Acta Tropica 226 (2022) 106224

Contents lists available at ScienceDirect

Acta Tropica

journal homepage: www.elsevier.com/locate/actatropica

Impact of the coronavirus disease 2019 lockdown on *Schistosoma* host Oncomelania hupensis density in Wuhan

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A R T I C L E I N F O

Keywords:
Coronavirus disease 2019
Schistosomiasis
Oncomelania hupensis density
Wuhan

A B S T R A C T

Background: Snails that host the parasitic worm *Schistosoma* were once controlled or eliminated in Wuhan, China. However, safety measures associated with the outbreak of novel coronavirus disease 2019 (COVID-19) halted snail detection and extermination efforts. The impact of the COVID-19 pandemic on urban schistosomiasis transmission remains unclear. This study aimed to investigate snail density and the associated risk of a schistosomiasis outbreak in Wuhan.
Methods: The density and infection status of snails were monitored by global positioning system satellites, and outbreak risk was calculated by adjusting the Kaiser model. SigmaPlot was used to create a three-dimensional risk matrix.
Results: The living snail frame occurrence rate was 1.48%, and the average living snail density was 0.054/0.11 m^2 in 2020, indicating an increase relative to the respective 2019 values (0.019/0.11 m^2). No infectious snails were observed in the survey area. The possibility, harmfulness, and uncontrollability indicator values were 0.842, 0.870, and 0.866, respectively. The areas at greatest risk were the northern bank of Tianxingzhou and the Tianxingzhou and Hongshan districts overall. The existing snail sites in the northern bank of Tianxingzhou exhibited the highest risk scores, followed by those in Pak Sha Chau, with the highest risk score found in Yangsiji Village. The events likely to occur in Hongshan District were also likely to have high severity.
Conclusions: During the COVID-19 outbreak, the risk of schistosomiasis increased due to snail colonies returning to their sites of origin in Wuhan, suggesting a need for strengthened infection control and prevention measures.

1. Introduction

Schistosomiasis is an infectious disease caused by the parasitic worm *Schistosoma* (Sun et al., 2017).Among the various species of *Schistosoma, Schistosoma japonica* has been the main pathogen infecting humans and animals for more than 2100 years in China(Li et al., 2020). Oncomelania hupensis is the only intermediate host of Schistosoma japonica, which belongs to the genera Mollusca and Oncomelania. It is a dioecious, egg-laying, amphibious freshwater snail commonly referred to as Oncomelania hupensis in China. Mature adult worms reside in the mesentery (Schistosoma japonicum), where female worms lay eggs, which are secreted into the environment either through feces or urine (McManus et al., 2018). The eggs that reach freshwater will hatch, releasing free-living ciliated miracidia that then infect a suitable snail host. In the snail, the parasite undergoes asexual replication through mother and daughter sporocyst stages, eventually shedding tens of thousands of cercariae (the infectious form for human beings) into the water(Colley et al., 2014). After ~30 days, cercariae emerge from the snail in response to sunlight and penetrate the skin of a human host; in the skin, they drop off and the larvae transform into schistosomulae (McManus et al., 2018). Through the abovementioned process, *Schistosoma japonica* completes its life cycle from the freshwater snail intermediate host to the human host. Therefore, it is essential to interrupt the infection cycle by controlling the growth and development of Oncomelania hupensis as an intermediate host to control schistosomiasis.

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https://doi.org/10.1016/j.actatropica.2021.106224
Received 10 July 2021; Received in revised form 12 September 2021; Accepted 25 October 2021
Available online 30 October 2021

Abbreviations

COVID-19 novel coronavirus disease 2019
GPS global positioning system

Wuhan, Hubei Province is one of the most important epidemic areas of schistosomiasis in China(Zhang et al., 2020). Wuhan City is located on the Yangtze River Basin, which belongs to the subtropical monsoon humid area. It has a wide range of jurisdiction, rich water system, and warm and humid climate, allowing some water systems to form a favorable environment for snail breeding (Chen et al., 2015). In the middle of August 1989, acute schistosomiasis infection was observed in nearly 3000 individuals on Yangyuan Street of Wuhan City(Tang et al., 1991), causing the loss of life and property of the large working population. Consequently, Jiang Zemin, the president of the People's Republic of China, provided orders and ensured the public that a mass treatment would be implemented. From 1991 to 2000, small outbreaks of schistosomiasis occurred in the urban center of Wuhan(wang et al., 2002). Owing to this, more than 200 individuals were infected in 1991. In 1997, residents from non-schistosomiasis endemic areas visited Zuoling Town, Hongshan District, Wuhan City, and were subsequently infected with schistosomiasis (Yao et al., 2006). This incident received great attention from urban managers, who proposed to strengthen the prevention and control of schistosomiasis in urban centers. In September 2004, four confirmed cases of acute schistosomiasis infection were observed in Houhu Town, Jiangan District, Wuhan City, and other schistosomiasis infections were successively found through screening. Road development in Wuhan City has been associated with disease outbreaks, as the route runs through a region where *Schistosoma* is particularly common. Although great progress has been made in controlling schistosomiasis in recent years, Wuhan City has been consistently considered at risk of schistosomiasis outbreak.

After the outbreak of the novel coronavirus disease 2019 (COVID-19) in Wuhan, China in 2020(Chen et al., 2020), Wuhan immediately went into lockdown from January 23, 2020 (Leung et al., 2020) to April 8, 2020, during which time schistosomiasis control measures were suspended. Targeted molluscicides, which use a handheld global positioning system (GPS) to determine the snail's position, and the use of high-temperature molluscicides in plastic mulch film were discontinued. This may have led to a large increase in the breeding density of snails during the COVID-19 pandemic. Sokolow SH's results showed that extensive snail control contributed to a reduction of schistosomiasis prevalence by 92%, whereas the control programs with little or no snail control interventions achieved a 37% reduction, which highlights the critical role of snail control in schistosomiasis control programs (Coelho and Caldeira, 2016; Sokolow et al., 2016). Therefore, the risk of schistosomiasis after COVID-19 may increase significantly.

A classical method of expert evaluation that is widely used is the Delphi method. Due to the value of expert evaluation, this method gives immediate results for medical experts or public health advisors to provide impartial, objective, and professional recommendations (Varndell et al., 2021). The Kaiser model is a disaster vulnerability analysis tool developed by some emergency management departments and research institutions in the United States. It has been used for reference in medical research in recent years to evaluate the possibility of risk events and has been recognized by experts in the field of public health for its rapid efficiency (Guppy et al., 2019).The risk matrix method is a method used to identify risk grade (Gul and Ak, 2018). In November 2020, Wuhan mainly monitored the distribution of snails in Jiangan and Hongshan districts. At that time, the average densities of snails in Jiangan and Hongshan districts (0.019 and 0.054/0.11 m^2, respectively) were higher by 21.79% and 980%, respectively, compared with those in 2019. The average density of snails in Hongshan District was high and fast-growing. To explore the risk and severity of schistosomiasis, the snail situation in Hongshan District was taken as the representative of the overall situation of schistosomiasis in Wuhan City.

The aims of this study were to assess the impact of the COVID-19 epidemic on snail density in Wuhan, the severity of the risk of schistosomiasis, and to remind people to continue schistosomiasis prevention and control measures during the COVID-19 pandemic.

2. Methods

The density of Oncomelania hupensis was investigated by environmental sampling, with its location determined using a handheld GPS(He et al., 2019). The presence of *Schistosoma japonicum* cercariae in Oncomelania hupensis was detected by crushing microscopy(Place the snails on the slide and put the snails in the anatomic mirror . Using dissecting needle to pull out the shell and tear up the soft tissue such as digestive gland of Oncomelania hupensis successively, we found that the cercariae and cercariae of Schistosoma japonicum were infected Oncomelania hupensis. Sometimes the mother cercariae could be detected in the early stage of infection). Based on previously collected surveillance data from Wuhan City, schistosomiasis-affected areas were divided into existing, historical, and emerging snail sites. According to the field pre-investigation, the number of people moving to each area were divided into five levels (0–10, 10–50, 50–100, 100–200, and more than 200 persons/day).

2.1. Ethics statement

The characteristics of the resident crowd activity study were approved by the Ethics Committee ofWuhan University School of Medicine (2021YF0038), and the snail study conformed to the national law.

2.2. Expert consultation

Twelve experts in schistosomiasis control and prevention were invited to attend a video conference; all experts are currently working in teaching and research institutes, or at the Centers for Disease Control and Prevention, and are part of a health administration. Based on snail monitoring findings and social behavioral characteristics of the population in Wuhan City, the experts were instructed to score a selection of assessment indicators and provide an overall risk assessment score (Zheng et al., 2020).

The survey response rate was used to represent the participation coefficient (E), which was calculated as the number of experts consulted divided by the number of experts who participated. The expert authority degree Cr represented the arithmetic mean of the proficiency degree (C_α) and the expert judgment base values (C_β) and evaluated the experts' understanding of the field and the credibility and reliability of their assessment. Cr values were in the range of 0–0.95, with the cutoff value of $\geq$0.7, which was obtained by dividing the sum of the coefficients by two. According to the five-point Likert scoring method, the proficiency of the indicators ranged from very familiar to very unfamiliar, with a value of 1.0–0.2 points. The judgment base category was divided into theoretical analysis (0.3, 0.2, 0.1/points), practical experience (0.5, 0.4, 0.3/points), reference to foreign scholars' work (0.1, 0.08, 0.06/points), and intuition (0.1, 0.08, 0.06/points). In addition, these items were categorized as large, medium, and small, according to their degree of influence on experts.

2.3. Adjusted Kaiser model

A risk assessment system was based on the Kaiser model and the results of the expert meeting. The index of harmfulness and non-hollowness was weighted by experts (w_i). Weighted average was calculated as follows:

$$\overline{\omega_{j=1}^{m}} = \frac{1}{n}\sum_{i=1}^{n} w_i, \tag{1}$$

where j stands for the number of indicators, m stands for the total number of indicators, i stands the number of experts, and n stands for the total number of experts. The relative risk of schistosomiasis outbreak was calculated, using the following Kaiser tool table calculation formula: Relative risk (Risk%)=(Possibility/3) $\times$ (Population health impact score $\times$ w_1+ Impact on production and life of local residents $\times$ w_1 + Increase capital investment $\times$ w_1+ Influence of public opinion $\times$ w_1+ Emergency preparedness $\times$ w_2 + Internal response $\times$ w_2 + Implementation of prevention and control policies $\times$ w_2)/6 $\times$ 100%.

2.4. Risk matrix

Quantitative scores were obtained based on expert assessments of event risk and severity. In this study, two-dimensional risk matrix values were obtained from the scoring values of the risk assessment system (0–3). The level of risk was divided into five levels (negligible, low, moderate, high, and extremely high), corresponding to blue, green, yellow, orange, and red zones, respectively. Based on the likelihood, harmfulness, and uncontrollability scores of the event, as determined by the expert score, a three-dimensional risk matrix was drawn.

2.5. Data analysis

Google Earth (Google, n.d.) was used to import GPS Exchange Format files and draw the Keyhole Markup Language information snail situation map. Excel software was used to input and sort out expert evaluation data and conduct a general, descriptive analysis. According to the Excel tool table of the Kaiser model, the improved risk value calculation was performed. SigmaPlot 12.5 (Systat Software Inc., San Jose, California, USA) was used to draw a three-dimensional risk matrix.

3. Results

The total area surveyed was 2,259,955 m^2, a total of 1025 snails were captured in 290 snail frames(A survey frame with an area of about 0.1m^2 (0.33m $\times$ 0.33m) was set at a certain distance to investigate the snails in the frame.), and the occurrence rate of snail frames was 1.70%. Moreover, 924 living snails were dissected in 253 snail frames, the occurrence rate of snail frames was 1.48%, and the average density of living snails was 0.054/0.11 m^2. No snails were found at the emergency monitoring points. No infectious snails were observed in the survey area (Fig 1). A comparison of the snail situation in Wuhan between 2018 and 2020 is presented in Table 1.

3.1. The number of people activity each area

Existing snail points, i.e., Tianxingzhou and Pak Sha Chau, historical snail point villages, emergency-monitoring snail points, and Qingling River crowd activities are shown in Table 2. The analysis of the population characteristic distribution and snail site superposition chart revealed that the existing areas with high snail population activity were consistent with the snail site distribution (Fig 2).

3.2. Expert assessment

The expert panel included 8 (66.67%) men and 4 (33.33%) women; 4 (33.33%) participants were senior experts, and 5 (41.68%) participants

Table 1
Comparative analysis of snail situation in Wuan from 2018 to 2020

		Snail Index	2018	2019	2020
Existing Snail	Tian xing Zhou	Snail area(m2)	303200	399700	2111800
		Occurrence rate of snails frame(%)	0.68	0.85	2.45
		Occurrence rate of living snails(%)	0.48	0.63	2.14
		the average density of living snails(/0.11 m^2)	0.0172	0.0167	0.0658
		the positive rate of snails(%)	0	0	0
	Pak sha Chau	Snail area(m2)	24,310	53,924	113922
		Occurrence rate of snails frame(%)	0.96	1.01	2.199
		Occurrence rate of living snails(%)	0.58	1.01	2.199
		the average density of living snails(/0.11 m^2)	0.064	0.041	0.197
		the positive rate of snails(%)	0	0	0
Historical Snail		Snail area(m^2)	-	-	24187
		Occurrence rate of snails frame(%)	-	-	0.28
		Occurrence rate of living snails(%)	-	-	0.28
		the average density of living snails(/0.11 m^2)	-	-	0.019
		the positive rate of snails(%)	0	0	0

Fig. 1. Distribution of snails in Wuhan City in 2020. A: Tianxingzhou, B: Pak Sha Chau, C: Yangsi Ji Village.

Table 2
The number of people activity at each snail area in WuHan City

Position	Area	Number of active people (persons/day)	Population Characteristics
Existing Snail	Tian xing Zhou -Chau head	>200	The South Bank of Chau head embankment is mostly for fishing people and tourists, and the embankment is a residential area
	Tian xing Zhou -Middle of the continent	>200	Residential areas, but also foreign visitors
	Tian xing Zhou -End of the continent	100-200	Mostly people engaged in construction work as well as the planting crowd
	Tian xing Zhou -North Shore	10~50	Environment is more complex, there are fishing and planting operations crowd
	Tian xing Zhou -South Bank	<10	Part of the drinking water protection zone, the original ecological environment, less active people
	Pak sha Chau	<10	A small number of vegetable growers at the end of the continent
Historical Snail	HengDi Village	100-200	Forestland with fishing and sand picking or forestry activities
	Rocket Village	100-200	Forestland with fishing and sand picking or forestry activities
	Yangsiji Village	100-200	Part of the beach is hardened, with foreign tourists and fishermen
	Shizui Village	10~50	Residents grow vegetable fields, and the number of people working there has been reduced because of flooding
	Xiwan Village	<10	Wetland environment, mainly for anglers
	Jianhe Village	<10	Drinking water mouth protection area, reed more, less activity crowd
	Changjiang Village	<10	Drinking water mouth protection area, reed more, less activity crowd
Emergency Monitoring Point	Qingling River	>200	Residents of urban zone travel, walk, fishing, play in the majority

were deputy seniors, with an average duration of experience in schistosomiasis control of 20.92±12.28 years. Moreover, 8 experts had more than 15 years of schistosomiasis control experience (Table 3). A personalized evaluation index system was established based on the characteristics of schistosomiasis control in Wuhan City, which is shown in Supplementary File Table 1. A total of 12 questionnaires were distributed and returned, yielding a response rate of 100%. The expert indicator values of possibility, harm, and uncontrollability were 0.842, 0.870, and 0.866, respectively, all of which were >0.7, indicating assessment validity and reliability (Table 4).

3.3. Kaiser model risk values

The areas associated with the highest risk scores were the outer north bank of the Tianxingzhou dike, followed by the Tianxingzhou and Hongshan districts overall. The north bank outside the Tianxingzhou polder had the highest risk score, followed by the existing snail point Pak Sha Chau. The highest risk value was found in the Yangsiji Village, which is a historical snail site. The risk value of emergency snail monitoring was significantly low, as shown in Supplementary Table 2.

3.4. Two-dimensional risk matrix

The north bank of Tianxingzhou was located in the orange zone, which belonged to the high-risk area. The entire Hongshan District, the existing snail site of Tianxingzhou, and end of the islet of Tianxingzhou were located in the yellow zone, belonging to the moderate-risk area. The remaining sites were located in either the blue or green zone, which represented negligible- and low–risk zones, respectively (Fig 3).

Table 3
Basic information of experts

Variables	Category	n	%
Sex	Male	8	66.67
	Female	4	33.33
Age(year)	30~40	3	25
	40~50	3	25
	50~60	6	50
Highest education	Doctor's degree	2	17
	Master's degree	4	33
	Bachelor's degree	6	50
Professional and Technical Title	Senior	4	33.33
	Deputy Senior	5	41.68
	Intermediate	1	8.33
	Primary	1	8.33
	No title	1	8.33
Years of working in schistosomiasis control	<15	4	33.33
	15~30	3	25
	≥30	5	41.67

Fig. 2. Schematic diagram of population characteristic distribution and snail point superposition. A: Tianxingzhou, B: Pak Sha Chau, C: Yangsi Ji Village.

Table 4
Expert authoritative results

	Basis of Juddgement (C_α)	Proficiency(C_β)	Cr
Possibility	0.817	0.867	0.842
Harmfulness	0.873	0.867	0.87
Uncontrollability	0.865	0.867	0.866

3.5. Three-dimensional risk matrix

The three-dimensional matrix of the existing Tianxingzhou snail sites fluctuated greatly, and the corresponding uncontrollability score was relatively large at the point of the greatest likelihood and harmfulness. However, the maximum risk value corresponded to the point of the lowest uncontrollability and harmfulness scores, indicating that the risk of outbreak in Tianxingzhou was very high (Fig 4A). The existing snail sites in Pak Sha Chau were likely least harmful; the corresponding risk events were most likely to occur and uncontrollable, indicating the seriousness of the risk events (Fig 4B).

At the historical snail sites, the downward fluctuation of the three-dimensional matrix indicated that the likelihood of the risk event was low; however, the event was likely to be moderately or highly harmful and uncontrollable once it occurred (Fig 4C). The likelihood of event uncontrollability at emergency monitoring points increased gradually with an increase in the risk score (Fig 4D). With the increase in risk values, the uncontrollability level first increased and then decreased; however, once the risk event occurred, the corresponding uncontrollability level increased instantaneously.

The overall three-dimensional matrix of the Hongshan District fluctuated little, but in the lowest-risk areas, the corresponding risk events were likely to be highly uncontrollable once they occurred; their severity score was high (Fig 4E). These findings were consistent with those of a two-dimensional risk matrix, offering both quantitative and qualitative evidence of the likelihood of the risk events of interest.

4. Discussion

Schistosomiasis is an infectious disease that spreads through contact with contaminated water. Although it is rare worldwide, several areas, including Wuhan, are considered to be in the acute phase of a schistosomiasis epidemic(Zhang and Zhao, 2020). The present study examined the distribution of a snail totality in Wuhan in 2020, showing that snail density and coverage area both increased in the Tianxingzhou and Hongshan districts. In addition, snails were found to be returning to their historical sites.

Previous studies have shown that risk assessment specialists are highly motivated (Song et al., 2020),. Indeed, in this study the specialists averaged more than 20 years of experience in schistosomiasis control, and the evaluation index value of >0.7 indicates high validity of expert evaluation. The present experts were knowledgeable and recognized in the field of schistosomiasis control.

The present findings indicate that the Tianxingzhou dike is associated with the largest risk value of schistosomiasis outbreak, followed by the Tianxingzhou and Hongshan districts overall. The Kaiser evaluation system allowed the participating experts to independently assess the entire Hongshan and Tianxingzhou districts, historical snail sites, and the Pak Sha Chau area. The overall risk value of Tianxingzhou was not derived from the weighted average of scores from all parts of the district; therefore, the presented value may be an underestimate. The results show that experts empower 21% of the public opinion influence index, highlighting the influence that the consensus of experts has on public opinion after the spread of acute infectious diseases. In the early stages of the COVID-19 outbreak, public disorientation created challenges to infection control (Rawson et al., 2020). In general, the spread of misinformation through social media and other channels may cause intervention delay, increasing the risk of poor schistosomiasis control. In the adjusted Kaiser model, expert experience and extent of knowledge were both accounted for, giving the results some practical relevance.

The two-dimensional risk matrix and three-dimensional risk matrix showed the occurrence level of each risk event in Wuhan City from plane and three-dimensional perspectives, respectively, which were consistent. The results obtained by the above three methods were essentially consistent, mutually verifying the reliability and credibility of the expert evaluation results.

The density of Oncomelania snails increased, which further indicated the possibility of schistosomiasis outbreak in Wuhan. During the period of New Coronavirus controled, Wuhan had took the strategy of blocking the city, which the residents were isolated from their homes that unable to go out to work or to live and work. This reduced the risk of water contact with schistosomiasis to some extent. However, the cancellation or postponement of snail inspection and extermination missed the best opportunity for snail control in spring, resulting in a large number of snails and a significant increase in snail density. Moreover, the snails which the lack of monitoring of the snail environment were reignited and the breeding density gradually increased in the historical snail spots. The closure of COVID19 partially expanded the increase in snail density and increased the chance of people coming into contact with the snails once production activities resumed, which increasing the risk of schistosomiasis outbreaks.

The limitations of this study include the strict requirements of the expert consultation method, content complexity, involvement of many evaluation indicators, and the time required for expert evaluation, which may have affected the presented estimates. All participants were senior experts in the field of public health; however, clinical experts

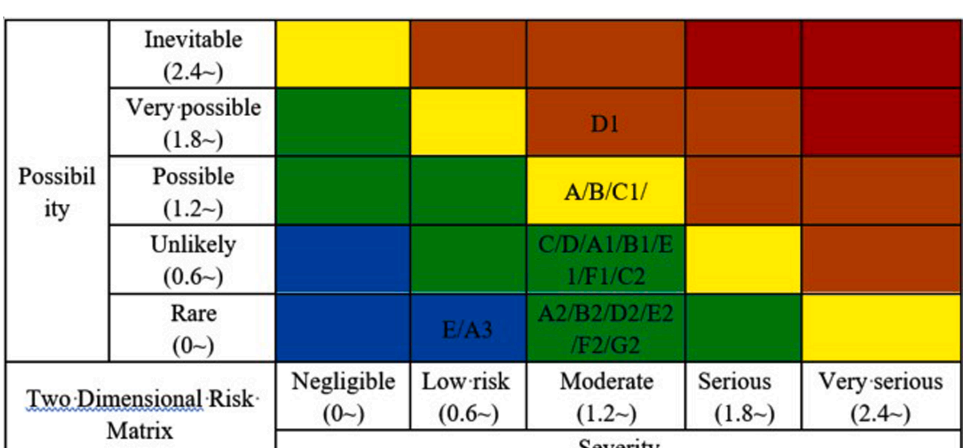

Fig. 3. Two-dimensional risk matrix diagram of *Schistosoma* control risk events in Hongshan District
Note: A=Hongshan District, B=Existing snail point-Tian xing Zhou, C=Existing snail point-Pak Sha Chau, D=Historical, E=Emergency monitoring point, A1=Tian xing Zhou-Chau head, B1=Tian xing Zhou-middle of the islet, C1=Tian xing Zhou-end of the islet, D1=Tian xing Zhou-north shore, E1=Tian xing Zhou-south bank, F1=Pak Sha Chau, A2=Hengdi Village, B2=Rocket Village, C2=Yangsiji Village, D2=Shizui Village, E2=Xiwan Village, F2=Jianhe Village, G2=Changjiang Village, A3= Qingling River.

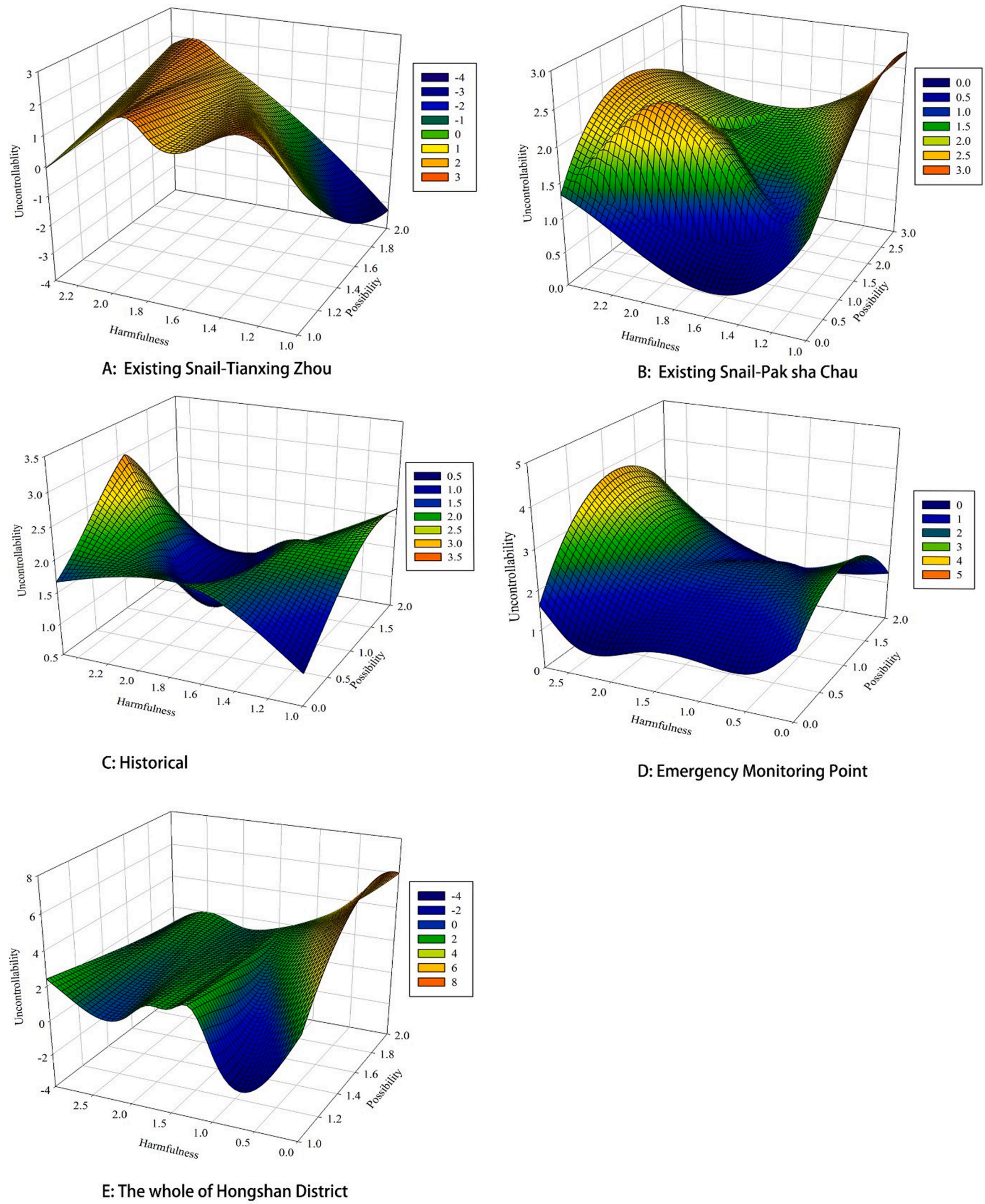

Fig. 4. Three-dimensional risk matrix diagram of Wuhan

dedicated to the treatment of schistosomiasis were not included, which may have biased the present findings(Humphrey-Murto and de Wit, 2019).

5. Conclusion

The outbreak of COVID-19 has resulted in an increase in the density of snails and the corresponding risk of schistosomiasis outbreaks in Wuhan. The Hongshan District as a whole and the existing snail site Tianxingzhou and that outside the northern bank of Tianxingzhou were associated with the highest risk of schistosomiasis infection. Moreover, the return of snails to their historical sites has increased the risk of schistosomiasis outbreaks in Wuhan. As the COVID-19 pandemic continues, Wuhan City authorities should strengthen schistosomiasis prevention and control measures, including historical snail site inspection, and increase the efforts associated with health education, including information on the risks of schistosomiasis.

Authors' contributions

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Funding

The China Association for Science and Technology (No.20200608CG111306).

Supporting information:

Supplementary Table 1: Evaluation Index System.

Supplementary Table 2: Risk value of the adjusted Kaiser model.

Declaration of Competing Interest

All authors declare that they have no conflict of interest.

Acknowledgments

The authors would like to thank the staff of the Hongshan and Jianan district of Schistosomiasis Control and Prevention for their hard work in data collection. The authors would also like to thank schistosomiasis specialist of Wuhan Center for Disease Control and Prevention who given advice. Editors and reviewers are thanked for their valuable comments.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.actatropica.2021.106224.

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