Characteristics and trends of water quality in underground caverns in island

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Abstract. Underground caverns can be used as a supplementary water resource in those islands away from the continent. The groundwater quality is then becoming an important condition for ensuring the safety of water supply. Based on the water quality monitoring data from April 2017 to July 2019, the trend of water quality indices such as pH, COD₅₆o(permananate index), NH₃-N(ammonia nitrogen), turbidity, TN(total nitrogen), TP(total phosphorus) and chloride were analysed by Kendall-trend-test method. The Pearson-correlation-method is also used to analyse the relationship among these indices in this study. The results show that: (1) For different forms of underground caverns, the concentration of pollutants and the number of bacteria in fully closed cavern is relatively low compared to the semi-closed cavern, the total number of bacteria is only 9 CFU/mL, and the DO(the dissolved oxygen) is as low as 5.12 mg/L. The concentration of pollutants in underground caverns with surface water is higher than the rainwater, which demonstrates that the groundwater quality is actually worse than the water source. (2) The water quality of underground caverns will change variously with time. The concentrations of COD₅₆o and NH₃-N will decrease gradually with time, the TN will increase gradually, the concentration of TP will decrease significantly in fully closed caverns, while it will not change too much in semi-closed caverns. (3) Correlation analysis showed that there was no significant relationship among TP, TN and chlorophyll in different forms of caverns. In order to ensure the safety of water quality, the underground caverns should be disinfected, sterilized, and moreover, the sludge should also be cleaned up regularly.

1. Introduction
Groundwater reservoir refers to the use of underground water storage space to artificially construct a special caverns with the function of storing and regulating groundwater[1]. Compared with surface reservoirs, underground caverns have the advantages of less evaporation and low risk of water pollution, and can also achieve the purpose of supplementing and regulating the spatial distribution of water resources[2]. Therefore, it has a wide range of applications at water-deficient areas.

The island area is limited by the area of the rain collection and the conditions for building the reservoirs. The fresh water resources is relatively lacking, and now the underground caverns is an important exploration to alleviate the contradiction between water supply and demand in the island area. At present, there have been many studies on the water storage technology and the current water quality...
of groundwater at domestic and foreign. In 1972, Japan built the world's first groundwater caverns in the island of Kashima, Nasaki-cho, Nagasaki, in response to water shortages and seawater intrusion[3]. After the 1980s, the United States began to implement the "Aquifer Storage and Recovery (ASR) Project", which injected water into a suitable aquifer through a water injection well and pumped it to use[4]. However, the change of water quality after storage in the groundwater caverns has become an important issue affecting water safety, and has gradually received attention. At present, the research on the water quality of groundwater reservoir is mainly a simple analysis of the current water quality[5,6,7], there is still no relevant report on the trend and regularity of water quality change.

As an important island city in China, Zhoushan City has realized the storage of 35 groundwater caverns in six remote islands by transforming abandoned islands in recent years. The annual effective water supply capacity is 70,000 m$^3$, which is especially important to ensure the safety of water storage in the caverns. This study takes the typical island underground caverns of Zhoushan City as the research object, and monitors the water quality data from April 2017 to July 2019. Study the variation law of water quality in underground caverns through the analysis of the continuous water quality data, summarizing treatment measures, providing a theoretical reference for ensuring the safety of water storage in the underground caverns.

2. Materials and methods

2.1 Research area
There are four island underground caverns in this research study area, such as cavern 1, cavern 2, cavern 3, and cavern 4 (Figure 1). The cavern 1 is 135 m long, 2.4 ~ 3.4 m wide, and 0.6 ~ 2 m high, and the hole is completely closed. The cavern 2 is 73 m long, 2.4 ~ 3.4 m wide, 1~1.55 m high, and the hole is semi-closed. The cavern 3 is 200m long, 6m wide and 3m high, and the hole is semi-closed. The cavern 4 is 100m long, 2.5m wide, 2m high, and the hole is semi-closed.

2.2 data collection
Sample collection uses environmentally-friendly samplers and environmentally-friendly sample bottles to collect water samples in underground caverns. Water quality, dissolved oxygen (DO), pH and turbidity are measured on-site using water quality multi-parameters. Indoor analysis of water quality indicators includes total nitrogen (TN), ammonia nitrogen (NH$_3$), nitrate nitrogen (NO$_3^-$), total phosphorus (TP), permanganate index (COD$_{Mn}$), chemical oxygen demand (COD), zinc (Zn), manganese (Mn), chloride and chlorophyll a.
2.3 research method

2.3.1 Pearson correlation analysis

To test whether \( \rho \), the linear correlation between variables \( X \) and \( Y \), is zero against a given alternative hypothesis, the following product-moment statistic was defined by Karl Pearson [8]:

\[
r = \frac{\sum_{i=1}^{n} (X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n} (X_i - \bar{X})^2 \sum_{i=1}^{n} (Y_i - \bar{Y})^2}}
\]  

(1)

Where \( X_1, \ldots, X_n, Y_1, \ldots, Y_n \) and \( \bar{X} \) and \( \bar{Y} \) denote random samples of size \( n \) for variables \( X \) and \( Y \) and the corresponding sample means, respectively. In the parametric approach, the calculation of the probability of significance for \( r \) is based on a \( t \)-test with \( n-2 \), i.e.,

\[
t(n-2) = \frac{r}{\sqrt{\frac{1-r^2}{n-2}}}
\]  

(2)

The null hypothesis of no linear correlation between \( X \) and \( Y \) is not true when the two variables covary positively (i.e., \( \rho > 0 \)) or negatively (i.e., \( \rho < 0 \)). Recall that a small (large) value of \( X \) is likely to be associated with a small (large) value of \( Y \) when \( \rho > 0 \), whereas a small (large) value of \( X \) is likely to be associated with a large (small) value of \( Y \) when \( \rho < 0 \). In hypothesis testing, we consider both the case of a one-tailed alternative and that of the two-tailed alternative. For the Lake Erie data, parametric linear correlation analysis was carried out with SAS procedure CORR (SAS Institute 1990a). In the simulation study, it was incorporated in a computer program performing the permutational Mantel analysis on the derived Euclidean distances.

2.3.2 Seasonal Kendal test

(1) Principle of seasonal Kendall test

The seasonal Kendall test is a water quality assessment method first proposed by Hirsch in 1984 [9]. The principle of the seasonal Kendall test is to compare the water quality data for the same month over the years. If the value of the following year is higher than the previous value, it is marked as "+1", the value less than the previous value is marked as "-1", and the same value is marked as "0". If the number of "+1" is more than the number of "-1", it may be an upward trend. Conversely, if the number of "-1" is more than the number of "+1", it may be a downward trend.

(2) Technical means of seasonal kendall test

The null hypothesis \( H_0 \): The random variable water quality indicator detection data is independent of time.

The n-year p-month water quality indicator detection data arrangement matrix is:

\[
X = \begin{bmatrix}
a_{11} & a_{12} & L & a_{1p} \\
a_{21} & a_{22} & L & a_{2p} \\
L & L & L & L \\
a_{n1} & a_{n2} & L & a_{np}
\end{bmatrix}
\]  

(3)

Where: \( a_{11}, a_{21}, \ldots, a_{np} \) are the detection values of each water quality index.

(1) For the case of the i (i \( \leq \) p) month in p month

The sum of the positive and negative numbers of the water quality indicator test values for the \( i \) month year is \( S_i \).
The sum of the positive and negative values of the water quality indicator of the i month of each year is $S_i$

$$S_i = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} G(a_{ij} - a_{ik}) \quad (1 \leq k < j \leq n)$$

(4)

Where $G(a_{ij} - a_{ik})$ is

$$G(a_{ij} - a_{ik}) = \begin{cases} 
1 & (a_{ij} - a_{ik}) > 0 \\
0 & (a_{ij} - a_{ik}) = 0 \\
-1 & (a_{ij} - a_{ik}) < 0 
\end{cases}$$

(5)

Where $n_i$ is the number of non-leakage measurements in the series of water quality detection values in the month.

Under the $H_0$ hypothesis, the random sequence $S_i (i = 1, 2, ..., p)$ approximately obeys the normal distribution, and $E(S_i) = 0$

Variance is

$$\sigma_i^2 = Var(S_i) = \frac{n_i(n_i-1)(2n_i+5)}{18} - \sum_t \frac{t(t-1)(2t+5)}{18}$$

(6)

Where $t$ is the number of $n_i$ numbers of non-missing values.

for the overall situation of $p$ months

Under the $H_0$ hypothesis, the mean and variance of $S$ for $p$ month are

$$E(S) = \sum_{i=1}^{p} E(S_i) = 0$$

(7)

$$\sigma_S^2 = Var(S) = \sum_{i=1}^{p} \frac{n_i(n_i-1)(2n_i+5)}{18} - \sum_t \frac{t(t-1)(2t+5)}{18}$$

(8)

Where $t$ is the numbers of the non-missing $n_i$ values that are equal.

$S$ obeys a normal distribution and the standard deviation is:

$$Z = \begin{cases} 
\frac{S - 1}{Var(S)^{1/2}} & S > 0 \\
0 & S = 0 \\
\frac{S + 1}{Var(S)^{1/2}} & S < 0 
\end{cases}$$

(9)

(2) Trend test

If $|Z| \leq Z_{a/2}$, accept the hypothesis test, and $F(Z_{a/2}) = a/2$, $F$ is a standard normal distribution function.

$$a = \frac{2}{\Gamma \left(\frac{1}{2}\right)} \int_{-\infty}^{\infty} e^{-1/2t^2} dt$$

(10)

Where $a$ is the significant level of trend test.

The significance level $a$ in the Kendall test is 0.1 and 0.01, respectively. When $S$ is positive, $a \leq 0.01$, it shows a highly significant upward trend; $0.01 \leq a \leq 0.1$, indicating a significant upward trend. When $S$ is negative, $a \leq 0.01$, it shows a highly significant downward trend; $0.01 \leq a \leq 0.1$, indicating a significant downward trend, there is no trend when $S$ is zero.
3. Results and analysis

3.1 Water quality characteristics of different caverns

3.1.1 Common features

The pH of the four island caverns is between 7 and 8, which is a weak alkaline water; the turbidity of the water is between 0.23 and 1.74, indicating that there is less suspended solids in the water; COD, COD\textsubscript{Mn} and BOD are lower. It indicated that the water storage in the cavern was less affected by exogenous organic pollutants; the content of chlorophyll \textsubscript{a} was lower, indicating that the algae content in the water was less, and there was no problem of eutrophication; the chloride content was 44.4~70.4 mg/L, which was higher than the surface water, indicating that it was mainly affected by the regional geological salt content; the total coliform, heat-resistant coliform, and Escherichia coli are lower than the detection line, and there is no risk of contamination of this type of flora (Table 1).

3.1.2 Different characteristics

At the same time, the water temperature of the four island caverns is different, indicating that the water temperature of the cavern is greatly affected by the ambient temperature; the cavern 1 is completely closed, and the internal dissolved oxygen is not replenished by the outside, resulting in dissolved oxygen content in the cavern 1 is obviously lower than the other three caverns, only 5.12 mg/L; the TP, TN and NO\textsubscript{3} content of the cavern 2 is higher than other caverns, mainly because of two reasons, on the one hand, the hole of cavern 2 is semi-closed compared with the cavern 1, which is greatly affected by external pollution sources. On the other hand, the original water of the cavern 1 and the cavern 2 is reservoir water, so the TP, TN and NO\textsubscript{3} content are higher, the original water of the cavern 3 and the cavern 4 is rainwater, which is relatively clean; the Zn and Mn contents of the cavern 2 are significantly higher than those of other caverns, on the one hand, because the geological conditions of the cavern 2, rainwater flows into the caverns 2 through surface seepage, resulting in relatively high Zn and Mn contents; the total number of colonies in the cavern 1 is the least, only 9 CFU/mL, which is mainly because the hole is completely closed and is isolated from external sources of pollution, while other caverns are half-opened and are subject to air. The risk of fungal contamination is greater (Table 1).

| Water quality index | Cavern 1 (completely closed) | Cavern 2 (semi-closed) | Cavern 3 (semi-closed) | Cavern 4 (semi-closed) |
|---------------------|-----------------------------|-----------------------|-----------------------|-----------------------|
| pH                  | 7.81                        | 7.04                  | 7.78                  | 7.84                  |
| Temperature (°C)    | 17.1                        | 17.2                  | 15.7                  | 13.2                  |
| DO(mg/L)            | 5.12                        | 6.07                  | 9.68                  | 9.92                  |
| Turbidity (NTU)     | 0.23                        | 0.63                  | 1.74                  | 1.44                  |
| COD\textsubscript{Mn} (mg/L) | 1.33          | 1.24                  | 1.49                  | 0.98                  |
| COD (mg/L)          | < 4                         | < 4                   | < 4                   | < 4                   |
| BOD (mg/L)          | < 0.5                       | 0.9                   | < 0.5                 | < 0.5                 |
| TP (mg/L)           | 0.06                        | 0.08                  | 0.02                  | 0.02                  |
| TN (mg/L)           | 4.50                        | 6.57                  | 3.03                  | 1.83                  |
| NO\textsubscript{3} (mg/L) | 4.08          | 5.57                  | 2.90                  | 1.62                  |
| Chl-a (μg/L)        | <0.11                       | <0.11                 | 0.15                  | 0.24                  |
| Zn (mg/L)           | < 0.05                      | 0.64                  | < 0.05                | < 0.05                |
| Mn (mg/L)           | < 0.01                      | 0.30                  | < 0.01                | < 0.01                |
| Chloride (mg/L)     | 44.4                        | 51.2                  | 45.2                  | 70.4                  |
| Total coliform (MPN/100mL) | -              | -                    | -                     | -                     |
| Heat-resistant coliform(MPN/100mL) | -          | -                    | -                     | -                     |
| Escherichia coli (MPN/100mL) | -              | -                    | -                     | -                     |
| Total number of colonies (CFU/mL) | 9          | 84                    | 12                    | 1.6×10\textsuperscript{3} |
3.2 Evolution of water quality indicators

(1) pH: The pH of the cavern 1 and the cavern 2 is 7.43~8.65 and 7.28~8.59 respectively. Before March 2018, the pH changes of the two caves are basically the same, and then the cavern 1 water body pH is higher than that of the cavern 2 (Figure 2 a), and the Kendal test method shows that the pH of the cavern 1 is significantly increasing, and the cavern 2 has no obvious change trend (Table 2 a).

(2) Turbidity: The turbidity of the water in the cavern 1 and the cavern 2 is gradually increased and then gradually decreased. Comparing the turbidity with the local rainfall, it was found that the turbidity of the water in the caverns increased significantly from May to July. This may be caused by the seepage of rainfall into the cavern through the surface, resulting in an increase in the turbidity of the water in the cavern (Figure 2 b).

(3) COD$_{Mn}$: The COD$_{Mn}$ of cavern 1 and cavern 2 water bodies decreased gradually from 2.9 mg/L, 3.04 mg/L to 1.2 mg/L and 1.3 mg/L, respectively. This may be due to the fact that microbial activity consumes organic pollutants in the water body, resulting in a gradual decrease in COD$_{Mn}$ in the water (Figure 2 c).

(4) TN, NH$_3$+: TN in the water bodies of cavern 1 and cavern 2 increased gradually. The Kendal test showed that the concentration of TN in cavern 2 showed a significant upward trend (Table 2), mainly because the cavern 2 was semi-closed, which is affected by bacteria, insects and other animals in the air except for the external source of seepage, so there are many potential sources of pollution; NH$_3$+ in cavern 1 and cavern 2 gradually decrease, there are studies shown that under aerobic conditions, nitrifying bacteria converts NH$_3$+ into NO$_3$- [10] by using inorganic or organic matter in water, which makes the concentration of NH$_3$+ in cavern 1 and cavern 2 decreased from 0.20 mg/L and 0.35 mg/L gradually to 0.042~0.20 mg/L and 0.014~0.168 mg/L respectively (Figure 2 d-e).

(5) TP (mg/L): Kendal test showed that the concentration of TP in the cavern 1 showed a significant downward trend (Table 2), while the concentration of TP in the cavern 2 was higher and there was no obvious change trend (Figure 2 f). This was mainly because the cavern 2 was semi-closed and affected by external pollutants.

(6) Chloride: The concentration of chloride in cavern 1 is 42.1~58.6 mg/L, and the concentration of cavern 2 is 44.6~51.2 mg/L, which is higher than the concentration of chloride in the mainland. This is mainly related to the geological conditions of the islands [6-7] (Figure 2 g).
Figure 2. Trends of water quality indicators in cavern1 and cavern2

| Water quality index | cavern 1 | Trend analysis | cavern 2 | Trend analysis |
|---------------------|----------|----------------|----------|---------------|
| pH                  | 8.02     | ↑              | 7.79     | -             |
| \( \text{COD}_{\text{Mn}} \) (mg/L) | 2.12     | ↓              | 1.99     | ↓             |
| \( \text{NH}_3 \) (mg/L)   | 0.11     | -              | 0.10     | -             |
| Turbidity (NTU)     | 1.34     | -              | 1.18     | -             |
| TN (mg/L)           | 3.54     | -              | 4.89     | ↑             |
| TP (mg/L)           | 0.07     | ↓              | 0.12     | -             |
| Chloride (mg/L)     | 50.23    | -              | 46.38    | -             |
3.3 Correlation analysis of water quality indicators

(1) Correlation between water quality indicators and temperature

There was a significant negative correlation between water temperature and pH in cavern 1 with a correlation coefficient of -0.999 (P<0.05) (Table 3). Because cavern 1 was completely closed, its pH was mainly related to the dissolution and release of CO$_2$ and it was almost free from external bacteria and other sources; the water temperature of the cavern 2 is positively correlated with COD$_{Mn}$, and the correlation coefficient is 0.975 (P<0.05) (Table 4). It is judged that the cavern 2 is greatly affected by external pollution, the pollutants in the water body are released at a higher temperature, which leads to an increase in COD$_{Mn}$.

(2) Correlation between TN and NH$_3^+$

There was a significant negative correlation between TN and NH$_3^+$ in cavern 1 (Table 3) and cavern 2 (Table 4), and the correlation coefficients were -0.554 (P<0.05) and -0.485 (P<0.05), respectively. Rainfall seepage will increase the concentration of NO$_3^-$ in cavern, which has less contribution to NH$_3^+$. The nitrifying bacteria consume NH$_3^+$ in the water under aerobic conditions, which leads to a decrease in the concentration of NH$_3^+$ in cavern, while TN shows an upward trend.

(3) Correlation between nitrogen, phosphorus and chlorophyll a

There was no significant relationship between chlorophyll a and nitrogen and phosphorus in the water bodies of cavern 1 (Table 3) and cavern 2 (Table 4). Illumination was a necessary condition for algae production [11]. The caverns in this study were all protected from light, and algae could not be used for photosynthesis. Therefore the concentration of chlorophyll a was low and there was no significant relationship with nitrogen and phosphorus.

| Table 3. Correlation analysis of water quality indicators in cavern 1 |
|--------------------------|----------|----------|----------|----------|----------|----------|
| pH          | -0.997  | 0.534*  | -0.40   | -0.632*  | -0.444*  | 0.81     |
| temperature | 1.00     | 0.54     | 0.99    | 0.94     | 0.98     | -0.84    |
| TN          | -0.554*  | 1.00     | -0.556* | 0.21     | 1.00     | -0.46    |
| NH$_3^+$    | -0.40    | 0.99     | -0.554* | 1.00     | 0.21     | 0.34     |
| TP          | -0.632*  | 0.94     | -0.556* | 0.21     | 1.00     | 0.46     |
| COD$_{Mn}$  | -0.444*  | 0.98     | -0.34   | 0.34     | 0.46     | 1.00     |
| chlorophyll a| 0.81    | -0.84   | 0.81    | 0.13     | -0.86    | 0.80     |

| Table 4. Correlation analysis of water quality indicators in cavern 2 |
|--------------------------|----------|----------|----------|----------|----------|----------|
| pH          | -0.40    | 0.00     | -0.19   | -0.20    | -0.27    | -0.89    |
| temperature | 1.00     | 0.20     | 0.29    | -0.74    | 0.975*   | 0.70   |
| TN          | 0.00     | 1.00     | -0.485* | 0.535*   | -0.484*  | 0.26     |
| NH$_3^+$    | -0.19    | 0.29     | -0.485* | 1.00     | -0.12    | 0.442*   |
| TP          | -0.20    | -0.74    | -0.535* | -0.12    | 1.00     | -0.15    |
| COD$_{Mn}$  | -0.27    | 0.975*   | -0.484* | 0.442*   | -0.15    | 1.00     |
| chlorophyll a| -0.89  | 0.70     | 0.26    | 0.18     | -0.56    | 0.75     |

* When the confidence level (double test) is 0.05, the correlation is significant.
** When the confidence (double test) is 0.01, the correlation is significant.

4. Discussion

Affected by the form of the cavern and the water source of the cavern, there are differences in the quality of stored water in different cavern. The form of the cavern is mainly divided into the full closure hole and the semi-enclosure hole. In this study, the hole of the cavern 1 is completely closed, and no external oxygen is added, resulting in the lowest dissolved oxygen in water, which is 5.12 mg/L, but it also isolates airborne fungi and other sources of pollution, with the smallest number of flora [12][13][14], only 9 CFU / mL, the concentration of other pollutant indicators is relatively small. The water source of the cavern has a great influence on the water quality. In this study, the order of TN, NO$_3^-$ and TP in the cavern is in the order of cavern 2 > cavern 1 > cavern 3 and cavern 4, which mainly because the water
source of both the cavern 1 and the cavern 2 are from external diversion, while the cavern 3 and the cavern 4 are derived from rainfall, so the concentration of pollutants in the cavern 3 and the cavern 4 is significantly smaller than that of the cavern 1 and the cavern 2. The hole of the cavern 2 is semi-closed, and it is subject to more external pollution, so its pollutant concentration is higher than that of the cavern 1.

The water quality of the reservoir in the cavern will change with time. Studying the law of change has theoretical reference significance for mastering the trend of water quality change in the reservoir and selecting necessary treatment measures. This study found that the pH of the cavern was alkaline, and its turbidity values and magnitude of change are small. The concentration of COD$_{Mn}$ and NH$_3$$^+$ in the water body showed a trend of decreasing with time, while TN showed gradually increasing trend. There is a difference in TP concentration between cavern 1 and cavern 2, because the hole of cavern 1 is completely closed and is not affected by external pollution sources, the TP is gradually adsorbed by the sediment[15], showing a significant downward trend, while the cavern 2 is affected by external sources of pollution, and its concentration of TP is relatively high and no obvious change trend. The water storage caverns is a relatively closed system, and there is a certain correlation between the water quality indicators. The correlation analysis results of this study show that the temperature of the cavern 1 is significantly negatively correlated with the pH, and the temperature of the cavern 2 was significantly positively correlated with COD$_{Mn}$. Affected by microbial nitrification and exogenous pollution [16][17], there was a significant negative correlation between TN and NH$_3$$^+$ in cavern 1 and cavern 2 water bodies. Algae growth is the main factor affecting water quality, but there is no significant correlation between the concentration of nitrogen, phosphorus and chlorophyll a, and the concentration of chlorophyll a is low in this study, so there is no eutrophication in groundwater reservoir.

In view of the water quality changes in the caverns in this study and the relevant literature, the water storage in the caverns should be disinfected, infiltrated, dredged, filtered and purified. First of all, bacterial reproduction is one of the important factors affecting the water quality of the reservoir [16][17], so it is necessary to disinfect the inner wall and water source of the reservoir. Secondly, the infiltration of rainfall through the surface, bringing the external pollutants to the caverns is also an important factor affecting the water quality of the caverns. Therefore, the caverns need to be treated with anti-seepage treatment. Third, long-term storage of water easily forms a silt layer in the reservoir and becomes an internal source of pollution. Therefore, it needs to be cleaned regularly to ensure the safety of the stored water. Fourth, there are Zn, Mn, micro-organisms, TN and other indicators exceeding the standard of water storage quality, so it is not suitable for drinking water directly. Membrane filtration, disinfection and other purification measures are taken to ensure drinking water safety.

5. Conclusion
   (1) Influenced by the form of the cavern, the concentration of pollutants in the fully enclosed cavern is relatively low compared with the semi-closed cavern, and the antibacterial effect is better. The total number of colonies is only 9 CFU/mL, but the dissolved oxygen is low(5.12 mg/L). Affected by water sources, the concentration of pollutants in the caverns where the water source is surface water is higher than the concentration of pollutants in the caverns where the water source is rainwater.

   (2) The water quality of the reservoir will change regularly with time. The concentration of COD$_{Mn}$ and NH$_3$$^+$ will gradually decrease with time, the TN will increase gradually; The concentration of TP in the fully enclosed caverns gradually decreased, and the concentration of TP in the semi-closed caverns is no obvious change. Correlation analysis showed that there was no significant difference between TP, TN and chlorophyll a in the cavern.

   (3) The water storage in the cavern should be disinfected and sterilized in the inner wall and water source of the cavern, and the anti-seepage measures of the water storage space should be done well; The regular dredging work should be done according to the water quality of the cavern, reducing the input of external pollution and the release of internal pollution. When using the cavern water, it should be cleaned by membrane filtration and disinfection.
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