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RESEARCH

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Impact of water physicochemical properties on the survival of *Oncomelania hupensis* snails, the intermediate host of *Schistosoma japonicum*

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Abstract

Background *Schistosoma japonicum*, the causative agent of schistosomiasis, heavily relies on its single intermediate host, the *Oncomelania hupensis* snail, for its life cycle. Controlling these snails effectively plays a pivotal role in curbing the transmission and prevalence of this disease. While prior research has extensively investigated the impact of environmental factors such as temperature and vegetation on snail survival, growth, and reproduction, the contribution of water physicochemical properties has been notably underexplored. This study presents laboratory experiments designed to comprehensively explore the influence of water physicochemical properties on snail survival, offering valuable insights into environmental factors for more precise predictions of snail distribution.

Methods We meticulously conducted laboratory snail survival experiments using water from different sources (river water/tap water), and employed a statistical approach amalgamating principal component analysis with Cox regression to preliminarily investigate the effects of different water physicochemical properties on the survival of snails.

Results Our analysis indicates that after a 6-month laboratory snail survival experiment, the survival rate in the tap water group was significantly higher than that in the river water group for infected snails ($\chi^2=7.74$, $p=0.005$), while the difference in survival rates for non-infected snails was not statistically significant ($\chi^2=0.61$, $p=0.434$). The Principal Component-Cox regression analysis revealed that in the infected snail group, total phosphorus, pH value, five-day biochemical oxygen demand, conductivity, and nitrite were protective factors for snail survival, while phosphate and total nitrogen were risk factors. In the non-infected snail group, total phosphorus, pH value, five-day biochemical oxygen demand, conductivity, and nitrite were protective factors for snail survival, and total nitrogen, ammonia nitrogen, phosphate, and nitrate were risk factors.

Conclusions This study underscores the substantial impact of water quality's physicochemical properties on snail survival. The effects of water quality on snails are complex, and maintaining an appropriate level of organic matter content and controlling the pH value at a weak alkalescency level prove beneficial for snail survival. These findings hold significant promise for advancing our understanding of snail-borne diseases and optimizing control strategies.

Keywords *Oncomelania hupensis* snail, Laboratory snail survival experiment, Water physicochemical properties

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Introduction

Schistosoma japonicum, the causative agent of schistosomiasis, heavily relies on its single intermediate host, the *Oncomelania hupensis* snail, for its life cycle [1]. *S. japonicum* infection map is compatible with the intermediate snail distribution [2]. Snail eradication can significantly lower the population's infection rate, which is crucial for the prevention of *Schistosomiasis japonica* [3]. In recent years, the prevention and control have achieved remarkable results, but there are still risks of snail recurrence and diffusion [4, 5].

Environmental factors have a great influence on the survival and reproduction of snails, and the effects of temperature, vegetation, and water level have been extensively studied [6–9]. Water environment plays an important role in the whole life of snails [8], but very few research has been done on how water physicochemical properties affect *Oncomelania* snail survival and distribution, and with differing perspectives. Some studies have indicated that water eutrophication offers food for the snail and is beneficial to the snail's survival, whereas field investigations have shown that water pollution may cause massive death of the snail [10, 11]. Similarly, some studies have also proposed that certain specific indicators affect snail survival, such as pH value, dissolved oxygen, and five-day biochemical oxygen demand (BOD5) [12–14]. Current research methodologies for determining the relationship between water physicochemical properties and snail survival are based on field research. However, the field investigation lacks specificity for the study of water physicochemical properties, and the covariance between the indicators will affect the survey results [15].

In the laboratory setting, the survival environment for snails can be simulated with human control to keep other environmental variables consistent, thereby permitting an independent analysis of the impact that changes in water physicochemical properties have on the survival outcomes of the snails. Therefore, in this study, laboratory snail survival experiments were conducted using water from different sources (river water/tap water) and collect data on the survival time and outcome of the snails, so as to compare the effects of water physicochemical properties on the survival of snails.

Methods

Experiment design

The infected and non-infected snails used in the experiment were provided by Jiangsu Institute of Parasitic Diseases.

Six Hundred infected and 600 non-infected adult snails with good vitality and similar size were selected. They were randomly divided into river water group and tap water group, 300 infected and 300 non-infected snails for each.

The snails were placed in an enamel plate covered with sponge and straw paper, soaked in tap water and river water respectively. Then they were covered with gauze windows and glass plates to prevent the snails from climbing out. To ensure the living space for the snails and to validate the reliability of the experiment, 300 snails in each group were divided into two plates to feed, with 150 snails per plate. The straw paper soaked in respective tap water or river water in the plate was replaced twice a week. We observed the survival of snails in each group every day and recorded the number of dead snails. The survival was identified by water-feeding crawling method combined with needle-stimulation method [16]. The plates of snails were placed in an incubator with a temperature of 25 ℃ and a relative humidity of 50.0%. Except for the infection status of the snails and the water used in the laboratory, all other experimental conditions were maintained consistently. The duration of the whole experiment was 6 months.

Water for experiment

The tap water used in the experiment is dechlorinated by naturally drying for 3 days; the river water for the experiment was collected from the tributaries of Lake Tai, and the coordinates of the sampling points were 31° 33 ′ 9 ′′ N, 120° 13 ′ 9 ′′ E.

Detection of water physicochemical properties

In this study, water physicochemical properties include chemical indicators pH, dissolved oxygen, five-day biochemical oxygen demand, total nitrogen, total phosphorus, ammonia nitrogen, nitrite, nitrate, sulfate, phosphate, silicate, chloride, alkalinity, sodium, potassium, calcium, magnesium ions and physical indicators suspended solids, electrical conductivity.

Water samples were collected at 0.5 m below the river surface using a 2L plexiglass sampler. The detection method followed preferentially Chinese national standards (GB), otherwise industry standards (HJ)and *Water and wastewater monitoring and analysis method -fourth edition supplement* (see Additional file 1). The dechlorinated tap water used in the experiment was tested using the same method. These indicators are tested once every two weeks by Jiangsu Greenlees Testing Technology Company, China.

Data analysis

Principal component analysis

Principal component analysis can reduce the influence of water quality index collinearity on the experimental results [17], and Cox regression can fully utilize the survival time and survival outcome variables [18], so the results were analyzed using the statistical analysis method combining principal component analysis and Cox regression.

Principal component analysis and Cox regression analysis methods were implemented by applying SPSS 22.0 software to investigate the relationship between water physicochemical properties and snail survival.

Before conducting principal component analysis, KMO test and Bartlett's spherical test are needed to determine whether the analyzed data are suitable for principal component analysis. KMO test is used to determine the correlation between the variables, and its value is between 0 and 1. The closer the value is to 1, the better the effect of factor analysis is. When the KMO value is less than 0.5, the data are generally considered unsuitable for principal component analysis [19, 20].

Principal Component Analysis was proposed by Hotelling in 1933, and its basic idea is to reduce the dimensionality of the data through orthogonal transformation, so that multiple correlated variables are transformed into a set of uncorrelated composite indicators [21]. The resulting composite indicator is the principal component. According to the actual demand, fewer principal components are selected to reflect as much information of the original data as possible, and the number of principal components is generally selected with the cumulative contribution rate greater than 80% [22]. In this study, the main steps of principal component analysis include the following:

(1) Standardization of water quality indicator data;
(2) KMO (Kaiser–Meyer–Olkin) test and Bartlett's sphericity test;
(3) Calculate the eigenvectors of the correlation coefficient matrix of water quality indicators;
(4) Calculate principal components of water quality date.

Cox regression analysis

The Cox regression model was proposed by the British statistician Cox and its basic formula is:

$$h_i(t) = h_0(t)\exp(\beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_n x_n) \tag{1}$$

In the formula, $h_i(t)$ represents the risk function for exposure to risk factors $(x_1, x_2, \cdots, x_n)$ at time t, and $h_0(t)$ represents the risk function when the risk factors $(x_1, x_2, \cdots, x_n)$ are not present, which is also called the baseline risk; The Cox regression model employs the principle of partial likelihood with no restriction on the baseline risk, and $\beta_1, \beta_2, \cdots, \beta_n$ are a set of regression coefficients to be estimated, so the Cox regression model is also semi parametric [23, 24]. In this study, the dependent variable was the survival time and outcome of snails, and the composite variable generated by principal component analysis of the measured concentrations of water quality indicator was the independent variable. From this, the regression coefficient β and hazard ratio (HR) were obtained. When the regression coefficient β is greater than 0, the HR is greater than 1, which is a risk factor; when the regression coefficient β is less than 0, the HR is less than 1, which is a protective factor. The main computational steps for Principal Component Analysis-Cox regression are detailed in Additional file 2.

Results

Comparison of snail survival rate among different groups

After 6 months of laboratory snail breeding, the survival rate of snails was less than 10.0% in all groups. Within each group, snails were divided into two pots for cultivation. By the end of the experiment, there was no statistically significant difference in the survival rates among the groups, which to some extent reflects the reliability of the experiment. Among infected snails, the 6-month survival rates of snails were 3.7% for the river water group and 9.7% for the tap water group (Table 1). The monthly survival count variation chart of infected snails also indicates that the number of survivors in the tap water group is consistently higher than that in the river water group (Fig. 1). Among non-infected snails, the 6-month survival rates of snails in the river water and tap water groups were 6.3% and 8.3%, respectively. The monthly survival count variation chart of non-infected snails also reveals that there is an intersection and overlap between the survival quantity change curves of the tap water group and the river water group (Fig. 2).

Chi-square tests were conducted for both groups, and the results showed a statistically significant difference between the river water and tap water groups in infected

Table 1 Monthly survival number (n) and survival rate (%) of snail

Time(month)	Infected snail		Non-infected Snail	
	River water group (*n*/%)	Tap water group (*n*/%)	River water group (*n*/%)	Tap water group (*n*/%)
1	193(64.3)	244(81.3)	197(65.7)	216(72.0)
2	154 (51.3)	158(52.7)	162(54.0)	114(38.0)
3	82(27.3)	101(33.7)	95(31.7)	93(31.0)
4	23(7.7)	63(21.0)	49(16.3)	49(16.3)
5	14(4.7)	39(13.0)	29(9.7)	31(10.3)
6	11(3.7)	29(9.7)	19(6.3)	25(8.3)

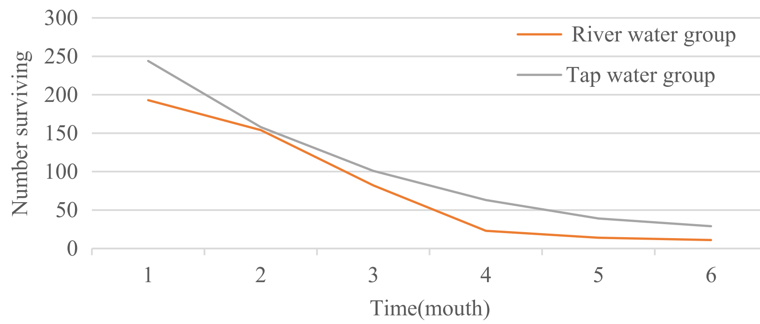

Fig. 1 Variation in the monthly number of infected snails surviving

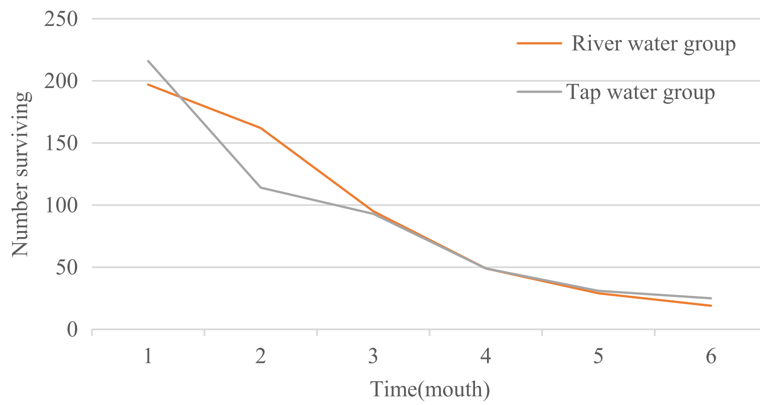

Fig. 2 Variation in the monthly number of non-infected snails surviving

snails in terms of snail 6-month survival rate ($\chi^2 = 7.74$, $p = 0.005$), the survival rate of snails in the tap water group was higher than that in the river water group.; among non-infected snails, the difference was not statistically significant, $\chi^2 = 0.61$, $p = 0.434$.

Detection results of water physicochemical properties

During this experiment, the fluctuation range of the measured values of the physicochemical properties of water quality is shown in Table 2. The water quality was tested 14 times during the experiment. It can be observed that there were considerable variations in water quality status during the experimental period. The surface water environmental quality standards for basic project standards are divided into five functional categories. Different functional categories have corresponding standard values. According to the technical specification for surface water quality assessment, Class I and II water is of high-quality; Class III water is of good quality; Class IV water is mildly polluted; Class V water is severely polluted. Based on the "People's Republic of China Environmental Quality Standards for Surface Water", the highest concentration of total phosphorus in the river water is in the standard range of Class V water, total nitrogen and ammonia nitrogen concentrations exceeded the maximum standard limit of Class V water. Dissolved oxygen content of the lowest concentration below the standard limit of Class V water. Five-day biochemical oxygen demand detection range are in the range of Class I water. Chloride, sulfate, nitrate content is lower than the standard limit.

Principal component analysis

According to the results of KMO test and Bartlett's spherical test, in this study, KMO value > 0.5, $P < 0.05$, this data information is suitable for principal component analysis.

According to the table of total variance explained in the infected and non-infected groups (see Table 3), the first four principal components could explain 86.5% of the original data information. The cumulative contribution rate is more than 80%, which can better reflect the information of the original water quality data. After obtaining the eigenvector matrix, the eigenvectors corresponding to the first four eigenroots are selected to generate four principal components (see Additional file 3).

Table 2 Detection results of water physicochemical properties

Water physicochemical properties	Minimum detection concentration	Maximum detected concentration	Average detected concentration	Water class level
pH	6.84	7.34	7.08	-
Dissolved oxygen(mg/L)	0.90	7.70	3.55	I-V
Five-day biochemical oxygen demand(mg/L)	0.50	2.50	1.29	I
Total nitrogen(mg/L)	1.71	4.04	3.08	V
Total phosphorus(mg/L)	0.02	0.38	0.19	I-V
Ammonia nitrogen(mg/L)	0.22	2.32	1.29	I-V
Nitrite(mg/L)	< 0.004	0.27	0.11	-
Nitrate(mg/L)	0.31	2.37	1.11	-
Sulfate(mg/L)	12.60	51.20	37.23	< standard limit(250 mg/L)
Phosphate(mg/L)	0.01	0.34	0.16	-
Silicate(mg/L)	0.92	9.42	3.04	-
Chloride(mg/L)	26.50	55.00	40.84	< standard limit(250 mg/L)
Alkalinity(mg/L)	76.40	146.00	117.41	-
Sodium(mg/L)	20.40	35.9	27.95	-
Potassium(mg/L)	4.97	9.34	6.20	-
Calcium(mg/L)	30.80	168.00	52.97	-
Magnesium ions(mg/L)	7.47	11.10	9.42	-
Suspended solids(mg/L)	4.00	47.00	11.00	-
Electrical conductivity(mS/m)	0.34	0.50	0.44	-

Cox regression analysis

Based on the results of the principal component analysis, the first four principal components (C_1, C_2, C_3, C_4) were selected as new variables for Cox regression. In the infected snail group, principal components 1, 3, and 4 were finally included in the model; in the non-infected snail group, principal components 2, 3, and 4 were included in the mode, as shown in Tables 4 and 5. The Cox regression model was:

Infected snail group: $h_i(t) = h_0(t)\exp(0.069C_1 - 0.144C_3 - 0.241C_4)$

Non-infected snail group: $h_i(t) = h_0(t)\exp(-0.174C_2 - 0.327C_3 + 0.121C_4)$

The standardized variables were transformed into the original variables and brought into the Cox regression model for transformation, and finally the regression coefficients β and HR of the original variables were calculated, as shown in Table 6.

Based on the regression coefficients β and HR it can be concluded that for infected snails, total phosphorus, pH, conductivity, nitrite, five-day biochemical oxygen demand, ammonia nitrogen, silicate, dissolved oxygen, potassium, sulphate, chloride, nitrate and alkalinity were the protective factors suggesting that as the concentration of these factors increased, it favored the survival of infected snails in the present study. Among them, total phosphorus had the lowest HR value of 0.27. Phosphate, total nitrogen, suspended solids, sodium, magnesium and calcium ions were risk factors indicating that as the concentration increased, it was unfavorable for the survival of infected snails. Phosphate had the highest HR value of 1.099.

For non-infected snails, conductivity, pH, nitrite, total phosphorus, five-day biochemical oxygen demand, magnesium ion, silicate, chloride, sulfate, potassium, dissolved oxygen, calcium, suspended solids, and alkalinity were protective factors indicating that as the concentration of these factors increased, it favored non-infected snail survival. Conductivity had the lowest HR of 0.26. Phosphate, nitrate, ammonia, total nitrogen, and sodium were risk factors indicating that as the concentration of these factors increased, it was unfavorable for the survival of non-infected snails, where phosphate had the highest HR value of 3.38.

Discussion

In this study, we carried out a snail laboratory survival experiment to investigate the association between snail survival and water physicochemical properties. The different effects of water physicochemical properties on infected and non-infected snails were collated (Fig. 3).

The chi-square test analysis showed that among infected snails, the 6-month survival rate of snails in the tap water group was significantly higher than that in the river water group; whereas, in non-infected snails, the difference between the two groups was not statistically

Table 3 Total variance explained

Component	Infected snail						Non-infected snail					
	Starting eigenvalue			Extraction Sums of Squared Loadings			Starting eigenvalue			Extraction Sums of Squared Loadings		
	Eigen value	% of variance	Cumulative % of variance	Eigenvalue	% of variance	Cumulative % of variance	Eigenvalue	% of variance	Cumulative % of variance	Eigenvalue	% of variance	Cumulative % of variance
1	9.594	50.497	50.497	9.594	50.497	50.497	9.817	51.667	51.667	9.817	51.667	51.667
2	3.376	17.767	68.264	3.376	17.767	68.264	2.900	15.265	66.932	2.900	15.265	66.932
3	2.167	11.404	79.668	2.167	11.404	79.668	2.229	11.733	78.665	2.229	11.733	78.665
4	1.293	6.803	86.471	1.293	6.803	86.471	1.482	7.802	86.467	1.482	7.802	86.467
5	0.959	5.045	91.516				0.828	4.359	90.825			
6	0.651	3.428	94.944				0.715	3.764	94.589			
7	0.387	2.036	96.979				0.484	2.546	97.135			
8	0.324	1.705	98.684				0.244	1.287	98.422			
9	0.173	0.912	99.596				0.173	0.908	99.33			
10	0.050	0.261	99.857				0.078	0.41	99.74			
11	0.025	0.129	99.986				0.042	0.222	99.962			
12	0.002	0.013	99.999				0.007	0.037	99.998			
13	0	0.001	100				0	0.001	100			

Table 4 Cox regression results (infected snail)

Variant	β	SE	Wald	df	p	Exp(B)	Exp(B)95%CI	
							Lower	Upper
C_1	0.069	0.014	23.974	1	0.000	1.072	1.042	1.102
C_3	-0.144	0.031	22.245	1	0.000	0.866	0.815	0.919
C_4	-0.241	0.037	43.418	1	0.000	0.786	0.731	0.844

Table 5 Cox regression results (non-infected snail)

Variant	β	SE	Wald	df	p	Exp(B)	Exp(B)95%CI	
							Lower	Upper
C_2	-0.174	0.036	23.647	1	0	0.84	0.783	0.901
C_3	-0.327	0.036	81.318	1	0	0.721	0.672	0.774
C_4	0.121	0.036	11.506	1	0.001	1.128	1.052	1.21

Table 6 Cox regression coefficient and HR of original variables

Infected snail			Non-infected snail		
Water physicochemical properties	β	HR	Water physicochemical properties	β	HR
Total phosphorus	-1.3	0.272	Electrical conductivity	-1.341	0.262
pH	-0.455	0.634	pH	-0.533	0.587
Electrical conductivity	-0.207	0.813	Nitrite	-0.324	0.724
Nitrite	-0.126	0.881	Total phosphorus	-0.14	0.869
Five-day biochemical oxygen demand	-0.119	0.888	Five-day biochemical oxygen demand	-0.122	0.885
Ammonia nitrogen	-0.095	0.909	Magnesium ions	-0.081	0.922
Silicate	-0.045	0.956	Silicate	-0.072	0.931
Dissolved oxygen	-0.022	0.979	Chloride	-0.026	0.974
Potassium	-0.011	0.989	Sulfate	-0.018	0.982
Sulfate	-0.005	0.995	Potassium	-0.006	0.994
Chloride	-0.004	0.996	Dissolved oxygen	-0.004	0.996
Nitrate	-0.003	0.997	Calcium	-0.003	0.997
Alkalinity	-0.002	0.998	Suspended solids	-0.001	0.999
Calcium	0.002	1.002	Alkalinity	-0.001	0.999
Magnesium ions	0.004	1.004	Sodium	0.004	1.004
Sodium	0.005	1.005	Total nitrogen	0.01	1.01
Suspended solids	0.005	1.005	Ammonia nitrogen	0.035	1.036
Total nitrogen	0.007	1.007	Nitrate	0.053	1.054
Phosphate	0.094	1.099	Phosphate	1.216	3.375

significant. The results of the principal component-Cox regression analysis also indicated that the impacts of nitrate, ammonium, calcium ions, magnesium ions, and suspended solids on snails and infected snails were different. After infected by *Schistosoma japonicum*, the snails' immune system could be activated, where hemolymph cells play a significant role in defending against the parasitic invasion of schistosome larvae through phagocytosis and cytotoxic reactions. The hemocytes of snails also play an important role in defense processes such as wound repair and inflammatory responses. Therefore, the presence of Schistosoma japonicum within snails may affect the normal functioning of their biological systems, enhance immune defense functions, and subsequently influence their tolerance to the environment [25]. But the underlying mechanism how different elements interact

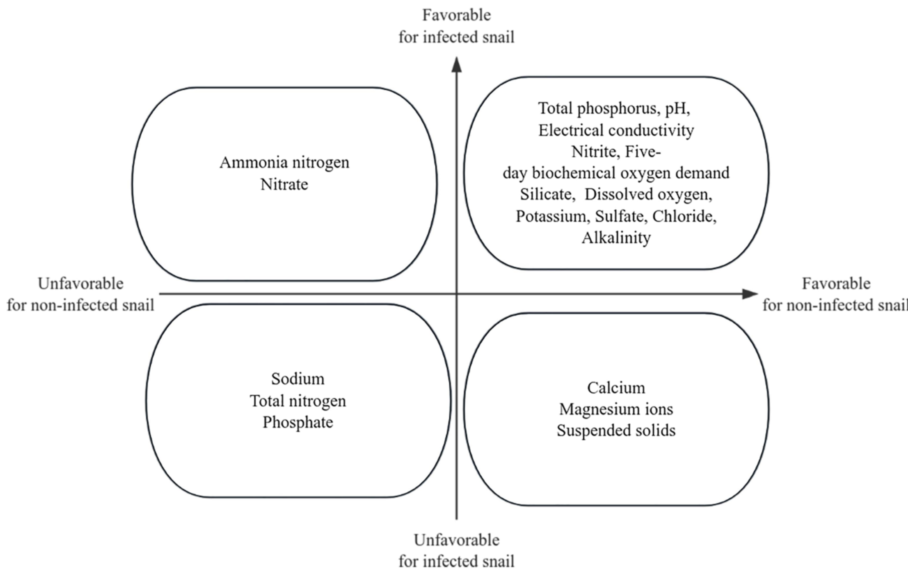

Fig. 3 Differential effects of water physicochemical properties on infected and non-infected snails

with these internal processes in the snail biological system worth further exploration.

Since the physicochemical properties of the water that we used for snail breeding were constantly changing, as well as the collinearity between water quality indicators may lead to overlaps of information [26], we further adopted principal component-Cox regression to explore the effects of changing water physicochemical properties on the survival of the snails. Principal component analysis is widely used in water quality evaluation by obtaining mutually independent composite variables through data dimensionality reduction [27].

We found the pH value a favorable factor for the survival of infected and non-infected snails. In this experiment, the pH value range was 6.84–7.34, which is consistent with the suitable pH range for snail survival (6.80–7.80) [28]. Alkalinity reflects the amount of bicarbonate in the water and is consistent with the value of pH [29]. These indicated that within the suitable pH range, the more alkaline the water becomes, the better the snail survives. In the study exploring the spatiotemporal distribution patterns of the population structure of the *Pomacea analiculata*, it was found that the number of adult snails increased with the rise of pH value [30]. This may be related to the fact that weak alkalescency water bodies are more conducive to the survival of adult snails and the formation of their calcium carbonate shells. It indicated that the variation in water body pH values could be a predictive factor of the distribution of snails.

Dissolved oxygen and five-day biochemical oxygen demand, also favorable for snails, are comprehensive indicators to reflect the pollution status of the water body by organic matter [31, 32]. Dissolved oxygen refers to the molecular oxygen dissolved in water. The five-day biochemical oxygen demand indicates the amount of oxygen needed by aerobic microorganisms in the water body to decompose organic matter. The range of dissolved oxygen in this study was 0.90–7.70 mg/L, which fluctuated in a wide range, the lowest value was lower than the standard of the surface water class V water, the highest value was higher than the minimum value of class I water. However, the range of five-day biochemical oxygen demand was 0.50–2.50, which belongs to Class I water. The content of dissolved oxygen is greatly affected by environmental factors such as temperature and precipitation. However, the five-day biochemical oxygen demand is relatively stable and has little correlation with temperature and rainfall [33]. Since this experiment was implemented from June to December, when the temperature and precipitation in summer and winter were quite different, it thus resulted in a large fluctuation of dissolved oxygen. Therefore, moderate amount of organic matter is favorable to the survival of snails when the water body is not highly polluted. The finding about dissolved oxygen is consistent with studies on other snails like *Pomacea canaliculata*, which found that low dissolved oxygen environments can cause oxidative damage to biological cells [34].

Conductivity is an indicator to reflect the conductive capacity of the water body. The value not only depends on the ion concentration in the water body, but also is related to the type of ions and gases dissolved in water, such as carbon dioxide, which can also produce conductive ions [35]. The concentration ranges of chloride and sulfate measured in the experimental water were

26.50–55.00 mg/L and 12.60–51.20 mg/L, respectively. It was much lower than the standard limit of 250 mg/L for surface water, indicating that the water body is less polluted by chloride and sulfate, which are mainly related to geology and the discharge of domestic and industrial effluents [36]. In our study, the chloride and sulfate favored snail survival, while sodium ions, ranged from 20.40–35.90 mg/L, were the opposite. The impact of various ions on the survival of snails requires further investigation.

Total phosphorus and silicate in water were found to be favorable for snail survival. They are closely related to the formation of algae in the water. Some studies showed that snails have a higher density where diatoms and cyanobacteria are distributed, and diatom cells were found in the gut of the dissected snails [37]. It could be speculated that phosphorus and silicate in water might be favorable for snail survival by supporting the formation of their food algae. Total phosphorus includes both phosphates and organic phosphorus. In our study, we only measured the levels of total phosphorus and phosphates in water, and the effects of these two on snail survival were found to be opposite. Therefore, we inferred that organic phosphorus, like total phosphorus, was also beneficial for snail survival. Organic phosphorus primarily comes from domestic wastewater and organic phosphorus-containing pesticides, while phosphates originate from soil, plants, and fertilizers [38, 39]. Different water bodies are subjected to different types of pollution, which could have varying impacts on snails. In the study of the distribution characteristics of the *Biomphalaria straminea*, it was also found that its distribution density is positively correlated with the concentration of total phosphorus [40]. Further research is required to understand the impact of different types of phosphorus pollution could have on the distribution of snails.

In our study, we found total nitrogen detrimental to snail survival. Total nitrogen in this study ranging from 1.71–4.04 mg/L, with the lowest concentrations falling into Class V water, which meant the water was severely polluted by this substance. Nitrogen in water is mainly derived from the heavy use of agricultural fertilizers, domestic and industrial effluents including human and animal feces [41]. Total nitrogen is the total amount of both inorganic nitrogen including ammonia nitrogen, nitrate nitrogen, nitrite nitrogen, and organic nitrogen (proteins, organic amines, etc.) [42]. Ammonia nitrogen, nitrite nitrogen, and nitrate nitrogen are interconverted, which is part of the water body's self-purification process. An increase in ammonia nitrogen concentration indicates an excess of organic matter in the water body, an increase in nitrite nitrogen concentration suggests that organic matter is being decomposed, which means the organic matter concentration is decreasing, and a rise in nitrate nitrogen levels indicates that the water body is tending toward self-purificated. Different from total nitrogen, elevated concentrations of nitrite nitrogen are beneficial for the survival of snails. Therefore, it can be inferred that an appropriate level of organic matter is beneficial for snail survival, which is consistent with the results reflected by dissolved oxygen and the 5-day biochemical oxygen demand.

This study has some limitations. First, this study measured most of the water quality indicators, but still omit some other indicators that may have an impact on the survival of the snail, which could be explored in the future study. Second, we used straw paper method to breed snail rather than the mud bowl method, which are now the two main ways breed snails in labs [43, 44]. The reason is the straw paper method could exclude the influence of soil, and is more convenient to observe and count the snail survival, although the mortality of the snail could be higher, which, in this study, reached over 90% after 6 months. Moreover, this is a simulation experiment in the laboratory, and snails can survive both in water and on land, so in the field, the combination of other factors will make the determination of the influencing factors more complicated.

Conclusions

The concentrations of water quality indicators in the river water used in this study were dynamically changing, and within this range, we conducted the study to underscores the substantial impact of water physicochemical properties on snail survival. Maintaining an appropriate level of organic matter content and keeping pH within an optimal range prove beneficial for snail survival. These findings can add water physicochemical properties to the prediction of snail distribution and increase the accuracy of prediction, and hold significant promise for advancing our understanding of snail-borne diseases and optimizing control strategies. The effects of water physicochemical properties on snail survival are relatively complex. Further research is needed to understand how water quality affects the overall health condition of snails. The growth and development of snails are associated with a variety of factors, and their survival status may also be the result of a combination of multiple factors. However, this study focuses solely on the aspect of water physicochemical properties, without incorporating other factors for analysis, which significantly differs from the natural environment and represents the main limitation of this research.

Abbreviations

KMO Kaiser–Meyer–Olkin
HR Hazard ratio

Supplementary Information

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Additional file 1.

Additional file 2.

Additional file 3.

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Authors' contributions

Maomao Liu and Yun Feng contributed equally to this work. MML, YF and KY designed this study. MML implemented the snail survival experiment and analyzed data and wrote the paper. LS, XYW and CRX contributed to snail survival experiment. YF has contributed to improving data analysis. YF and KY are the main contributors to research design, data analysis and improvement of the paper. All authors read and approved the final manuscript.

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Data availability

Data is provided within the manuscript or supplementary information files.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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