Assessment Of Schistosomiasis Transmission In The River Nile At Greater Cairo Using Malacological Surveys And Cercariometry

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Research Article

Keywords: Snail surveys, Biomphalaria alexandrina, Bulinus truncatus, cercariometry, schistosomiasis

Posted Date: February 11th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1331604/v1

Abstract

Continuous field studies on the abundance and distribution of freshwater snails and cercarial populations are important for schistosomiasis control programs. In the present work, snail surveys and cercariometry were conducted for four successive seasons at 12 sites on the Nile River banks in the area of Greater Cairo to identify potential transmission foci for schistosomiasis. In addition, water physicochemical parameters were recorded. The results showed that the electrical conductivity, total dissolved solids, dissolved oxygen, and pH were within the permissible levels, except that the water temperature showed an increase, especially in the spring season. Malacological surveys identified 10 native snail species at the studied sites of the Nile River, namely *Bulinus truncatus, Biomphalaria alexandrina, Lymnaea natalensis, Lanistes carinatus, Cleopatra bulimoides, Melanoides tuberculata, Helisoma duryi, Bellamya unicolor, Physa acuta, Thedoxus niloticus,* and one invasive snail species, *Thiara scabra*. The calculated diversity index indicated that the structure of snails' habitats was poor, while Evenness index indicated that the individuals were not distributed equally. Results of natural infection identified no schistosome cercariae in *B. truncatus* and *B. alexandrina*. However, results of the cercariometry recovered *Schistosoma* cercariae in all the surveyed sites during all seasons with variable distribution. The preceding data suggest that, there are still some active transmission foci for schistosomiasis infection in the Nile River. Moreover, the present finding highlights the importance of cercariomety as a complementary approach to snail samplings for the identification of transmission foci for schistosomiasis.

Introduction

Schistosomiasis is a widespread, neglected tropical disease that represent a public health problem in many tropical and subtropical countries. Schistosomiasis transmission has been reported in 78 countries, and recent estimates show that 229 million people required medication in 52 countries with moderate-to-high transmission (WHO 2022; https://www.who.int/news-room/fact-sheets/detail/schistosomiasis). Schistosomiasis is caused by blood flukes of the genus *Schistosoma*, of which three main species infect humans, namely *Schistosoma mansoni*, *S. haematobium*, and *S. japonicum*, which are transmitted by intermediate host snails *Biomphalaria* spp., *Bulinus* spp., and *Oncomelania* spp., respectively (Gryseels et al. 2006).

Egypt has long been thought to be endemic for intestinal schistosomiasis caused by *S. mansoni* infection, as well as uro-genital infection caused by *S. haematobium* infection. These two parasites are transmitted by *Biomphalaria alexandrina* and *Bulinus truncatus* snails, respectively (Othsman and Soliman 2015). *S. haematobium* infection spreads south of Cairo through the Nile Valley, whereas *S. mansoni* infection is restricted to the Nile Delta. The National Schistosomiasis Control Programme (NSCP), started in 1977, has been largely successful in reducing the prevalence of the two kinds of schistosomiasis (Barakat, 2013). Despite the plan initiated by the Egyptian Ministry of Health and Population (MoHP) and supported by the World Health Organization to inject 10 million dollars for five successive years to eliminate schistosomiasis (WHO 2016), transmission is still being recorded from different parts of Egypt for *S. mansoni* (El Sharazly et al. 2016; Haggag et al. 2017; Saad and Watany 2019) and *S. haematobium* (Bayoumi et al. 2016; Ahmed et al. 2020; El-Kady et al. 2020).

Schistosomiasis is mainly linked to human socioeconomic situation. In poor communities, there is an inadequate water supply and personal hygiene can lead to infection if confronted with manifested water (Bergquist and Whittaker 2012). Thus, it is important to ensure access to clean water and a healthy sanitation system. It is also important to assess the quality of bodies of water from time to time. Most of the research on schistosomiasis focuses on disease prevalence among humans, and little is done to survey and identify intermediate hosts of the disease. The pattern of schistosomiasis snail intermediate hosts' distribution and the prevalence of infection are among the measurable indicators that reflect the magnitude of transmission and offer precise maps for the potential distribution of the disease (Opisa et al. 2011). Integrating snail distribution with parasitological data from humans is a reliable approach for schistosomiasis mapping. However, distortions in human infection and snail sampling complicate identifying the presence and distribution of the intermediate host snails in the areas (Standley et al. 2010). In schistosomiasis control, the application of chemotherapy is effective in reducing schistosomiasis morbidity, but its high costs and logistical problems limit its application on a wider scale. Snail control is recommended as a preventive measure side by side with chemotherapy, but this needs a detailed knowledge of snail distribution (Opisa et al. 2011). A thorough understanding of the ecological factors that control snail abundance is needed to understand and predict their distribution (Habib et al. 2016). For example, temperature and water chemistry have an important impact on snail ecology, physiology, and infection with schistosomes (Appleton and Madsen, 2012; Habib et al. 2021).

Besides snail surveillance, the detection of schistosome cercariae in water is another important method for the identification of active transmission sites. In this regard, numerous techniques have been proposed for this purpose, such as the use of sentinel rodents (Chen et al. 2020) and cercariometry (Prentice, 1984; Ouma et al. 1989). Cercariometry is complementary to snail samplings because, in some cases, it provides information on the magnitude of the parasitic connection from vertebrates to snails (Theron, 1986). In addition, the distribution of ceracariae obtained from sampled snails is dependent on various ecological parameters such as water currents, periods of day light, layering effects, and the presence of snail predators. All of these parameters may differ on the same day and from season to season. Cercariometry can overcome these concerns and give a direct quantitative measure of the transmission potential of a specific water-contact site on a spatially and temporally basis (Prentice, 1984; Aoki et al. 2003).

Greater Cairo is given due consideration as one of the world's 15 largest cities by urban and population growth. Many industrial, commercial, tourist, and fishing activities extend along the Nile River banks as there are many water stations, rowing and social clubs, floating houses, restaurants, and water body police centers. Since the Nile River represents the main water resource for most Egyptian human beings, it is mandatory to periodically evaluate the characteristics of its water to identify the major sources of pollution and their environmental and health consequences, as well as to identify the potential sources of parasitic infection, especially the occurrence of schistosomiasis intermediate hosts. Ibrahim et al. (2005) conducted the most recent comprehensive study on the status of schistosomiasis transmission in the Nile River at Greater Cairo, using malacological and parasitological indicators in addition to cercariometry to detect schistosome larvae in the Nile. The result of that study revealed the distribution of *B. alexandrina* and *B. truncatus* in most of the studied sites. Moreover, the use of sentinel snails and mice as well as cercariometry identified active transmission of schistosomiasis at some sites along the Nile River. The present work was initiated to provide new insights on the risk of schistosomiasis transmission in the Nile River in the area of Greater

Cairo using malacological surveys to investigate and identify the snails' intermediate hosts and to examine them for natural infection as well as to use cercariometry to check the presence of any schistosome cercariae.

Materials And Methods

Study area

The research included 12 sites along the Nile, from Al-Qanater Al-Khairyah to El-Saff (Fig. 1 and Table 1). These are located in Greater Cairo in the south of the Nile Delta in the Nile basin (30° 03' 45.47" N, 31° 14' 58.81" E), the largest metropolitan area in Egypt and the largest urban area in Africa and the Middle East. The population density in this area is very high compared to other parts of Egypt, with a total population estimated at 20,901,000; area: 1,709 km^2; density: 10,400/km^2. Many human activities extend along the Nile River banks. The climate in Greater Cairo is a hot desert climate that characterizes subtropical regions. The annual average temperature is 21.3°C. Winter season is from December to February and it tends to be cold, moist, and rainy, while summer (June to August) is hot, dry, and rainless (Robaa, 2003). The warmest month is July, with a maximum temperature of 34°C, and the coldest month is January, with a maximum average temperature of 18°C. Precipitation is about 18 mm per year.

Sites selection

The sites were selected based on their proximity to human activities and the availability of aquatic vegetation that supports snail abundance. Sampling was done along the shoreline of the Nile using a motorized boat. The GPS coordinates for each site were recorded using the Google Map application (Google, LLC, California, USA) on an android smartphone (Table 1). Samples were collected during different seasons in 2019-2020 by two experienced technicians inspecting vegetation using a hand-held dip net (30 min/site) according to WHO (1965).

Table 1
GPS coordinates for the surveyed sites on Nile River at Greater Cairo area

Number	Sites	Latitude	Longitude
1	EL-Kanater El-khairiyah	30.174	31.142
2	El-Kerateen	30.154	31.146
3	West Cairo Electric Station	30.130	31.192
4	Ring Rd-Warrak	30.128	31.203
5	El-Warrak	30.095	31.230
6	Rod El-Farag	30.083	31.231
7	El-Tahrir	30.046	31.228
8	El-Manial	30.019	31.217
9	El-Hwamdeyah	29.987	31.221
10	Maadi	29.962	31.243
11	Helwan water station	29.925	31.283
12	Marazik	29.793	31.296

Water physicochemical characteristics

Water characteristics that might affect snail abundance were recorded. Dissolved oxygen (mg/L) was recorded by a dissolved oximeter electrode (HANNA HI 9146; Hanna Instruments, Nasr City, Egypt). Water temperature (°C), conductivity (measured in μmohs/cm), and pH were measured using a PH-200 handheld portable pH and temperature meter and an AP-2 aquapro conductivity meter (HM Digital, Inc., Culver City, USA).

Snail sampling

Collected snails were transferred to plastic aquaria containing water from the same site until they were transferred to the laboratory for identification and detection of trematode infections. Snails were identified based on shell morphology according to published keys (Mandahl-Barth, 1962; Brown, 1994). For trematode infection, snails from the same species were placed individually in multi-well plates (2 ml of dechlorinated tap water/well) and exposed to artificial light for 2 h (Frandsen and Christensen, 1984). The plates were then examined under a stereomicroscope. Non-infected snails were monitored for 4 weeks and examined for cercarial shedding on a weekly basis as described beforehand. Cercariae were identified based on gross morphological characteristics, swimming behaviour, and resting position as described by Frandsen and Christensen (1984). Cercariae belonging to the genus *Schistosoma* (*S. haematobium* and avian schistosomes) were identified by their morphological features.

Cercariometry

Cercariometry was performed at each site preceding snail collection based on the method of Prentice and Ouma (1984) with some modification (Yousif et al. 1996). Briefly, a 20-L sample was collected from a wide area using a suction bump attached to a 5 L conical cylinder. From the cylinder extends a long hose, tightly sealed at the opening by a rubber band that reaches the water surface. Following the collection of water, the sample was directly centrifuged using a tube centrifuge with an opening at the bottom for runoff (Fig. 2). The precipitates from the tubes were then collected in a 200-ml plastic bucket. The process was repeated four times, and at the end, formalin was added to the sample to kill any cercariae present before sealing and transferring it to the laboratory. In the laboratory, iodine solution was added to the samples before checking under dissecting microscope for cercariae presence. The number of schistosome cercariae was recorded (Ouma et al. 1989).

Statistical analysis

Data of snail species abundance were statistically analyzed for the significance of differences between different seasons by one-way ANOVA test at $p < 0.05$, using the statistical program SPSS version 17 (SPSS, Inc., Chicago, IL) for windows. Diversity indices for species richness were calculated using Margalef's diversity index (Margalef, 1948), and Evenness index (Hill, 1973).

Results

Water physicochemical parameters (i.e., water temperature, electrical conductivity (EC), total dissolved solids (TDS), dissolved oxygen (DO), and pH) were recorded *in situ* during sample collection (Table 2). The highest average temperature degrees among all sites investigated were recorded for the summer and spring seasons with 29.2 and 28.02 °C, respectively. The lowest temperature was recorded during winter (17.6 °C). The pH was within the neutral range from 7.3 to 7.43 during all seasons. Dissolved oxygen values in autumn, winter, and spring were significantly high compared to its value in summer. The concentration of dissolved oxygen ranged from 4.86 mg/l in summer to 9.4 mg/l in winter. Total dissolved solids fluctuated from 237.4 mg/L in spring to 273 mg/L in autumn. The electrical conductivity ranged from 340.5 µmohs/cm in summer to 435.4 µmohs/cm in winter.

Malacological surveys identified a total of 11 snail species at the studied stations of the Nile River, including 10 native species; *Bulinus truncates*, *Biomphalaria alexandrina*, and *Helisoma duryi* (Family: Planorbidae), *Lymnaea natalensis*. (Family: Lymnaeinae), *Lanistes carinatus* (Family: Ampullariidae), *Cleopatra bulimoides* (Family: Paludomidae), *Melanoides tuberculata* (Family: Thiaridae), *Bellamya unicolor* (Family: Bellamyinae), *Physa acuta* (Family: Physidae), *Theodoxus niloticus* (Family: Neritidae) and one invasive snail species, *Thiara scabra* (Family: Thiaridae).

The total number of collected snails was 1339 specimens during four seasons, and the highest number of snails (669) was recorded during the summer season. *Melanoides tuberculata* and *Bellamya unicolor* were the most abundant snail species recording 217 and 228, respectively. The most common medically important snail species was *B. truncatus*, with 74 individuals. The invasive snail, *T. scabra* (Fig. 3) was found during all seasons with a total number of 91 individuals (Table 3). Snail distribution data for the summer, autumn, winter, and spring seasons of 2019-2020 are summarized in Figure (4). *M. tuberculata* and *B. unicolor* showed 24% and 22%, respectively, of the total number of collected snails during summer, while *C. bulimoides* was 39% during autumn. On the other hand, *T. niloticus* showed the highest percentage of 20% during winter, while both *L. carinatus* and *B. unicolor* had the highest percentages during spring (33%).

Table 2
Water physicochemical parameters during different seasons

Sites		El Kanater	Kerateen Island	Electrical Station	Al Daary	El Warrak	Road Elfarag	Al Tahreer	El Manyal	El Hawa-mdeya	El Maady	Helwan	El Saff	M[illegible]
Parameters	**Seasons**	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**	**S11**	**S12**	
Temp (°C)	Summer	25	29.5	29.5	29.5	31.5	31	29.8	29.5	29.9	30	25	25	**2**[illegible]
	Autumn	20.9	20.1	20.1	19.7	19.7	19.9	20.3	20.4	20.4	20.3	22.3	22.3	**2**[illegible]
	Winter	17.3	17.2	17.4	-	16.8	18.3	18.3	18.6	19.1	18.9	15.9	16.7	**1**[illegible]
	Spring	28.6	28.2	28.6	28.2	28.5	27.9	27.8	27.7	29.4	28.5	26.4	26.5	**2**[illegible]
pH	Summer	7.2	7.1	7.21	6.98	7.3	7.35	7.63	7.6	7.79	7.75	7.6	7.2	**7**[illegible]
	Autumn	7.6	7.7	7.6	7.9	7.4	7.4	7.2	7.1	6.9	7	6.9	6.9	**7**[illegible]
	Winter	7.05	7.21	7.7	-	8.2	7.3	7.2	7.46	7.7	7.43	6.82	7.01	**7**[illegible]
	Spring	7.6	7.33	7.21	7.53	7.6	7.21	7.4	7.28	7.8	7.5	7.34	7.41	**7**[illegible]
DO (mg/L)	Summer	4.67	4.9	4.87	5.03	4.73	4.25	5.2	5.1	4.6	4.52	5.92	4.67	**4**[illegible]
	Autumn	7.8	7.4	8.9	7.9	8.4	9	7.6	8	8.9	9.4	8	7.7	**8**[illegible]
	Winter	8.9	10.7	8.8	-	8.9	8.83	9.2	10.2	8.5	10.1	7.9	9.73	**9**[illegible]
	Spring	8.66	9.38	8.4	9.77	10.2	7.8	9.2	9	9.07	7.33	11.7	12.2	**9**[illegible]
TDS (mg/L)	Summer	132	266	274	243	283	281	367	242	256	248	260	132	**2**[illegible]
	Autumn	269	273	200	294	281	222	308	313	306	215	397	202	**2**[illegible]
	Winter	244	226	240	-	244	235	320	338	328	240	263	255	**2**[illegible]
	Spring	260	255	261	245	226	233	223	228	230	229	224	235	**2**[illegible]
EC µmohs/cm	Summer	206	318	397	287	406	405	367	347	373	380	206	267	**3**[illegible]
	Autumn	386	393	401	425	402	447	446	453	450	432	410	425	**4**[illegible]
	Winter	353	326	348	-	350	450	475	480	795	465	372	375	**4**[illegible]
	Spring	370	365	375	350	322	336	321	330	325	326	335	340	**3**[illegible]

(-) dash refers to undetermined data during winter season

Table 3
The abundance of snails' species during different seasons

Snail species	Summer	Autumn	Winter	Spring	Total	% of abundance
Bulinus truncatus	29	21	15	9	74	5.50
Biomphalaria alexandrina	24	–	–	–	24	1.80
Lymnaea natalensis	20	–	–	1	21	1.60
Lanistes carinatus	86	32	1	59	178	13.30
Cleopatra bulimoides	44	37	36	5	122	9.10
Melanoides tuberculata	163	35	17	2	217	16.20
Helisoma duryi	76	31	19	10	136	10.20
*Thiara scabra**	41	28	8	14	91	**6.80**
Bellamya unicolor	150	–	20	58	228	17.00
Physa acuta	18	1	36	6	61	4.60
Theodoxus niloticus	18	117	38	14	187	14.00
Total	**669**	**302**	**190**	**179**	**1339**	
Mean ± SE	60.82±15.9^{B}	27.45±10.1^{A}	17.27±4.4^{A}	16.18±6.5^{A}		
F-value	**4.214**					
P- value	**0.011**					

*****an invasive snail species. ^{A}insignificant difference at $p > 0.05$; ^{B}significant difference between different seasons at $p < 0.05$

The diversity index was below (1), which indicates that the structure of snails' habitats was poor. Meanwhile, Evenness index ranged between 0.037 to 0.048, which indicated that the individuals were not distributed equally (Fig. 5).

Screening of the collected snails for natural infection did not identify any trematode cercariae. However, the results of cercariometry revealed the presence of cercariae belonging to the genus *Schistosoma* in all investigated sites. However, it was not possible to identify the exact species (*mansnoni* or *haematobium*) under microscope. The highest percentage was during the spring season (100% cercarial distribution; cercariae were present in all investigated sites), followed by autumn (42%), summer (25%), and winter (8%). Out of the 12 investigated sites, El-Sasff and Helwan sites, showed the highest percentages of cercarial with 14 and 22%, respectively, during the summer season (Fig. 6).

Discussion

The Nile River is a vital source of life in Egypt, particularly in the Greater Cairo area, where many human activities take place along the river's banks. While these activities have a detrimental impact on the water quality and biodiversity of the Nile, they also represent a potential source of parasitic infections, especially with schistosomiasis, a disease that has a long history with Egyptian human beings. Therefore, it is crucial to investigate any risks of schistosomiasis transmission represented by the presence and distribution of snails, the intermediate hosts or cercariae, the human infective stages. The distribution of the snails that transmit schistosomiasis is controlled by various biotic and abiotic factors (Gilioli et al. 2017; Habib et al. 2021) and it delineates the epidemiology of the disease (Habib et al. 2016; Habib et al. 2021). Moreover, the abundance and distribution of snails are unpredictable, making it challenging to understand their impacts on indigenous freshwater populations (Larson et al. 2020).

The chemical parameters of water for the surveyed sites along the Nile River in Greater Cairo revealed that water temperature tends to increase during the spring season (26.4–29.4ºC), which was nearly equal to that recorded during the summer season (25-31.5°C) in the current study. These results exceeded the concern level determined by the National Recommended Water Quality Criteria for temperature (25ºC) (EPA 2009). Although summer was the highest season in terms of snail numbers collected (669 snails), there was no association between temperature and the number of snails collected. This was obvious in spring, for example, where the mean temperature from all sites was 28.02°C and the number of snails collected was the lowest (179 snails) of all seasons. Temperature is a major contributor to ongoing climate change (Stocker, 2014). The change in temperature has an evident effect on schistosomiasis as it controls the distribution and reproduction of the snail intermediate hosts (Campbell-Lendrum et al. 2015). Opisa et al. (2011) found a positive correlation between temperature and the abundance of *B. pfeifferi*, *B. sudanica*, and *Bulinus globosus*. Mathematical modeling indicates that the effect of small temperature rises in areas where schistosomiasis is prevalent will be determined by the species of snail acting as an intermediate host. For example, the temperature range for the survival of simulated *B. alexandrina* populations was 12.5-29.5°C compared to 14.0-31.5°C for *B. pfeifferi* populations. In areas where *B. alexandrina* is the host, a 2°C increase in temperature can more than double the risk of *S. mansoni* infection (McCreesh and Booth 2014).

Under laboratory conditions, both *B. alexandrina* and *B. truncatus* have the same optimum temperature for growth and reproduction (26-28°C) (El-Emam and Madsen 1982). However, El-Khayat et al. (2009) declared that *B. alexandrina* and *B. truncatus* could tolerate a wide range of temperatures reaching 34°C. Furthermore, Joof et al. (2021) observed that water temperatures ranged from 22.1 to 38.3˚C did not show any statistically significant association with the seasonal abundance of *Bulinus* spp. *Bulinus* snails can tolerate higher temperatures due to their ability to aestivate and adapt, which explains the occurrence of *S. haematobium* in warmer areas than *S. mansoni* (Rubaba et al. 2016). Schistosomiasis transmission can occur at lower or higher threshold temperatures. For instance, *S. mansoni* can maintain its life cycle at low temperatures of as low as 11.5°C and high temperatures of up to 40°C (Pflüger 1982). Studies on the effect of temperature on *Schistosoma japoniucm* and its snail host, *Oncomelania hupensis*, revealed that the rise in temperature could expand the potential transmission areas of schistosomiasis japonica (Yang et al. 2005; Zhou et al. 2008). However, Stensgaard et al. (2013) expected that climate change and global warming will reduce the habitats suitable for schistosomiasis vectors in Africa.

The pH of the water was found to be neutral at all the investigated sites during different seasons. Spring and summer showed the highest and lowest snail abundance, respectively, and yet both were identical in their pH values. The impact of pH on snails' abundance remains a controversial issue. Marie et al. (2015) found that the highest percentage of snails was recorded in the neutral pH range, while it decreased when pH was below 7 and higher than 9. Also, Makela and Oikari (1992) reported that an acidic pH level was shown to be unfavorable to the occurrence of molluscs. Similarly, Joof et al. (2021) found the abundance of *Bulinus* snails to increase with a decrease in water pH. Furthermore, Logronio (2020) observed that pH was negatively correlated to the number of infected snails and declared that the highest level of water pH may lead to a decrease in infection level. However, Opisa et al. (2011) did not find any correlation between pH (at 6.7–11.2) and the abundance of *B. pfeifferi*, *B. sudanica*, and *Bulinus globosus.*

The present work showed that dissolved oxygen was recorded at the lowest level during the summer season range of 4.25–5.92 mg/L. Previous research has found that the optimal dissolved oxygen concentration for snail intermediate hosts is between 0.4 and 16.0 mg/L (Harman and Berg 1971; Yirenya-Tawiah et al. 2011). These findings are in accordance with the present results of snail surveying, where the highest snail abundance (669) was recorded during the summer season. *B. pfeifferi*, *B. sudanica*, and *L. natalensis* snails prefer sites with low dissolved oxygen (Olkeba et al. 2020). The negative correlation between snail abundance and the high ration of dissolved oxygen may be attributed to the snails' ability to occupy sites rich in organic matter (Gallardo-Mayenco and Toia 2002). With regards to total dissolved solids (TDS), the highest mean value was recorded in the autumn season, with a concentration of 273 mg/L. *Biomphalaria* snails can be found in habitats with extremely variable TDS concentrations. For example, Barbosa et al. (2017) found *B. straminea* and *B. glabrata* in breeding sites with TDS ranging from 148 to 661 ppm. Moreover, Allan et al. (2020) found a positive correlation between the presence of intermediate host snails and total dissolved solids. The present study indicated that the summer season had the lowest conductivity with 340.5 µmohs/cm. This is correlated with the observed highest abundance of snails during the summer season. A positive correlation was also observed with the abundance of different *Biomphalaria* species and low conductivity (Kazibwe et al. 2006; Rowel et al. 2015; Trienekens et al. 2022).

Melanoides tuberculata and *Bellamya unicolor* were the most abundant snails recorded (16.2 and 17.1%, respectively) in the current study. These findings are partially consistent with El-Khayat et al. (2017), who found *M. tuberculata* and *B. unicolor* abundances in the Nile River to be 13.9 and 16.7%, respectively. Meanwhile, the most common medically important snail species was *B. truncatus*, and this result agrees with the findings of Ibrahim et al. (2005), who revealed that *B. alexandrina* was less abundant than *B. truncatus* in the Nile River at Greater Cairo. On the other hand, other species of competitor snails such as *Pomacea glauca, Marisa cornuarietis, Melanoides tuberculata*, and *Helisoma duryi* may also have a role in the control of medically important snail populations (Pointier et al., 2000; Frandsen and Madsen, 1979). Also, Pointier et al. (1994) attributed the absence of *B. glabrata*, snail host of *S. mansoni*, to the invasion of *Thiara granifera* and *M. tuberculata* in the rivers of the littoral central region of Venezuela.

Several factors have been reported to introduce invasive freshwater snails into new water bodies (Yirenya-Tawiah et al. 2011; Oladejo et al. 2021). In the present work, the invasive snails, *T.a scabra*, were found during all seasons, with a total number of 91 individuals and an abundance percentage of 6.8%. Previous surveys have shown that the genus *Thiara* (Roding, 1798) was not considered to be represented in the molluscan fauna of Egypt (Ibrahim et al. 2006; Hussein et al. 2011; Abd Elwakeil et al. 2013; Abdel-Gawad and Mola 2014; Lotfy and Lotfy 2015). However, *T. scabra* as an invasive snail has been recorded for the first time in the Nile stream, Upper Egypt by Moustafa and Hussien (2018). These findings may be the interpretation of the current abundance of *T. scabra* snails at investigated sites in the Nile River. *T. scabra* is native to Asia with a distribution range from South and Southeast Asia, South China, and western Pacific Islands (Brandt, 1974). Its introduction to the Nile River still unknown until now. However, it might be introduced by some migratory birds. Recently, there has been an increasing interest among parasitologists in the Thiaridae family for harboring numerous species that serve as intermediate hosts of human and animal diseases. *T. scabra* acts as an intermediate host for different trematode species. The most dangerous ones are the lung flukes of the genus *Paragonomus* and the intestinal flukes (Jayawardena et al. 2010; Krailas et al. 2011; Chontananarth et al. 2017). In the present study, the findings revealed that the invasive snails were less than the indigenous species. On the contrary, Oladejo et al. (2021) found that the invasive freshwater snails were more abundant (82.15%) than indigenous species (17.85%). Also, Oloyede et al. (2017) recorded 77.17% of invasive freshwater snails at Eleyele dam, southwest Nigeria.

According to the calculated diversity index, the present results indicated that the structure of snails' habitats was poor, while the Evenness index indicated that the individuals were not distributed equally. These results are in parallel with Mahmoud and Sayed (2018), who found 13 species of snails at 5 sites in the Damietta Governorate with a diversity index ranging from poor to bad. Also, El-Zeiny et al. (2021) studied the five stations in Damietta Governorate, Egypt, and discovered that the diversity index ranged from poor to bad. Many agricultural chemicals, the degree of aquatic pollution (Ojija 2015), and the speed of the water may lead to changes in the status of snail habitats and cause adverse effects on their distribution and population (Mahmoud et al. 2018).

No schistosome cercariae were recovered from neither *B. alexandrina* nor *B. truncatus* snails collected during the present snail survey. However, cercariometry identified *Schistosoma* cercariae in the investigated sites during the spring season (100% cercarial distribution), followed by autumn (42%), then summer (25%), and winter (8%). Cercariometry is a technique for determining the diurnal, seasonal, and spatial distribution of cercariae in natural water bodies. Cercariometry has some flaws in its practices and data analysis, but it does provide valuable information on active schistosomiasis transmission sites (Aoki et al. 2003). The results of cercariometry and snail sampling were significantly different. The distribution of cercariae was not positively correlated with *B. alexandrina* or *B. truncatus* numbers or the occurrence of natural infection. We couldn't confirm whether the recovered cercariae belong to *S. mansoni* or *S. haematobium*, but we suggest that these cercariae belong to schistosomiasis haemtaobia because *B. truncatus* was found during all seasons while *B. alexandrina* was found only in the summer season. These findings show that cercariometry is more sensitive than other methods for detecting potential schistosomiasis transmission sites. This is in accordance with Yousif et al. (1996), who found that snail sampling revealed only 7 positive sites in the governorates of Kafr El-Sheikh, Ismailia, and El-Minia, whereas cercariometry revealed 45 positive sites. In Kwale, Kenya, Muhoho et al. (1997) observed an apparent discrepancy between cercariometry and snail sampling results. However, Ouma et al. (1989) discovered a moderately positive relationship between *S. mansoni* cercariae recoveries and the number of infected *B. pfeifferi* detected by sampling. Because of the complexities of transmission foci, water velocity, snail distribution, and cercarial shedding patterns from snails, establishing a precise relationship between cercarial densities and the number of infected snails is likely difficult. Furthermore, the majority of malacological surveys used to determine the natural infection of vector snails rely on a single annual sample of densely packed snail populations spread across a large area. In transmission foci where snail host species sampling is the only method used, this method may underestimate the true level of infectivity. Schistosomiasis transmission in large bodies of water such as the Nile is likely seasonal (Kloetzel and Schuster 1988). As a result, both cercariometry and snail surveys are recommended for pinpointing schistosomiasis transmission sites (Aoki et al. 2003).

Conclusion

Schistosomiasis remains a public health problem in some parts of Egypt. The present study identified some transmission foci for *S. haematobium* along the Nile River in the area of Greater Cairo. The present data indicate that periodic surveying of snail species, particularly those that serve as intermediate hosts of digenetic trematodes, is important for disease control. Combining snail sampling with cercariometry improves the accuracy of identifying schistosomiasis transmission foci in large bodies of water like the Nile. It is also important to identify the species of snails distributed in the Egyptian water courses to check for the presence of any invasive species that pose a threat to human health. Further studies are needed to investigate the origin of invasive snails, the relationship between the invasive and indigenous freshwater snails, and how they established themselves in the habitat and developed ecological links with the indigenous species.

Declarations

Acknowledgements

This work supported by an internal research project (grant No. 104C) from Theodor Bilharz Research Institute (TBRI), Egypt.

Compliance with ethical standards

Conflict of interest

The authors declare that they have no conflict of interest.

Ethical approval

All applicable institutional, national, and international guidelines for ethics were followed.

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Figures

Figure 1

A map of Egypt showing the investigated sites on the Nile River

Figure 2

Components of cercaiometry apparatus used in the current study

Figure 3

The invasive snails, *Thiara scabra*. Scale bar = 0.5 mm

Figure 4

Distribution of snail samples collected from the Nile River in the area of Greater Cairo during summer, autumn, winter and spring seasons 2019-2020

Figure 5

Diversity and Evenness indices during different seasons

Figure 6

The percentage of cercariae detected at investigated sites