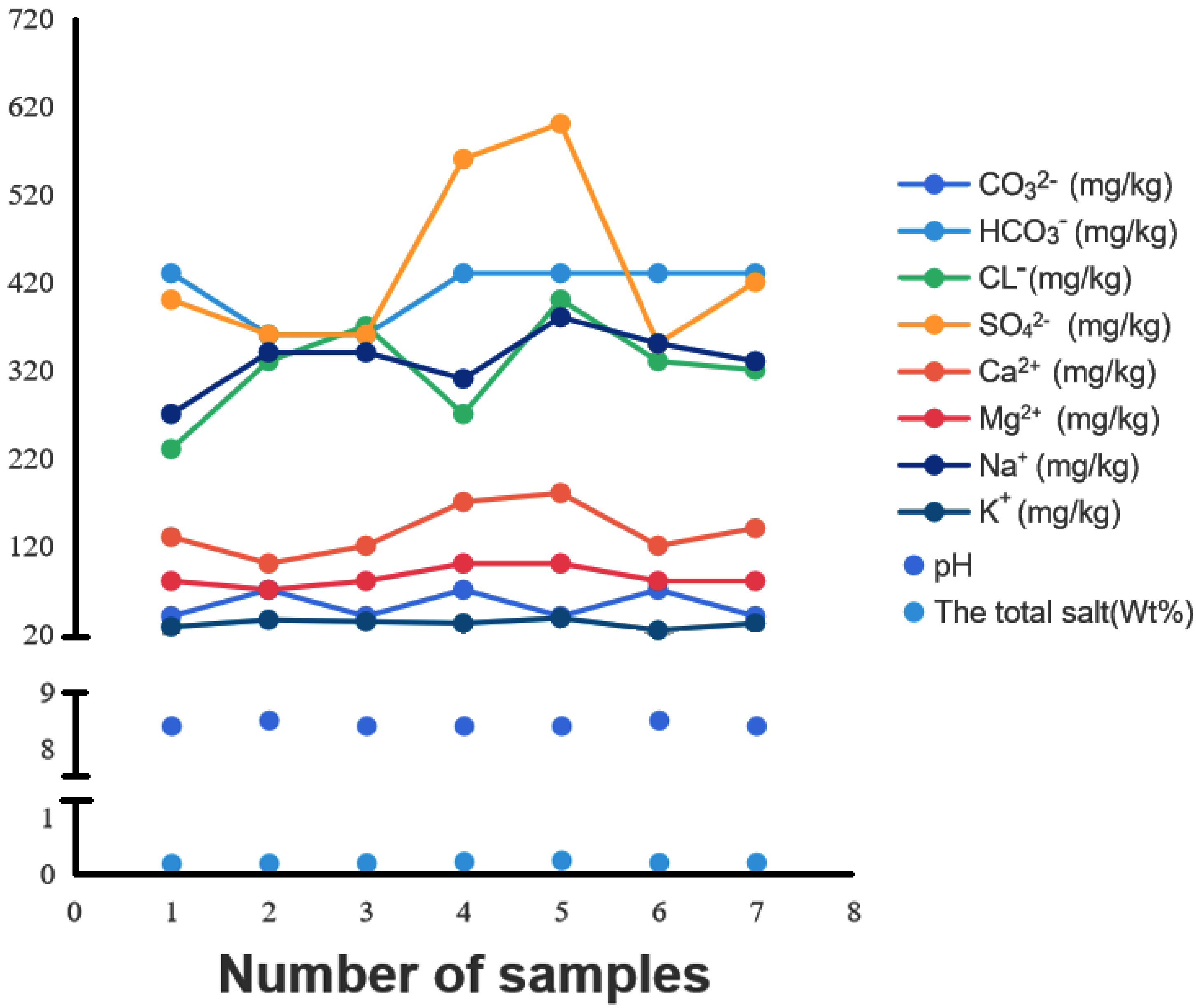

Figure 4

Different types of soluble salt content, pH and total salt content of the Shenna ruins in different sampling sites

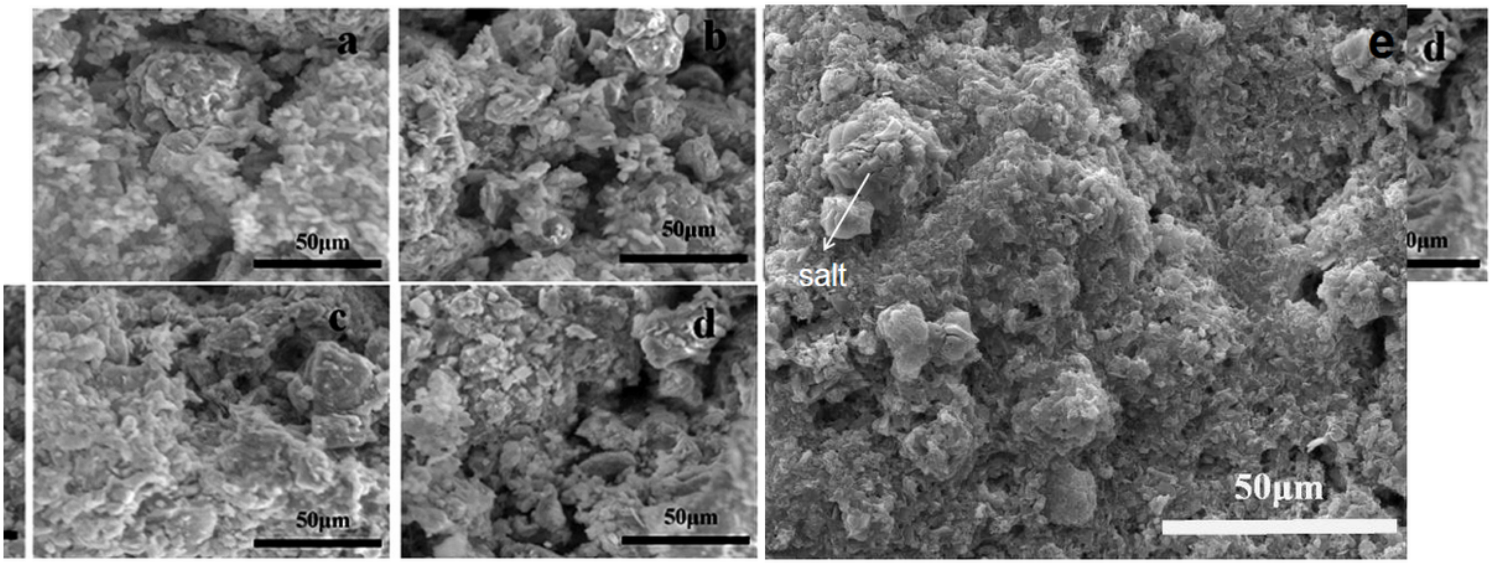

Figure 5

SEM morphology observation of crisp soil samples of SN-A (a), SN-B(b), SN-C(c), SN-D(d) and salt (e) at Shenna ruins.