PLOS Neglected Tropical Diseases

RESEARCH ARTICLE

Schistosomiasis and water resources development in Africa: A scoping review and multi-case evaluation of associated snail control

May N. Sule[1]*, Ibrahim El Lahham[1], Mutinta N. Munkombwe[1], Patricia Nasike[1], Anouk Gouvras[2], David Rollinson[2], Rashid Mbaziira[3], Comfort Kanshio[3], Giulio A. De Leo[4]

1 Centre for Water, Environment and Development, Cranfield University, Cranfield, United Kingdom, **2** Global Schistosomiasis Alliance, London, United Kingdom, **3** African Ministers' Council on Water (AMCOW), Asokoro Abuja, Nigeria, **4** Department of Oceans and Woods Institute for the Environment, Hopkins Marine Station, Stanford University, Pacific Grove, California, United States of America

* m.sule08@alumni.imperial.ac.uk

Check for updates

OPEN ACCESS

Citation: Sule MN, El Lahham I, Munkombwe MN, Nasike P, Gouvras A, Rollinson D, et al. (2025) Schistosomiasis and water resources development in Africa: A scoping review and multi-case evaluation of associated snail control. PLoS Negl Trop Dis 19(6): e0013180. https://doi.org/10.1371/journal.pntd.0013180

Editor: Olaf Horstick, University of Heidelberg, GERMANY

Received: August 6, 2024

Accepted: May 24, 2025

Published: June 12, 2025

Copyright: © 2025 Sule et al. This is an open access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

Data availability statement: The data used in this submission is available in the Supporting information.

Funding: This work was supported by the UK Engineering and Physical Sciences Research Council (EPSRC) Impact Acceleration Award

Abstract

Background

Water resources development (WRD), specifically infrastructural man-made water bodies such as dams and irrigation schemes, are built to improve water supply, provide energy, and enhance food security. However, dams and irrigation schemes may lead to a dramatic increase in the prevalence of schistosomiasis.

Methodology/Principal findings

We conducted a scoping review of WRD impacts on schistosomiasis transmission risk in Africa using electronic databases including Scopus, Web of Science, and grey literature. From 1483 retrieved records, we assessed 186 full-text papers and identified 122 articles covering 54 dams and irrigation schemes in 32 African countries. We found that, although the relationship between WRD and schistosomiasis transmission risk is well-documented in the scientific literature, the vast majority of the approximately 1,600 medium- to large-sized dams currently operating in endemic regions of Africa lack before-and-after prevalence data necessary to evaluate their actual impact on schistosomiasis transmission. Our analysis revealed that rigorous epidemiological data to assess WRD's effects exist for only 11 dams across 9 countries. Additionally, only a limited number of studies provided information on schistosomiasis control methods, surveillance, or monitoring for WRD. Few countries have implemented engineering and biological snail control measures, some of which have proven effective, enabling us to identify successful interventions employed at various stages of the WRD lifecycle. Lastly, to assess these measures in detail, we selected case studies from Africa that illustrate the success and challenges of schistosomiasis control with regard to WRD, thus gaining insights of the global relevance of lessons learnt for the future development of water resources.

block grant allocation to Cranfield University (grant # EP/X525534/1 to MNS). GADL was partially supported by the Belmont Collaborative Forum on Climate, Environment and Health (NSF grant # 2522282) and by the NSF (EEID) grant #DEB – 2011179. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Competing interests: The authors have declared that no competing interests exist.

Conclusions/Significance

Our analysis highlighted that an integrated and coordinated approach is vital for the successful control of schistosomiasis transmission risk associated with Water Resources Development. We provide key recommendations which could be adopted by the Continental Africa Water Investment Programme (AIP) with the ultimate goal of decreasing prevalence and moving towards elimination.

Author summary

Man-made water bodies such as dams and irrigation schemes, are built to improve water supply, provide energy, and enhance food security. However, dams and irrigation schemes may lead to a dramatic increase in the prevalence of schistosomiasis (Bilharzia), a neglected tropical disease (NTD) with water snails as intermediate hosts. Schistosomiasis poses a significant public health threat in tropical and subtropical regions worldwide, particularly in low-income countries with inadequate water supply and poor sanitation. This scoping review and multi-case study assessed the impact on schistosomiasis following the construction of dams in Africa. Our results show that epidemiological data are available for only a tiny fraction of the ~1600 dams in operation in Africa. Data show that schistosomiasis does increase with the construction of dams but engineering and biological snail control measures, implemented in a few African countries, can reduce transmission risk. Example case studies further reflect on the successes and failures of implementation measures. We provided key recommendations which could be adopted by the Continental Africa Water Investment Programme (AIP) as part of the Programme for Infrastructure Development in Africa Priority Action Plan. Dams are earmarked to be part of the AIP delivery towards climate resilient water and sanitation investments by 2030. Political commitment, advocacy and multisectoral collaboration to support a health and environment integrated approach to dam development will be essential for achieving success.

1. Introduction

Schistosomiasis, also known as Bilharzia, is a neglected tropical disease (NTD) which poses a significant public health threat in tropical and subtropical regions worldwide, particularly in low-income countries [1]. With more than 250 million people affected in 78 countries and over 700 million at risk of infection, the vast majority in sub-Saharan Africa, schistosomiasis represents a significant health burden [2]. This parasitic disease, caused by trematode worms of the genus *Schistosoma,* is particularly prevalent in regions with inadequate water supply and poor sanitation, and is one of the most common NTDs worldwide [1].

The life cycle of the parasite typically involves two main hosts - humans and freshwater snails. The parasite develops in snails residing in freshwater (hereafter

referred to as snail vectors). The most common species of snail that serve as hosts for schistosomes belong to the genera *Biomphalaria, Bulinus* and *Oncomelania*. Each transmits a different schistosome species: *Biomphalaria* hosts *Schistosoma mansoni* in Africa, the Caribbean and South America, *Bulinus* hosts *S. haematobium* in Africa and *Oncomelania* hosts *S. japonicum* in China, Philippines and Indonesia [2]. The snails have different habitat requirements and controlling snail populations is a key strategy in reducing the transmission of schistosomiasis. The larval stages of the parasite, the cercariae, exits the aquatic snail into freshwater and enter the bloodstream of the human host by penetrating the skin of individuals who come into contact with contaminated freshwater [2]. Once inside the human body, the schistosome parasites mature into adult worms and migrate to the veins surrounding the intestines or bladder causing intestinal (*S. mansoni, S. intercalatum, S. guineensis, S. japonicum, S. mekongi*) and urogenital (*S. haematobium*) schistosomiasis, with symptoms of painful and bloody defecation or urination respectively [3]. If left untreated schistosome infections cause immune reactions and lead to progressive organ damage [2].

Water resources infrastructure, specifically man-made water bodies, such as dams and irrigation schemes, have been built to improve water supply, provide energy, and enhance food security. There are presently ca. 1,600 dams in operation in Africa and over 300 are currently being constructed or are proposed [4]. This number does not include the numerous small reservoirs used for cattle and small-scale agriculture. The construction of dams creates an aquatic habitat that is generally suitable for the snail vectors to thrive, leading invariably to an explosion of snail populations [5,6].

In Africa, limited integrated approaches exist between sectors involved in water resources development and management, such as the water, agriculture and energy sectors [7]. The lack of coordination leads to the absence of, or lack of compliance with, or enforcement of, regulatory frameworks, social and health impact assessments. Because of the lack of coordination, the development of large dams has impacted sustainable economic wellbeing, resilience in communities, health and gender equality [8]. Globally, 13.6% of people at risk of schistosomiasis live in close proximity to irrigation schemes and large dam reservoirs [9]. Given the significant disease prevalence in Africa, it is crucial to understand the connection between the water, energy and agricultural sectors, so that regulatory actions and control measures are adopted for schistosomiasis when introducing water infrastructure projects. This is especially important because of the Continental Africa Water Investment Programme (AIP) which has been adopted as part of the Programme for Infrastructure Development in Africa Priority Action Plan by Heads of State and Government of the African Union (AU), comprising all 55 African member states. Dams are earmarked to be part of the AIP delivery, which is leveraging an additional $30 billion towards climate resilient water and sanitation investments by 2030.

The evidence of a link between dams and schistosomiasis was established following the meta-analysis by Steinmann et al., 2006 [9] and Sokolow et al., 2017 [10]. Both those reviews merged information about dams with datasets, such as the Global Neglected Tropical Disease Database GNTD, that jointly provided evidence of a before/after effect. However, most of those studies reported schistosomiasis prevalence data before dams' construction, with studies that reported schistosomiasis prevalence data after dams' construction, sometimes in different villages, schools or locations at variable distance from the dam. Hence, they were not designed as Before-After-Control-Impact (BACI) analyses. For the majority of the dams (~1200), this information is not available, generally because of the lack of baseline epidemiological data before the dam was built and also often because of the lack of good data after the construction of the dam. The majority of these types of water resources infrastructures are built without adequate epidemiological monitoring and surveillance plans in place for schistosomiasis. Perhaps this is because schistosomiasis has not often been considered a major issue within existing regulatory frameworks such as environmental and social impact assessments.

Hence, the objectives of this scoping review are: (i) to assess the impact of dams and irrigation schemes on schistosomiasis prevalence in humans across Africa and (ii) to assess whether engineering and biological snail control measures implemented at various stages of the lifecycle of water management infrastructures have been able to curb the negative health outcomes of water resources development. In addition, we provide a selection of recommendations drawing on lessons learnt from Africa and other global examples. This study will support efforts to enhance water resources

management and public health outcomes in Africa and will help inform policy and decision-making at the national and regional levels.

2. Methodology

Our study protocol followed the PRISMA for Scoping Reviews (PRISMA-ScR) standards [11]. A comprehensive literature search was carried out from 6 March – 29 May 2023 to identify all relevant studies. The search was repeated from 20 – 21 October 2023 to identify any new relevant articles.

2.1. Search strategy

Firstly, African countries with dams and irrigation schemes were identified using the Food and Agriculture Organization of the United Nations' (FAO) Global Information System on Water Resources and Agricultural Water Management (FAO AQUASTAT). Secondly, the countries identified were then matched with the World Health Organization's (WHO) Expanded Special Project for the Elimination of Neglected Tropical Diseases (ESPEN) 2022 database of endemicity in prevalence of schistosomiasis across Africa, as shown in Fig 1. Through this process, we identified dams and irrigation schemes in African countries. A systematic search of studies relating to these identified dams, irrigation schemes and countries was conducted through searches of the following academic databases: Web of Science, Scopus and PubMed.

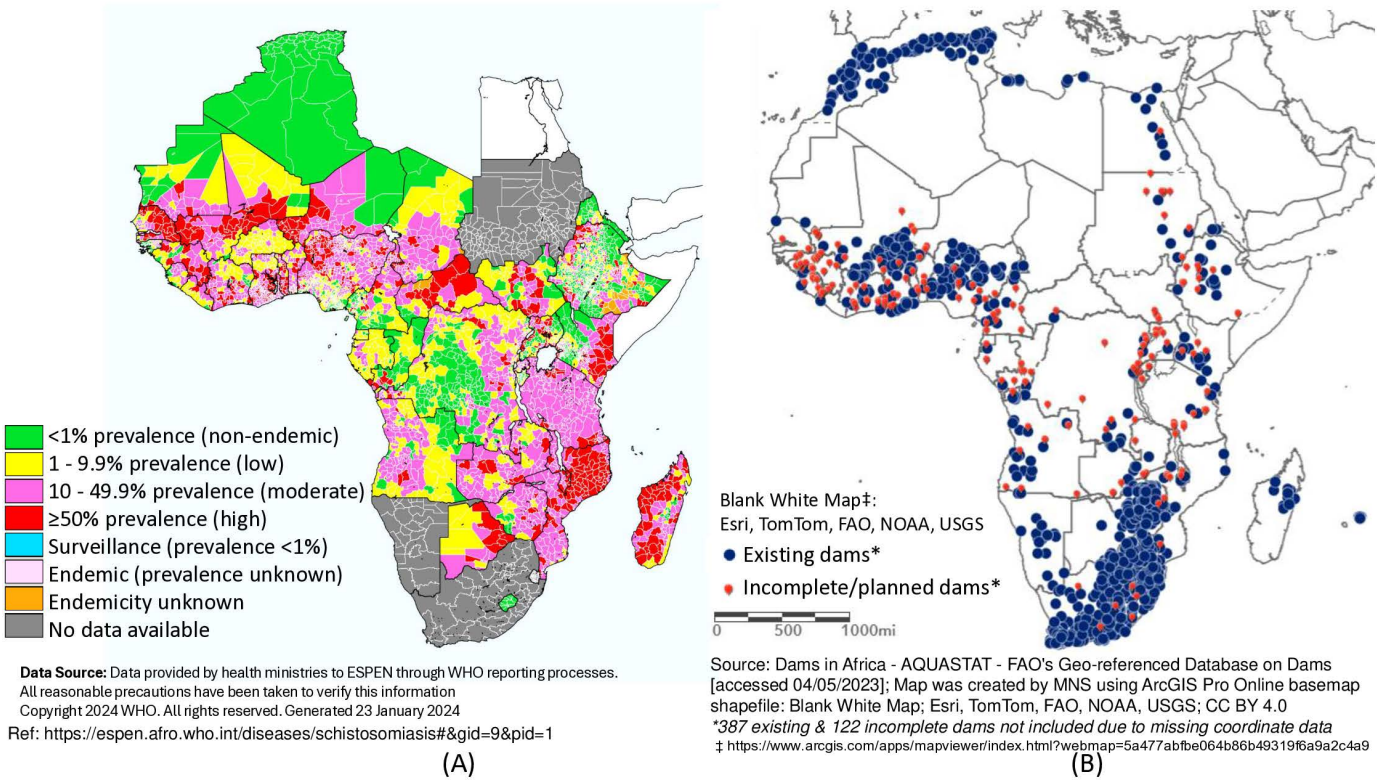


Fig 1. (A) Percentage range of people infected with Schistosomiasis, ESPEN-WHO [13] [accessed 09/05/2024]; the maps are updated annually and based on data sharing from countries; for countries indicated as "No data available" (e.g., South Africa) this is in reference to the indicated year, otherwise WHO has baseline data for those countries, and (B) Distribution of dams and reservoirs: FAO Geoportal database; survey data [4,14].

https://doi.org/10.1371/journal.pntd.0013180.g001

The online databases of WHO, FAO and the World Bank were searched. Books and other grey literature such as dissertations were also considered [12].

The search terms used are shown in S1 Text. There were no temporal limits or language restrictions that were set for the search. The bibliographies of selected studies were also searched for relevant references and studies. Data collected were stored in Mendeley reference manager and exported to Microsoft Excel 2016 for data extraction and analysis.

2.2. Criteria for paper selection

At the title and abstract screening phase there were no restrictions on study designs or type. Peer-reviewed articles and grey literature were considered. Application of standard schistosomiasis control measures of mass drug administration (MDA)/chemotherapy with praziquantel, behavioral change, and health promotion campaigns were not considered an inclusion criteria, because they were outside the scope of this review. However, these measures were included in the recommendations as part of the overall integrated cross-sectoral approaches for schistosomiasis control.

Full-text articles were assessed for study quality and strength of evidence. We excluded papers of low quality as assessed by two reviewers using a 14-point quality appraisal framework (S2 Text). Factors used to identify suitable articles for inclusion were the availability of data, ascertaining the observed changes in schistosomiasis prevalence due to dams and irrigation schemes, and evaluating the adoption of engineering and biological snail control measures. Source selection, screening and extraction were performed by reviewers IEL, MNM, PN, and MNS, and any disagreements solved by consensus or by the decision of MNS.

Using these criteria, countries with comprehensive data were further selected for detailed evaluation of approaches and given priority over those with incomplete or inconsistent data. Hence, we selected six African countries Ghana, Senegal, Cameroon, Morocco, Côte d'Ivoire, and Egypt as case study examples of positive and negative outcomes associated with dams and irrigation canals for lessons learnt. The engineering and biological snail control measures implemented at design, construction, post construction and operational phases of dams and irrigation schemes in the identified countries over time, and their corresponding results, were combined to suggest key recommendations for implementation. These recommendations are aimed at informing policy and practice in water resources management and schistosomiasis control. Additionally, in separate general literature searches, three non-African countries – Brazil, China and Japan, were highlighted to draw on lessons from their demonstrated success towards schistosomiasis elimination as a public health problem defined as <1% prevalence of heavy intensity infections, or having achieved complete elimination of schistosomiasis infection.

3. Results

3.1. Characteristics of included African studies

All articles with relevant literature for 46 countries were identified and then those with data on percentage infection reported, percentage increase in schistosomiasis due to dam, engineering and biological snail control measures adopted during/before/after construction of the dam, and monitoring/evaluation were considered. From 1483 retrieved records, 1297 studies on application of standard schistosomiasis control measures of mass drug administration (MDA)/chemotherapy with praziquantel, behavioral change, and health promotion campaigns were excluded at title and abstract, and 186 full-text papers were assessed. There were 122 articles finally included in the comprehensive review as shown in the flow diagram in Fig 2.

3.2. Distribution of studies, evidence gaps and approaches

We found an uneven distribution of studies with many African dam and irrigation scheme locations having insufficient or no data availability. Prevalence data were reported for 54 dam and irrigation scheme locations in 32 countries included

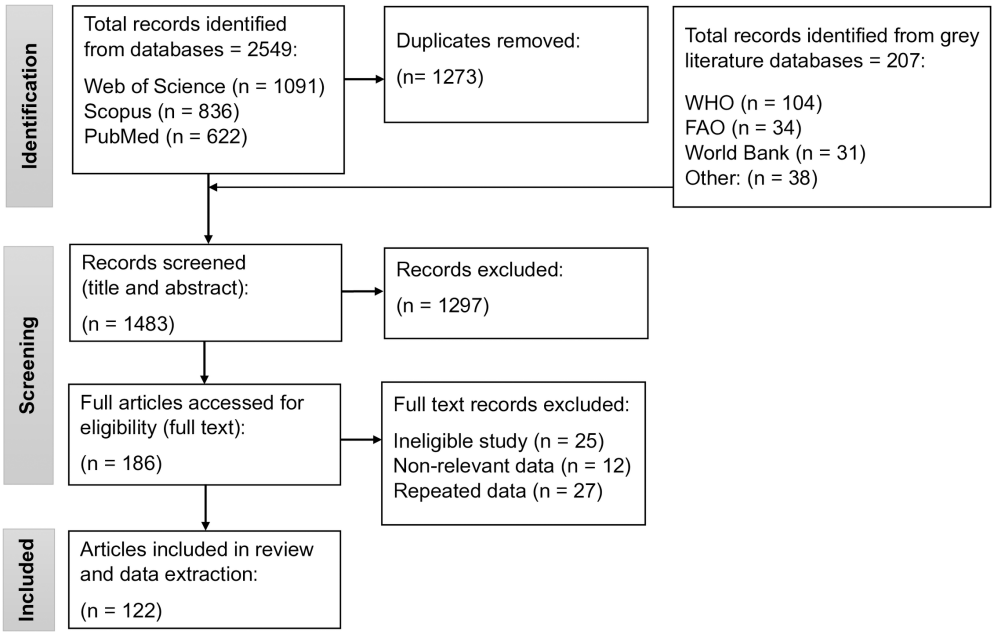


Fig 2. Flow diagram of article search and data extraction process for African countries.

https://doi.org/10.1371/journal.pntd.0013180.g002

in the study with sufficient evidence highlighting the impact on schistosomiasis (Fig 3). Some information was available about the prevalence of schistosomiasis and the percentage increase in infection around areas surrounding the dams. Reported prevalence since the year 1980 was available for 35 (65%) dam locations. Information on the actual increase in schistosomiasis cases associated with dams and irrigation schemes (measured as incidence, changes in infection prevalence or after:before odd ratios) was available for only 11 (20%) locations. The remaining 43 (80%) locations had no information or demonstrated evidence of an association of increased transmission risk with the construction of the dam or the irrigation system, generally because of the lack of baseline assessment and/or systematic surveillance. The lack of baseline epidemiological data in many endemic settings hinders the establishment of a clear connection between increased prevalence and dam, reservoir and/or irrigation construction. Information on engineering and biological snail control measures adopted during, before and/or after construction of the dams were available for 17 (31%) dam locations and there was some information about surveillance or Monitoring and Evaluation being carried out in 16 (30%) dam locations. There were no recent studies carried out on the relationship of dams, irrigation schemes and schistosomiasis for some locations which limited this study to much older information in 19 (35%) dam locations. The impact of dams on schistosomiasis and the control interventions reported in the reviewed articles are provided in detail in S1 Table. Several categories of engineering and biological snail control measures were reported, as shown in S1 Table.

Our review identified further research gaps in the literature. It was difficult to determine the effectiveness of the interventions in reducing snail habitats, transmission and infection rates because of the lack of longitudinal surveillance and tracking data after such intervention measures were put in place. Some information was embedded in overall country data and therefore difficult to unpack or separate the effect of changes due to dams and irrigation schemes in those countries.

A detailed analysis of data from eligible sources was used to identify approaches for control measures. Table 1 outlines the various engineering infrastructure and biological snail control measures we identified which had been developed and implemented to reduce the risk of schistosomiasis transmission during the design, construction, post construction and operational phases of the dams and irrigation schemes along with description. Several actions

Country	Dam and/or irrigation scheme Name	Number of articles	% Infection reported	Reported prevalence since 1980s	Reported % increase due to dam	Engineering and biological control	Reported Monitoring/ Evaluation
Algeria	El Hamiz River dam	3					
Angola	Capanda Dam	3					
Benin	Okpara Dam	4					
Botswana	Gaborone Dam	1					
Burkina Faso	Kompienga Dam	2					
Burundi	Rwegura Dam	1					
Cameroon	Lagdo dam	12					
Cameroon	Mape Dam	4					
Central African Republic	Boali Dam	1					
Democratic Republic of Congo	Inga II Dam	1					
Cote d'Ivoire	Kossou Dam	3					
Cote d'Ivoire	Taabo Dam	6					
Djibouti	Ali Sabieh Dam	1					
Egypt	Aswan High Dam	13					
Eritrea	Mai Nefhi Dam	1					
Ethiopia	Alwero Dam	1					
Ethiopia	Awash dam	4					
Ghana	Akosombo (Volta) Dam	9					
Kenya	Mwea Irrigation scheme	2					
Madagascar	Ankilivalo irrigation scheme	1					
Malawi	Nkula Dam	3					
Mali	Selingui Dam	5					
Mauritania	Foum Gleita	1					
Morrocco	Akka Oasis	9					
Mozambique	Cahora Bassa Dam	2					
Niger	Malanvile Dam	2					
Nigeria	Bakalori Dam	1					
Nigeria	Erinle Dam	3					
Nigeria	Malumfashi Dam	1					
Nigeria	Oyan River Dam	3					
Nigeria	Tomas/Rimin Gado dam	1					
Nigeria	Wasai Dam	1					
Nigeria	Warwade Dam	2					
Nigeria	Zobe Dam	1					
Senegal	Diama dam	7					
Senegal	Manantali dam	7					
Sierra Leone	Guma dam	1					
South Africa	Vaal Dam	2					
Sudan	Roseires Dam	2					
Tanzania	Baluchi Irrigation scheme	1					
Tanzania	Ikowa Dam	1					
Tanzania	Kalenga Irrigation scheme	1					
Tanzania	Kalimawe Dam	1					
Tanzania	Kilombera Irrigation scheme	1					
Tanzania	Kisangara dam	3					
Tanzania	Kisiwani Irrigation scheme	1					
Tanzania	Kitivo Irrigation scheme	1					
Tanzania	Mbarali Irrigation scheme	1					
Tanzania	Mangoini Irrigation scheme	1					
Tanzania	Mtera Dam	1					
Tanzania	Myumba ya Mungu Dam	1					
Togo	Kara Dam	1					
Zimbabwe/Zambia	Kariba Dam	2					
Zimbabwe	Mushandike dam	4					

Legend
Data available/reported
No data

Fig 3. Heat map chart of dams and irrigation schemes with schistosomiasis occurrence in Africa included in the study with evidence gaps.

https://doi.org/10.1371/journal.pntd.0013180.g003

Table 1. Implementation of engineering infrastructure and biological snail control measures at different phases.

Phase	Measures	Description and further notes	References
Design of the dam	Selected a site with minimal snail habitat	• Schistosome snails prefer freshwater habitats that are shallow, slow-moving, and have aquatic vegetation. However, some species of schistosome snails can tolerate habitats that are deep, fast-flowing, saline, or polluted to some extent. For example, *Biomphalaria pfeifferi*, a host for *Schistosoma mansoni* in Africa, is an example of a schistosome snail that can survive in brackish water and sewage-polluted habitats. • Schistosome snails require suitable substrates for attachment and egg-laying, such as mud, sand, rocks, or plants. • Environmental factors such as temperature, rainfall, pH, dissolved oxygen, and water chemistry influence the distribution and abundance of schistosome snails	[15–18]
	Designed the dam to include adequate drainage	• To further prevent the proliferation of snails and reduce the risk of transmission, it is essential to ensure that the dam has proper drainage systems in place. Installing drainage channels or pipes can direct water away from the dam and prevent the buildup of stagnant water where snails can thrive. • A fish ladder is a structure on a river that allows fish to pass around a dam or other obstacle in the river. Restoring the migration of *Macrobrachium vollenhovenii*, the African river prawn, using a fish ladder can reduce the transmission of schistosomiasis. *M. vollenhovenii* preys on the snails that host schistosomiasis, effectively decreasing the spread of the disease.	[10,19–22]
	Planned for the installation of irrigation gates	• Irrigation gates play an important role in promoting public health by controlling the spread of schistosomiasis. Irrigation gates help regulate water flow and prevent stagnation. Strategically placed gates can disrupt the life cycle of parasitic worms that cause schistosomiasis, reducing the risk of transmission.	[20]
During the construction of the dam	Constructed concrete banks to prevent snail colonization	• Concrete lining and concrete banks can significantly impact the spread of schistosomiasis by reducing the availability of suitable snail habitats. Concrete lining prevents the buildup of snail-friendly environments, such as mud and algae, which are necessary for snails to survive and reproduce. This leads to a decrease in the overall snail population in the water, which in turn reduces the transmission of the flatworms responsible for causing schistosomiasis.	[23,24]
	Introduced natural predators	• Introduction of certain fish species can help control schistosomiasis by preying on snails, which are intermediate hosts for the parasites causing the disease. • Crayfish and carp are effective fish species as they consume snails and their eggs, preventing the snail population from increasing and breaking the life cycle of the parasites.	[22,25]
	Other Infrastructure development introduced	• Improve access to water supply and safely managed universal sanitation coverage. • Construct bridges over upstream and downstream rivers.	[24,26,27]
Post construction	Dredging practiced	• Dredging the channels that branch out from the dam basin is an effective way to reduce the risk of schistosomiasis. • Improved water flow and reduced stagnant water bodies through dredging can help eliminate the habitat where the parasite causing schistosomiasis can thrive. • Dredging also helps to cover aquatic weeds growing on the banks of communities, which can eradicate intermediate host snails. • The implementation of dredging can result in a significant reduction in the incidence of schistosomiasis and improved health outcomes in affected communities.	[28]
Operation	Ongoing monitoring and maintenance	• Surveillance: Continue to monitor the dam and its surrounding areas for snail populations and any signs of damage or erosion. Conduct regular maintenance of the dam and its components to ensure that they are functioning optimally.	[29,30]
	Encouraged reduction of the risk of schistosomiasis transmission	• Encourage the use of protective clothing and equipment when using water for domestic or agricultural purposes, as well as avoiding high-risk areas, such as snail habitats or areas with contaminated water.	[29,31]
	Water flow regulation	• The “land-summer and water-winter” cycle is effective in controlling schistosomiasis, as it is contrary to the reproductive pattern of snails, which leads to a reduction in their population. This approach reduces flooding and snail density in marshlands, decreasing disease transmission	[32]

https://doi.org/10.1371/journal.pntd.0013180.t001

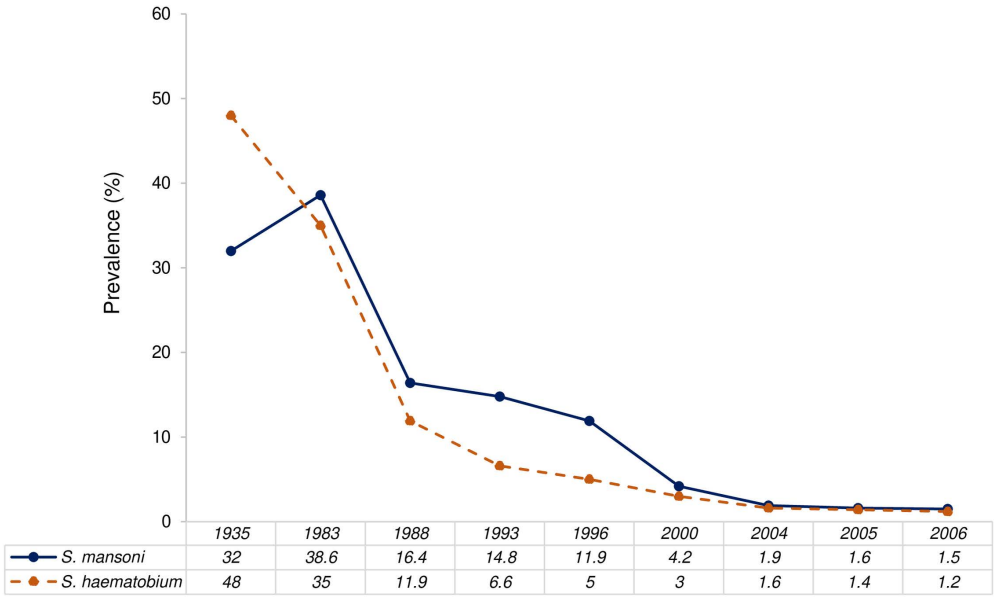
had been taken to modify the environment around dams with the aim of affecting the natural habitat of snails. It was observed that some negative impacts of these snail control measures/actions could occur if engineering measures are poorly implemented.

3.3. Selected case studies of effective measures and negative outcomes associated with dams and irrigation schemes on schistosomiasis in Africa

3.3.1. Egypt. Schistosomiasis in Egypt is largely attributed to irrigation canals and dams which provide suitable habitats for snails [33,34]. Until the 1930s, there was a high prevalence of urogenital schistosomiasis, at 60%, in the Nile Delta and Nile Valley regions, south of Cairo, where the Nile River flows past the Aswan High Dam and into districts with perennial irrigation [21]. However, the construction of the Aswan High Dam in 1964 resulted in a significant decline in the prevalence of urogenital schistosomiasis due to water flow regulation, which reduced snail habitats and in turn the transmission potential [35]. In contrast, intestinal schistosomiasis may have increased, both in terms of prevalence and distribution, after the construction of the dam in 1964 and until 1983. This increase can be attributed to the expansion of irrigation canals and drainage systems that favoured the snail hosts responsible for transmitting intestinal schistosomiasis [33]. Baseline levels of prevalence varying from 2 - 11% rose to 44–75% following dam expansion [36].

The national prevalence of intestinal schistosomiasis slightly increased from 32% to 39% between 1935 and 1983 [36]. However, Cline et al., 1989 [37] contested the accuracy of the 39% prevalence rate measured by Michelson et al., 1993 [36], suggesting that alternative testing methods could have yielded different results, including a potential decrease in the prevalence. Regardless, intestinal schistosomiasis steadily decreased after 1983 and until 2006 due to the integrated schistosomiasis control measures as shown in Fig 4 [37]. As a result, the prevalence of both types of schistosomiases decreased dramatically from 40% in 1967 to ≤ 3% in 2012 [38]. Currently, Egypt's control program covers the entire infected population, while less than 1% of the total population requires preventative chemotherapy [39].

3.3.1.1. Aswan High Dam water flow regulation: The Aswan High Dam, completed in 1967, had a major impact on the Nile River's ecology and irrigation patterns, leading experts to anticipate a higher incidence of schistosomiasis in



	1935	1983	1988	1993	1996	2000	2004	2005	2006
S. mansoni	32	38.6	16.4	14.8	11.9	4.2	1.9	1.6	1.5
S. haematobium	48	35	11.9	6.6	5	3	1.6	1.4	1.2

Fig 4. Overall prevalence of schistosomiasis in Egypt during the period 1935-2006 (Source: the National Schistosomiasis Control Program, quoted from WHO).

https://doi.org/10.1371/journal.pntd.0013180.g004

Egypt [40]. However, studies have shown that there was a subsequent reduction in both intestinal and urogenital prevalence which was partially because there was also an on-going effort to control the snail population, which was a confounding factor of the net effect of the dam [33]. Furthermore, the dam's regulation of water flow effectively reduced the transmission of urogenital schistosomiasis by preventing the formation of seasonal lakes, completely eliminating the snail habitat [21].

On the other hand, although the construction of the dam had a significant impact on disrupting the habitat of snails, it also resulted in an increase in water salinity and water logging, ultimately leading to a decline in soil quality and crop yields [35]. The construction of the dam also caused a deviation from the original course of the Nile River, resulting in erosion in the Nile Delta [41].

3.3.1.2. Drainage projects: The construction of drainage projects in the Nile River area has been a crucial strategy to prevent snail proliferation and reduce transmission risk in Egypt [21]. Drainage projects involved excavating canals and ditches to divert water away from snail habitats, disrupting their life cycle and reducing their populations effectively [42]. Although drainage projects have been proven to be effective in managing water flow and hence contributing to decreased snail populations, there are several potential drawbacks to consider. One significant disadvantage is the loss of land to the infrastructure required for an open drainage system [43]. Another potential concern is the extensive maintenance required to keep these types of drainage systems functioning properly [44].

3.3.1.3. Concrete lining of channels: Another method used by Egypt to control the transmission of schistosomiasis was to reduce the snail population in irrigation ditches. Two approaches used to achieve this were cement lining of ditches and the application of molluscicides [45]. The cement lining of ditches prevents snails from attaching and breeding, while molluscicides kill the snails. Although these techniques were successful in reducing the snail population, they have some drawbacks [46]. Canal lining can adversely affect groundwater supply, reducing the amount of water reaching the aquifer [47]. Additionally, installing and repairing the lining of the canal can be challenging and requires significant investment and maintenance costs [48].

3.3.1.4. Introduction of crayfish and black carp: During the early 1980s, the introduction of crayfish to the Nile Delta for aquaculture had unintended positive consequences in terms of reducing the snail population. The crayfish rapidly spread, became invasive, and were found to prey upon snails that transmit schistosomiasis, serving as a biological control agent [49]. Another biocontrol agent of snails in Egypt is the black carp, which feeds exclusively on snails. The introduction of both the black carp and crayfish led to a reduction in the biomass of aquatic plants and snails, resulting in a decrease in the population of the snails and consequently the transmission of schistosomiasis [49]. However, the introduction of these non-native species led to the displacement of native species along the Nile, which negatively impacted the biodiversity of the region [50]. Additionally, these invasive species compete with other native species for food, which can further disrupt the delicate balance of the ecosystem [51].

3.3.2. Morocco. Historically, schistosomiasis was not widely distributed in most parts of Morocco due to water scarcity. However, with the expansion of irrigation projects to arid parts of the country, the prevalence of the disease increased in the 1970s [31,52]. The number of cases detected and recorded during this time reached the highest peak of 13,416 in 1973. The construction of dams and canal systems provided favorable conditions for increased populations of *Bulinus truncatus*, the snail intermediate host. Consequently, as the canals became an important source of water for both agriculture and domestic use, there was an increased risk of exposure in areas which later became schistosomiasis foci [53].

In response to the increasing prevalence, in 1976 Morocco developed a National Schistosomiasis Control Programme (NSCP), which became operational in all provinces by 1982 [53]. The program outlined an integrated approach to control and elimination through screening, treatment, snail transmission control, health education and community participation. This approach was a success and as of 2004, no indigenous cases of schistosomiasis were reported [54]. An interruption of transmission was confirmed by a serological study of disease-endemic foci whereby results showed an absence

of antibodies in all serum samples [55]. Following the commencement of the NSCP, the total number of cases detected declined from 10,653 in 1983–6 in 2010, as shown in Fig 5 [52,56].

3.3.2.1. Mechanical methods: Mechanical measures to control snails involved modifying the snail biotope or habitat to prevent their proliferation. These methods included changing the physical environment of the snails, such as reducing the amount of stagnant water or eliminating vegetation that provides breeding ground for snails [29,30]. This was achieved by dredging or draining water bodies, removing aquatic vegetation, or excavating silt. Another mechanical method was the brushing of edges of the sumps after each irrigation exercise. Brushing the edges of sumps disrupted the snail habitat and dislodged snails. Periodic maintenance of various network structures was also used as a mechanical method of snail control [29,57]. This involved repairing or replacing broken pipes, valves, or other equipment that can cause water stagnation, which favours snail breeding.

The use of mechanical measures to control snails may be costly and time-consuming to implement, especially in large water bodies. For example, dredging or draining a large lake or river may require significant resources and equipment, which may not be available in some areas. Additionally, these methods may disrupt the natural ecosystem of the water body and impact other organisms that depend on snails and aquatic vegetation for their survival [51]. Moreover, mechanical methods may be temporary solutions and may require ongoing maintenance and monitoring to be effective. For example, brushing the edges of the sumps may remove snails, but if the snail habitat is not permanently disrupted, they may return to the area and re-establish their population.

3.3.2.2. Environmental management: Emphasis was also placed on reducing the population of the snail intermediate host in irrigation systems. Tertiary canals and siphon boxes were particularly important habitats for snails as they provided favorable conditions for breeding [58]. Focal and gravity molluscicide through the routine application of niclosamide was used as the main snail control measure in several irrigation schemes. Given the cost and potential effects on non-target organisms of molluscicide, alternative snail control measures were attempted alongside molluscicide in the Tessaout- Amont irrigation scheme [59,60]. These included placing concrete covers on syphon boxes to

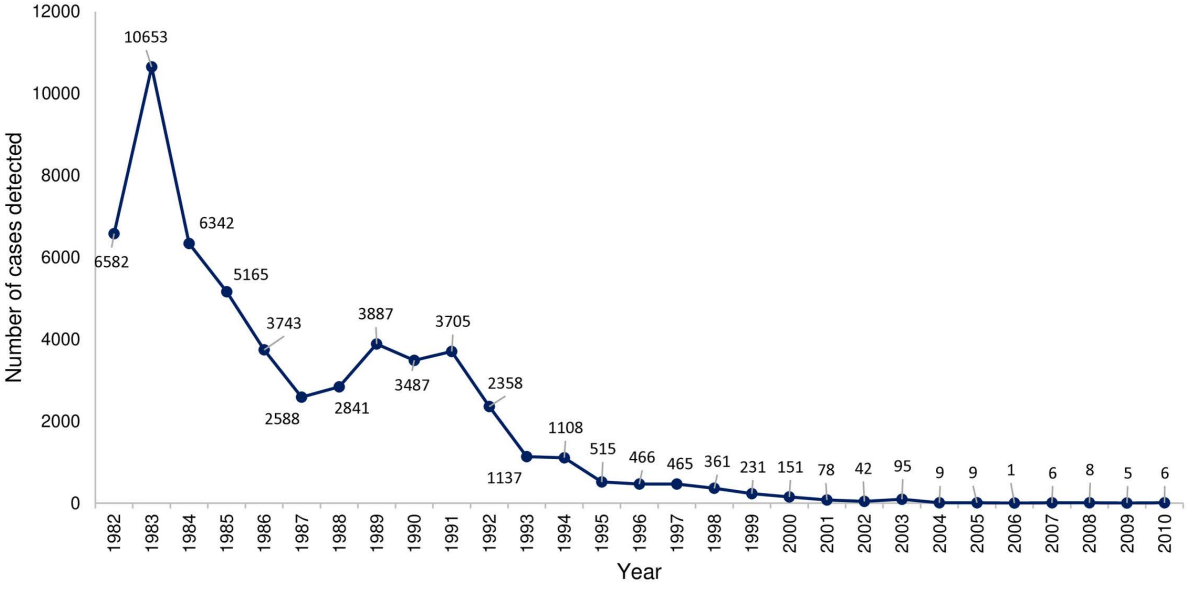


Fig 5. Decline in schistosomiasis cases, Morocco 1982 – 2010 (Sources: Annual Reports of the National Program against Schistosomiasis, Ministry of Health, [56]).

https://doi.org/10.1371/journal.pntd.0013180.g005

minimize light entry and brushing the sides of syphon boxes. All these methods were shown to reduce the snail population over the study duration period, however, periodic molluscicide was evaluated as the most effective method to prevent snail repopulation [60].

Community engagement also proved beneficial in the reduction of snail populations through environmental control. In the Akka Oasis in South Morocco, the local irrigation committee conducted routine cleaning and clearing of vegetation in canals and impoundments on the Akka riverbed. This practice yielded tangible results in the reduction of snail and egg mass densities in the area [29].

3.3.3. Ghana. Schistosomiasis had a high prevalence in Ghana, at 71% as of 2010 [61,62]. The presence of urogenital schistosomiasis has been identified in all regions, with varying levels of prevalence ranging from less than 10% to over 70%, with the western regions exhibiting the highest prevalence rates [63]. Prevalence rates can be as high as 80–90% in communities located along the lakeshores of the Volta basin, while the Volta estuary is also endemic, with infection rates of 76.2% for intestinal and 6.3% for urogenital schistosomiasis [62,64]. The construction of Lake Volta in the 1960s, as well the construction of Akosombo and Kpong Dams, significantly increased the incidence of schistosomiasis prevalence across Ghana, heavily infecting all regions [65]. Despite some regions exhibiting lower prevalence rates, the disease continues to pose a significant public health challenge in the country, particularly in areas where water contact is frequent.

While data published in the Global Burden of Disease (GBD) platform in 2023 demonstrated overall reductions in prevalence, population increases in many endemic areas have sustained or even increased the number of individuals considered at risk for schistosomiasis [66]. Despite these challenges, the prevalence of schistosomiasis in Ghana has decreased by approximately one-third since 2000, indicating the effectiveness of the various control measures implemented in the country [65].

3.3.3.1. Environmental improvement projects: Since the 1960s, interventions were initiated to control schistosomiasis in villages surrounding Lake Volta [67]. The various methods implemented, such as aquatic weed clearing, vector snail surveying and sampling, construction of low-maintenance pit latrines, and health education, had a significant impact on the transmission and control. These interventions helped reduce the abundance of snail populations, identified areas with high snail populations for targeted intervention and assessed the effectiveness of existing control strategies [67]. In some of the villages where these methods were implemented, there was evidence of decline in schistosomiasis incidences. However, despite this decline, the occurrence of the disease remained relatively high compared to the situation before the creation of the dam [68].

While the aquatic weed clearing can be effective in controlling schistosomiasis, its implementation can also have potential negative impacts such as unintended environmental disruption, resource-intensive and challenging implementation. For example, aquatic weed removals led to loss of habitats for some aquatic life and species (fish, plants etc.) as well as contributing to soil erosion in areas around dams and canals in Ghana [69].

3.3.3.2. Saltwater intrusion and dredging in Ghana: The construction of the Akosombo and Kpong Dams reduced river discharge and caused the formation of a sandbar, which prevented saline seawater intrusion upstream during high tides, creating a favorable snail habitat [70]. As a result, there was an increase in the growth of vector snails, which increased the incidence of schistosomiasis infections in the surrounding communities [71]. To address this, the Volta River Authority (VRA) dredged through the sandbar and deepened the silted channels to restore saltwater intrusion [28]. Dredging operations interconnected deeper ponds, allowing saltwater to penetrate the whole tidal area, and served as a protection for communities inhabiting the lower banks from flooding. Dredging also covered aquatic weeds growing on the banks of the communities, helping to eliminate snails. Dredging activities were beneficial in preventing floods and maintaining a salinity level to counteract snail colonies up to 9 km from the estuary [72]. As a result, the incidence of schistosomiasis has decreased significantly in recent years. Nevertheless, a major obstacle is insufficient equipment for the operations [28].

Dredging and saltwater intrusion pose a significant threat to the environment, with potential long-term effects that can be detrimental. These activities may impact on topsoil fertility, destroy essential fish spawning areas, making riverbanks unstable and vulnerable to erosion [73]. In turn, this can lead to habitat loss for riverbank animals and negatively impact local fish populations [74]. Saltwater intrusion can also have a dreaded consequence of negative impact on human health [75].

3.3.4. Cameroon. Schistosomiasis distribution is uneven in Cameroon, ranging from 1.7%-55.5%, with a higher prevalence in the northern regions [76,77]. The development of dams for hydroelectric power and irrigation canals, along with a lack of potable drinking water has led to a high prevalence in the country. The dams and irrigation schemes created optimal conditions for the multiplication of snails and consequently, the spread of schistosomiasis [10,78]. Mape dam increased schistosomiasis outbreaks.

In northern Cameroon, the distribution and hotspots of schistosomiasis are linked to proximity to Lake Chad and the Benue River, on which Lagdo dam is located [9,61]. The construction of Lagdo dam in 1982 created a 700-square-kilometre artificial lake, which is a reservoir for irrigation, consisting of a 3-kilometre open unlined main canal that divides into two concrete-lined principal canals, creating favorable snail breeding conditions [79]. In the area around Lagdo dam, the prevalence of schistosomiasis was at 15% in 1968, which then increased to 61% by 2000. Similarly, at the national level, the schistosomiasis situation worsened around 1987, when the first irrigation scheme was constructed. More specifically, the prevalence rose from between 7–21% in 1986 to 43% by 1992 [80]. These statistics suggest that the dams and irrigation projects may have contributed to the increase in the schistosomiasis prevalence. However, it is worth noting that some researchers attributed the increase in the early 1980's to the country's failure to develop a national strategy for the control of schistosomiasis [61,81].

3.3.4.1. Poor water flow management: Lagdo dam led to the creation of a large reservoir that allowed for the development of an extensive irrigation project covering thousands of hectares [82]. However, an unintended consequence of the project was the transformation of natural floodplain depressions into marshy areas [83]. These marshy areas provided ideal breeding grounds for freshwater snails, including some intermediate host species of schistosomiasis. Combined with the development of irrigation projects that lacked snail control measures, ideal snail breeding conditions were created, leading to an increase in the prevalence of schistosomiasis [83].

3.3.4.2. Absence of bridges: The villages located in the vicinity of Lagdo dam are situated on a low terrace, bordered by a river and a depression. People frequently walked through the depression to access the terrace, despite the fact that it is continuously inundated with water [83]. This geographical feature has negatively impacted the health of villagers around both Lagdo and Mape dams as the enhanced contact with the water has been linked to a higher prevalence of schistosomiasis [84,85].

3.3.5. Côte d'Ivoire. The prevalence of schistosomiasis in Côte d'Ivoire varies from as low as 1% to as high as 90% in different parts of the country [86–88] with high prevalence among school aged children living in close proximity to dams and irrigation schemes [89].

Kossou and Taabo are two of the largest dams, located along the Bandama River in central Côte d'Ivoire. Both were built in the 1970s to provide hydropower generation, irrigation, flood control and water supply. They are classified as embankment dams and are built with earth and rockfill [90]. A study revealed that the Kossou dam had a leakage problem at its base, providing a favorable habitat for snails [91]. As a result, the prevalence of *S. haematobium* increased from 14% to 53% around Lake Kossou. Similarly, the construction of the Taabo dam around Lake Taabo led to a surge in *S. haematobium* prevalence from 0% to 73%. Additionally, although the reservoir banks are steep, water in the dam covered vegetation that existed before dam construction, providing an ideal food base for snails [91].

3.3.5.1. Lack of water and sanitation infrastructure: The lack of adequate water, sanitation, and hygiene (WASH) facilities in Côte d'Ivoire posed a significant risk of infection to the local population [92]. Open defecation has also been linked to a higher prevalence of schistosomiasis in Côte d'Ivoire [86]. In addition, heavy rains and flood events exacerbated the situation in endemic areas. Poorly maintained sanitation infrastructure resulted in the overflow of sewage and

waste, leading to the contamination of water sources and increased coverage of schistosome-carrying snails [93]. Furthermore, activities, such as agriculture, fishing, and washing clothes, are often conducted around man-made dams and water sources, which further increases the risk of transmission [86].

3.3.5.2. Haphazard and unsystematic construction of dams: The construction of dams in Côte d'Ivoire has not followed a planned or organized approach. A total of 22 dams over 10m high were built mainly in the 1960s and 1970s without relevant regulations or guidelines, resulting in a lack of consideration for potential environmental and health impacts [94]. The impacts were due to several factors, including the creation of new water sources, alteration of water flow, extensive population movements, increased agricultural activities, and human contact with infected water [91].

3.3.6. Senegal. Schistosomiasis prevalence in Senegal has been affected by the ecological changes that have taken place in the Senegal River Basin (SRB) [95,96]. These changes are the result of two major construction projects: the construction of a dam at Diama on the Senegal River in 1986, which was built to prevent sea water from intruding into the river, and the construction of a dam at Manantali, Mali on the Senegal River Basin, which was built to regulate water flow and generate electricity [15]. Prior to the construction, there was low urogenital schistosomiasis prevalence in the region and intestinal schistosomiasis was not endemic. Following the completion of the Diama dam, there was a massive increase in schistosomiasis incidences. Prevalence of infections in school aged children ranged from 43% to 99% for urogenital schistosomiasis and between 2% and 95% for intestinal schistosomiasis, where transmission occurred all year round [97]. An outbreak of intestinal schistosomiasis occurred in the SRB, with a high prevalence of up to 100% in some local populations [96,98,99], making the SRB one of the most schistosomiasis hyperendemic regions of the world. More recent data show some reduction in intestinal schistosomiasis prevalence in the lower basin of the Senegal river with urogenital schistosomiasis becoming the dominant infection despite repeated rounds of mass drug administration in research settings and through the national control program [100,101]. On a small scale, manual removal from transmission sites of aquatic vegetation where snails thrive is effective in reducing schistosomiasis transmission. The harvested vegetation can be used to produce compost for agriculture and biogas or integrated in animal feeds for livestock, a win-win for human health and the fight against poverty and malnutrition that targets multiple SDGs at once [100].

3.3.6.1. Poor dam design: The construction of dams and irrigation schemes that alter the ecology and hydrology of the Senegal River basin by preventing saltwater intrusion played a major role in increasing the population of snails [95]. For example, in 1988, the construction of the Diama dam caused the elimination of saline water conditions at the mouth of the Senegal river, which was the intended goal of the dam. Permanent freshwater upstream from the dam and the increased use of agrochemicals associated to agricultural expansion and intensification have created favorable conditions for the proliferation of the aquatic vegetation that is suitable habitat for schistosome parasite-competent snails [10].

3.3.6.2. Elimination of natural predators: Once the Diama dam was finished in 1986, it prevented the yearly migration of river prawns which feed on snails [102]. Before the construction of the dam, when river prawns were plentiful, cases of human schistosomiasis were rare [103]. However, the dam now obstructs the migration of female prawns downstream to the estuary and prevents the upstream movement of larvae, leading to the decrease in prawn population [102]. This decline in the prawn population above the dam coincided with a significant increase in the prevalence of human schistosomiasis in the Lower Senegal River Basin [10,22].

3.4. Examples outside Africa

S. mansoni is endemic in central- and north-eastern Brazil. Here the prevalence of schistosomiasis infections decreased from 15.6% to 9.5% between 1950 and 1990 [104], thanks to increased surveillance and medical treatment, improved sanitation, and the construction of sewage treatment facilities [105]. Historically, schistosomiasis was largely endemic in three areas of Japan where the parasite *S. japonicum* infects snails of the genus *Oncomelania*, such as *Oncomelania hupensis* as intermediate host, and, in addition to humans, more than 30 mammals' as definitive hosts, including several wildlife species as well as cattle, dogs, cats, rodents, pigs, horses, and goats [106]. However, Japan implemented a

successful schistosomiasis control program that mainly focused on snail control. The last reported human case of schistosomiasis was in 1977, and the country declared elimination in 1996 [107,108]. Similarly, before the mid-1950s, China had one of the world's worst schistosomiasis situations, with a high prevalence and intensity of infection caused by *Schistosoma japonicum* [109]. This parasite was endemic in 12 provinces and affected about 11.6 million people in 433 counties or cities in the mid-1950s [110]. The number of individuals infected has declined from 11.6 million in 1956 to just 0.3 million in 2015 [111]. China declared schistosomiasis to no longer be a public health concern in 2015 and is currently striving to halt transmission and eliminate the disease by 2030 [109].

The implementation of mechanized irrigation systems contributed significantly to the reduction of schistosomiasis prevalence in certain areas. For example, a study conducted in the State of Bahia, Brazil, found that the expansion of irrigation systems did not lead to an increase in urogenital schistosomiasis infections [112]. This was attributed to the adoption of advanced technologies that require minimum human contact in irrigation and agriculture, which reduced direct contact between farmers and water. Similarly, schistosomiasis elimination in Japan coincided with the development of mechanized agriculture, such as use of tractors instead of oxen and horses [113]. However, mechanized irrigation systems have several challenges, including high installation and maintenance costs, high energy requirements, potential soil erosion, and limited crop selection [114].

Environmental modifications were made to snail habitats through the widespread use of concrete in Japan [106]. Snail populations were known to be highest in rice field ditches and to counter this, ditches were lined with concrete [115]. Similarly, China used concrete lining in irrigation ditches, which involved covering the walls and floors of these ditches with concrete and they also modified marshlands [116]. This technique helped to prevent snails from living in the moist environment of the ditches, thus reducing the risk of disease transmission [117]. As of 2015, roughly 40% of wetlands in villages where the disease was common had been drained, and about 30% of irrigation ditches had been lined with concrete [118]. Cement lining in Japan disrupted the natural flow of water, destroyed habitats, reduced the availability of nutrients for rice cultivation, increased the risk of flooding, and caused soil erosion [119]. It was disruptive to the natural habitats of species living along the banks [120]. The use of concrete lining can also be expensive to maintain [121].

Between 1985 and 1995, Brazil decreased the prevalence of schistosomiasis through the implementation of small dams. These dams were used to raise tilapia fish, which served as biological control for snails [122]. As a result of the project, the prevalence of schistosomiasis decreased significantly from 30.9% to 4.3%, and its intensity also decreased noticeably [123]. Tilapia tend to consume native plants like algae and water lilies, which can have negative consequences for other small animals that rely on these plants for survival [124]. Furthermore, tilapia can contribute to an increase in sediment in the water, which can hinder the growth of plants by blocking sunlight [125]. Japan also involved the introduction of snail predators such as geese or firefly larvae, although these measures showed no evidence of success [107]. The introduction of predators may not always be effective, and it can have unintended ecological consequences, particularly if the predators are not native to the region [107].

Changes in land use also had a significant impact on schistosomiasis control in Japan. Paddy fields were converted to orchards and residential areas, changing the economy and social structure in these areas [126]. The change in land use also saw the construction of social amenities, such as communal swimming pools, thereby limiting exposure to natural water bodies [107]. Agricultural practices were also transformed to prevent disease spread. Horses were recommended to replace cows as labor animals after studies showed that they were more resistant to schistosomiasis than cows. Night soil, commonly applied directly to rice plantations as a fertilizer, was stored for at least two weeks before use, killing the schistosome eggs [108]. Among fertilizers', caustic lime was found to have a killing effect. Environmental degradation caused by changes in land use can lead to soil erosion, loss of biodiversity, and degradation of water quality.

The Three Gorges Dam situated in the middle of the Yangtze River in China has an important role in flood control and regulating water flow. The dam changed the water levels spatial and temporal variability, leading to a significant impact on the ecology of the region and the spread of schistosomiasis [127]. The dam controls water flow by decreasing the water level in summer and increasing it in winter, which made it less favorable for snails to reproduce and survive. This, in turn, helped to decrease

snail density, which is a crucial factor in the spread of schistosomiasis [32]. However, early flooding in the spring can have a negative effect on the survival and spawning rates of snails, which can impact snail density [127]. By adjusting the flood peaks, the Three Gorges Dam minimises the effect of early flooding on snail density, thus reducing the risk of schistosomiasis.

Sluice gates are structures made from either concrete or metal, which can control the amount of water flowing through rivers, canals, and other water bodies [128]. These gates can be raised or lowered to manage water levels, prevent flooding, and regulate water flow for hydroelectric power plants and irrigation systems [129]. In China, specially designed sluice gates have been utilized to prevent the spread of snails [130]. These gates have been installed in lakes and dams across China since 1998 to prevent snails from migrating or moving from the lake to the rivers or irrigation channels [131].

Japan explored the application of hot water and the use of flame throwers as snail control methods [107]. Though hot water and flame throwers may seem like effective solutions, they can have adverse environmental effects. The use of flame throwers, in particular, may lead to environmental damage, which is not a sustainable solution in the long run.

3.5. Recommendations for integrated control approaches

The key snail control practices for dams and irrigation schemes as well as their advantages and disadvantages as identified from this review are summarised in Table 2.

Table 2. Key snail control practices for dams and irrigation schemes.

Intervention types	Advantages	Disadvantages/Weaknesses
Water flow regulation	Reduced snail habitats and transmission	Increased salinity and waterlogging
Drainage projects	Reduced snail habitats and transmission	Expensive and time-consuming
Concrete lining of channels	Significant reduction in prevalence; Reduced snail habitats and transmission in irrigation canals; Reduced snail populations in rice field ditches	Expensive and requires ongoing maintenance and upkeep; Disrupts natural water flow, destroys habitats, reduces availability of nutrients for rice cultivation, increases the risk of flooding, and causes soil erosion
Mechanized irrigation systems	Decreased schistosomiasis in agricultural areas	Expensive to construct and maintain; May require significant infrastructure changes
Sluice gates	Decreased prevalence of schistosomiasis in agricultural and rural areas	Inadequate management can lead to environmental damage
Mechanical methods; Brushing and covering siphon boxes	Decreased prevalence by removing snails and larvae from water bodies; Decreased prevalence by reducing snail habitat	Labour-intensive and time consuming; brushing has a marginal effect on decreasing snail populations; may not be feasible on a large scale in areas with limited resources or access to technology
Water quality improvement and sanitation projects	Reduced exposure to contaminated water sources and snail habitats; break transmission cycle	Requires cross-sectoral collaboration and investment which can be difficult
Installation of fish ladders and introduction of natural predators	Reduced snail population and controlled schistosomiasis transmission in rivers and lakes; restored migration of river prawn	May disrupt the ecosystem and have unintended consequences
Introduction of crayfish and black carp	Reduced aquatic vegetation that supports snails as well as feeding on snails	May affect local biodiversity and fish
Saltwater intrusion and dredging	Altered the ecology of freshwater snails and reduced their abundance	May have negative effects on agriculture and fisheries
Electrification of wells	Decreased schistosomiasis in rural communities	Expensive to install and maintain; May require a reliable source of electricity
Changes in land use and agricultural practices	Reduced schistosomiasis transmission through improved water services and changes in agricultural practices	Conversion of natural habitats to agricultural or urban areas can lead to environmental degradation
Construction of bridges	Reduced exposure to contaminated water sources and snail habitats; break transmission cycle	Expensive to install

https://doi.org/10.1371/journal.pntd.0013180.t002

A comprehensive approach to schistosomiasis control, where physical measures are combined with non-physical standard chemotherapy measures to ensure the long-term success of schistosomiasis control programmes, is an important strategy for areas of man-made water bodies. The results above highlight a variety of measures taken to prevent or overcome the challenges associated with managing both the snails and the disease. This range of interventions has, as common denominator, the integration of the necessary but clearly insufficient medical treatment based on praziquantel, with environmental interventions targeting the parasites when it is outside the human host [132,133]. Fig 6 highlights the overall integrated schistosomiasis control approaches recommended for areas where dams and irrigation schemes are built to improve water supply, provide energy, and enhance food security. We advocate for plant-based or other environmentally friendly molluscicides [134,135]. Community participation, planning and outreach programs should be developed to promote safe water practices and reduce the risk of schistosomiasis transmission [136]. This can include distributing educational materials, conducting workshops, and engaging with community leaders and stakeholders alongside infrastructure investments as part of integrated interventions [136,137]. Regarding integrated control approaches, multisectoral collaboration is crucial. Considering the role of environment, health, water, sanitation, energy and agriculture sectors in schistosomiasis control, multisectoral collaboration is highlighted as a recommended area for the elimination or control of schistosomiasis.

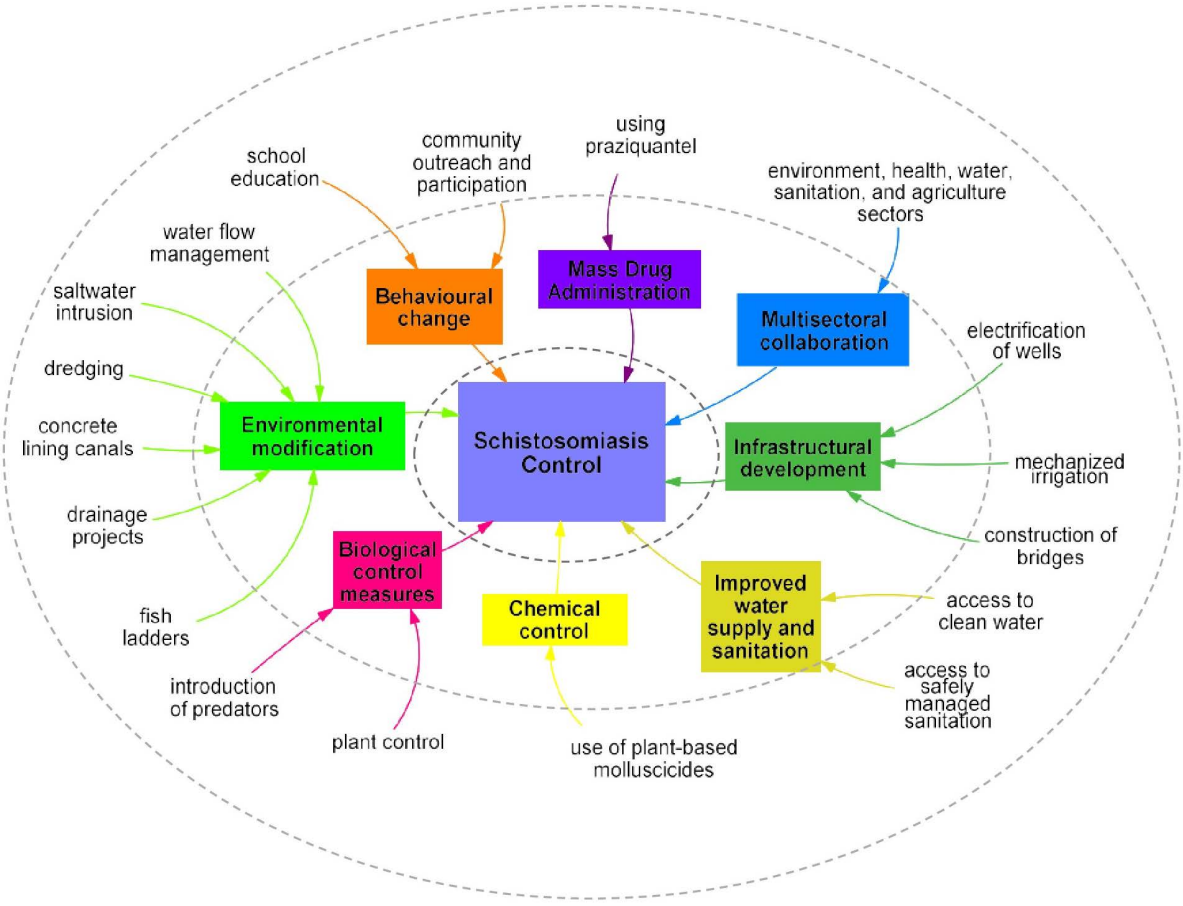


Fig 6. Integrated schistosomiasis control approaches recommended for areas with man-made water bodies (schistosomiasis control shown in the center requires overarching integrated control categories as shown in the inner ring/circle with corresponding appropriate intervention-types shown in the outer ring/circle).

https://doi.org/10.1371/journal.pntd.0013180.g006

4. Discussion

Data are crucial in understanding the impact of water resources management on schistosomiasis. There were few detailed and recent studies carried out on the relationship between dams, irrigation schemes, schistosomiasis and engineering or biological snail control in many African countries, which has created a huge research gap. Schistosomiasis control requires the implementation of a combination of measures to address the various factors contributing to the transmission. The success of control measures depends on effective monitoring and evaluation of systems to assess their impact and effectiveness.

Ecological and climatic conditions are important factors. Understanding the occurrence of the snail intermediate host and its habitat is key to achieving effective snail control. This was clear in Morocco, where snail control was mainly conducted through gravity and focal molluscicide [30]. The environmental and ecological studies on snails and their habitats were key in understanding the effectiveness of snail control measures in Japan [108]. Senegal's Diama and Manantali dams had increased prevalence due to reduced salinity in the associated water bodies. In some instances, the climate conditions and changes in hydrology of a catchment area affected and reduced the prevalence of schistosomiasis. This was the case in Ouarzazate, Morocco, where continuous droughts disturbed the habitats of the snail intermediate hosts [52]. These examples clearly display how understanding the ecological, environmental and climatic condition plays a role in managing snail populations and especially because of climate change effects.

Increased water and sanitation access is critical in the control of schistosomiasis. Notably, countries such as Brazil, China, Japan, and Egypt implemented successful measures to improve access to safe water and sanitation, leading to a reduction in the transmission of the parasite. However, the success of such measures ultimately relies on political commitment and collaborative efforts across sectors to ensure the availability of safe water and sanitation facilities to affected communities. It is important to consider other effective infrastructural measures during the design of a dam or irrigation scheme such as providing the accompanying necessary water supply and sanitation infrastructure as part of the deliverables for water resources development.

Governance and Integrated Control Plans are important. Successful elimination of the disease requires investment and capacity building across multiple sectors. The countries which achieved success in controlling schistosomiasis followed a path of convergence which ensured relevant departments were involved in addressing schistosomiasis. This integrated approach of governance provided a conclusive policy framework and its implication to handling the spread of schistosomiasis and to eventually controlling it within the existing resources available. The coordination among health, environmental and agricultural bodies was apparent in China, Japan, Morocco and Egypt. Each country developed a schistosomiasis control program which reflected the need for social change, environmental adaptation, snail control and other measures such as development of WASH infrastructure. These cases provide evidence for the justification of an integrated approach for the purpose of containing schistosomiasis.

4.1. Limitations of the study

Many countries had inadequate reporting with few detailed recent studies carried out in many African countries. This limited the analysis to older information on the subject in some countries. Few articles that were relevant for the study were published in Arabic, French and Portuguese, meaning that some vital information on dams and schistosomiasis may have been missed or lost in translation by IEL.

There was no registration of our scoping review protocol in PROSPERO, and it was not reviewed and published in PROCEED, the global database of prospectively registered systematic reviews in the environmental sector. It was drafted using PRISMA-ScR principles and revised by the research team, one library staff and one member of faculty at Cranfield University only. It was not disseminated publicly to solicit additional feedback, which could have possibly impacted the search strategy and limited the results of the searches.

4.2. Conclusions

This review assessed the impact of dams and irrigation schemes on schistosomiasis prevalence in humans across Africa and assessed whether control measures implemented at various stages of the lifecycle of water management infrastructures have been able to curb the negative health outcomes of water resources development. The impact of dams and irrigation schemes when constructed with inadequate engineering and snail control measures resulted in significant increase in schistosomiasis. Concrete lining of canals, use of regulation/irrigation gates and construction of concrete banks were identified as the main engineering measures that contributed to successful snail control. Engineering measures worked better when combined with biological and other control measures including chemical control, improved water supply and sanitation, behavior change approaches and mass drug administration. Conversely, common failure factors in the control of schistosomiasis included poor dam design and irrigation channels, poor sanitation and hygiene, inadequate access to safe water, and insufficient monitoring and evaluation of the impact and effectiveness of control strategies. The failure factors must be addressed to improve the effectiveness of the control strategies and reduce the burden of schistosomiasis. Further considerations for research and water resources development implementation include the need for baseline data and inclusion of surveillance with subsequent M&E to adequately track changes over time. Additional evidence and research gap include developing environmentally friendly snail control plant molluscicides and identifying suitable natural predators. We provided key recommendations which could be adopted by the Continental Africa Water Investment Programme (AIP) as part of the Programme for Infrastructure Development in Africa Priority Action Plan. Recommendations on normative guidance and regulatory frameworks include detailed environmental and social impact assessments being strictly enforced, appropriate intervention design for infrastructure and environment, and improved cross sector coordination.

Supporting information

S1 Text. Search terms.
(DOCX)

S2 Text. Quality Appraisal Framework and Scoring Guidelines.
(PDF)

S1 Table. Details of dams and irrigation schemes included in the study.
(PDF)

S1 File. Scoping Review Protocol.
(PDF)

S1 Checklist. PRISMA Checklist.
(PDF)

S1 Data. Non Relevant Data Assessment.
(DOCX)

Acknowledgments

We acknowledge the administrative support of African Ministers' Council on Water (AMCOW) Secretariat staff; Delphine Olandzobo, Librarian at Cranfield University for assisting during the main search; Moses Olitiku for contributing to the searches and data analysis; Alesia Ofori for reviewing some parts of the draft and providing feedback.

Author contributions

Conceptualization: May N Sule, Anouk Gouvras, David Rollinson, Rashid Mbaziira, Comfort Kanshio, Giulio A De Leo.

Data curation: May N Sule, Ibrahim El Lahham, Mutinta N Munkombwe, Patricia Nasike.

Formal analysis: May N Sule, Ibrahim El Lahham, Mutinta N Munkombwe, Patricia Nasike.

Funding acquisition: May N Sule, Anouk Gouvras, David Rollinson, Rashid Mbaziira, Comfort Kanshio, Giulio A De Leo.

Investigation: May N Sule, Ibrahim El Lahham, Mutinta N Munkombwe, Patricia Nasike.

Methodology: May N Sule, Ibrahim El Lahham, Mutinta N Munkombwe, Patricia Nasike.

Writing – original draft: May N Sule, Ibrahim El Lahham, Mutinta N Munkombwe, Patricia Nasike.

Writing – review & editing: Anouk Gouvras, David Rollinson, Rashid Mbaziira, Comfort Kanshio, Giulio A De Leo.

References

1. Adenowo AF, Oyinloye BE, Ogunyinka BI, Kappo AP. Impact of human schistosomiasis in sub-Saharan Africa. Braz J Infect Dis. 2015;19(2):196–205. https://doi.org/10.1016/j.bjid.2014.11.004 PMID: 25636189
2. World Health Organization. WHO. 2023 [cited 2023 Mar 2]. Schistosomiasis (Bilharzia). Available from: https://www.who.int/news-room/fact-sheets/detail/schistosomiasis
3. Nation CS, Da'dara AA, Marchant JK, Skelly PJ. Schistosome migration in the definitive host. PLoS Negl Trop Dis. 2020;14(4):e0007951 –e0007951. https://doi.org/10.1371/journal.pntd.0007951
4. FAO. Food and Agriculture Organisation AQUASTAT - FAO's Global Information System on Water and Agriculture. 2023 [cited 2023 Feb 7]. Available from: https://www.fao.org/aquastat/en/databases/
5. Ripert CL, Raccurt CP. The impact of small dams on parasitic diseases in Cameroon. Parasitol Today. 1987;3(9):287–9. https://doi.org/10.1016/0169-4758(87)90111-6 PMID: 15462987
6. Diakité NR, Winkler MS, Coulibaly JT, Guindo-Coulibaly N, Utzinger J, N'Goran EK. Dynamics of freshwater snails and Schistosoma infection prevalence in schoolchildren during the construction and operation of a multipurpose dam in central Côte d'Ivoire. Infect Dis Poverty. 2017;6(1):93.
7. French MD, Evans D, Fleming FM, Secor WE, Biritwum N-K, Brooker SJ, et al. Schistosomiasis in Africa: Improving strategies for long-term and sustainable morbidity control. PLoS Negl Trop Dis. 2018;12(6):e0006484. https://doi.org/10.1371/journal.pntd.0006484 PMID: 29953454
8. Rinaldo D, Perez-Saez J, Vounatsou P, Utzinger J, Arcand J-L. The economic impact of schistosomiasis. Infect Dis Poverty. 2021;10(1):134. https://doi.org/10.1186/s40249-021-00919-z PMID: 34895355
9. Steinmann P, Keiser J, Bos R, Tanner M, Utzinger J. Schistosomiasis and water resources development: systematic review, meta-analysis, and estimates of people at risk. Lancet Infect Dis. 2006;6(7):411–25. https://doi.org/10.1016/S1473-3099(06)70521-7 PMID: 16790382
10. Sokolow SH, Jones IJ, Jocque M, La D, Cords O, Knight A. Nearly 400 million people are at higher risk of schistosomiasis because dams block the migration of snail-eating river prawns. Philos Trans R Soc Lond B Biol Sci. 2017;372(1722):20160127.
11. Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D, et al. PRISMA Extension for Scoping Reviews (PRISMA-ScR): Checklist and Explanation. Ann Intern Med. 2018;169(7):467–73. https://doi.org/10.7326/M18-0850 PMID: 30178033
12. Sule MN, El Lahham I, Munkombwe MN, Nasike P, Gouvras A, Rollinson D, et al. Study protocol for Scoping Review of Schistosomiasis and water resources development in Africa and a multi-case evaluation of associated snail control. Database: figshare [Internet] Preprint. 2024; Available from: https://doi.org/10.6084/m9.figshare.26332741.v1
13. ESPEN-WHO. Schistosomiasis endemicity in Africa. Expanded Special Project for the Elimination of Neglected Tropical Diseases, World Health Organization. [cited 2024 May 9]; Available from: https://espen.afro.who.int/diseases/schistosomiasis
14. Mannaerts C, Maathuis B, Wehn U, Gerrets T, Riedstra H, Becht R, et al. Constraints and Opportunities for Water Resources Monitoring & Forecasting using the Triple Sensor approach; Source: FAO Geoportal database; survey data from 2011. 2017.
15. Shaikh N, Rahman-Shepherd A, Dar O. Schistosomiasis in the Senegal River basin. The Lancet Planetary Health. 2018;2:S27. https://doi.org/10.1016/s2542-5196(18)30112-8
16. Manyangadze T, Chimbari MJ, Gebreslasie M, Ceccato P, Mukaratirwa S. Modelling the spatial and seasonal distribution of suitable habitats of schistosomiasis intermediate host snails using Maxent in Ndumo area, KwaZulu-Natal Province, South Africa. Parasit Vectors. 2016;9(1):572. https://doi.org/10.1186/s13071-016-1945-0
17. Moen L, Tkacs J. Animal Diversity Web. 2013 [cited 2023 Mar 14]. Schistosoma mansoni. Available from: https://animaldiversity.org/accounts/Schistosoma_mansoni/
18. Kamel B, Laidemitt MR, Lu L, Babbitt C, Weinbaum OL, Mkoji GM. Detecting and identifying Schistosoma infections in snails and aquatic habitats: A systematic review. PLoS Negl Trop Dis. 2021;15(3):e0009175. https://doi.org/10.1371/journal.pntd.0009175

19. Food and Agriculture Organization. Chapter 7 - Health issues related to drainage water management. 1996 [cited 2023 May 2]. Available from: https://www.fao.org/3/W7224E/w7224e0b.htm
20. Hoevenaars J, Slootweg R. Rapid Assessment Study Towards Integrated Planning of Irrigation and Drainage in Egypt. Natural Resources Perspective. 2004 [cited 2023 Mar 9]; Available from: https://www.fao.org/4/a0021e/a0021e05.htm
21. Malek EA. Effect of the Aswan High Dam on prevalence of schistosomiasis in Egypt. Trop Geogr Med. 1975;27(4):359–64. PMID: 1216315
22. Sokolow SH, Huttinger E, Jouanard N, Hsieh MH, Lafferty KD, Kuris AM. Reduced transmission of human schistosomiasis after restoration of a native river prawn that preys on the snail intermediate host. Proc Natl Acad Sci U S A. 2015;112(31):9650–5. https://doi.org/10.1073/pnas.1501625112
23. Abdel-Motleb A, Gharieb M, Mohamed A, Kader A, Osman G. Effect of lining water courses on the occurrence of freshwater snails and its association with aquatic plants and fungi in certain governorates in Egypt. Fourrages. 2020;241:82–103.
24. Chimbari MJ. Enhancing schistosomiasis control strategy for zimbabwe: building on past experiences. J Parasitol Res. 2012;2012:353768. https://doi.org/10.1155/2012/353768 PMID: 22655171
25. Slootweg R, Malek EA, McCullough FS. The biological control of snail intermediate hosts of schistosomiasis by fish. Rev Fish Biol Fisheries. 1994;4(1):67–90. https://doi.org/10.1007/bf00043261
26. N'Diaye M, Dioukhane EM, Ndao B, Diedhiou K, Diawara L, Talla I, et al. Schistosomiasis sustained control program in ethnic groups around Ninefescha (Eastern Senegal). Am J Trop Med Hyg. 2016;95(3):614–22.
27. Evan Secor W. Water-based interventions for schistosomiasis control. Pathog Glob Health. 2014;108(5):246–54. https://doi.org/10.1179/2047773214Y.0000000149 PMID: 25175875
28. Nyekodzi G, Lawson ET, Gordon C. Evaluating the impacts of dredging and saline water intrusion on rural livelihoods in the Volta Estuary. International Journal of River Basin Management. 2017;16(1):93–105. https://doi.org/10.1080/15715124.2017.1372445
29. Boelee E, Laamrani H. Environmental control of schistosomiasis through community participation in a Moroccan oasis. Trop Med Int Health. 2004;9(9):997–1004. https://doi.org/10.1111/j.1365-3156.2004.01301.x PMID: 15361113
30. Laamrani H, Khallaayoune K, Boelee E, Laghroubi MM, Madsen H, Gryseels B. Evaluation of environmental methods to control snails in an irrigation system in Central Morocco. Trop Med Int Health. 2000;5(8):545–52. https://doi.org/10.1046/j.1365-3156.2000.00606.x PMID: 10995096
31. Boelee E, Madsen H. Irrigation and schistosomiasis in Africa: ecological aspects. Colombo, Sri Lanka. 2006.
32. Yang Y, Zheng S-B, Yang Y, Cheng W-T, Pan X, Dai Q-Q, et al. The Three Gorges Dam: Does the Flooding Time Determine the Distribution of Schistosome-Transmitting Snails in the Middle and Lower Reaches of the Yangtze River, China? Int J Environ Res Public Health. 2018;15(7):1304. https://doi.org/10.3390/ijerph15071304 PMID: 29933638
33. Barakat RMR. Epidemiology of Schistosomiasis in Egypt: Travel through Time: Review. J Adv Res. 2013;4(5):425–32. https://doi.org/10.1016/j.jare.2012.07.003 PMID: 25685449
34. Abdel-Wahab MF, Strickland GT, El-Sahly A, El-Kady N, Zakaria S, Ahmed L. Changing pattern of schistosomiasis in Egypt 1935--79. Lancet. 1979;2(8136):242–4. https://doi.org/10.1016/s0140-6736(79)90249-6 PMID: 89343
35. Abd-El Monsef H, Smith SE, Darwish K. Impacts of the Aswan High Dam After 50 Years. Water Resources Management. 2015;29(6):1873–85. https://doi.org/10.1007/s11269-015-0916-z
36. Michelson MK, Azziz FA, Gamil FM, Wahid AA, Richards FO, Juranek DD, et al. Recent trends in the prevalence and distribution of schistosomiasis in the Nile delta region. Am J Trop Med Hyg. 1993;49(1):76–87. https://doi.org/10.4269/ajtmh.1993.49.76 PMID: 8352395
37. Cline BL, Richards FO, El Alamy MA, El Hak S, Ruiz-Tiben E, Hughes JM, et al. 1983 Nile Delta Schistosomiasis Survey: 48 Years after Scott. The American Journal of Tropical Medicine and Hygiene. 1989;41(1):56–62. https://doi.org/10.4269/ajtmh.1989.41.56
38. Haggag AA, Rabiee A, Abd Elaziz KM, Gabrielli AF, Abdelhai R, Hashish A, et al. Elimination of schistosomiasis haematobia as a public health problem in five governorates in Upper Egypt. Acta Trop. 2018;188:9–15. https://doi.org/10.1016/j.actatropica.2018.08.024 PMID: 30145259
39. World Health Organisation. Egypt leverages domestic funding to eliminate schistosomiasis. 2016 [cited 2023 May 3]. Available from: https://www.who.int/news/item/29-11-2016-egypt-leverages-domestic-funding-to-eliminate-schistosomiasis
40. Van der Schalie H. New high dam, asset or liability. The Biologist. 1960;42:63–70.
41. Biswas AK, Tortajada C. Impacts of the high Aswan Dam. Impacts of large dams: A global assessment. Springer; 2011. p. 379–95.
42. World Bank. Project performance assessment report: Arab Republic of Egypt National Schistosomiasis Control Project. 2008 [cited 2023 Apr 2]. Available from: https://documents1.worldbank.org/curated/en/756051468036566715/pdf/444660PPAR0P0051520Box327410B01PUBLIC1.pdf
43. Awad A, El-Rawy M, Abdelmawgoud AH. Agricultural drainage strategies in Egypt as a protection tool against groundwater contamination by fertilizers: An overview. In. 2022. p. 203–33.
44. Abdel-Dayem S, Abdel-Gawad S, Fahmy H. Drainage in Egypt: a story of determination, continuity, and success. Irrig and Drain. 2007;56(S1):S101–11. https://doi.org/10.1002/ird.335
45. M. Ismail N, N. Sedek M, M. El-Said K, M. A. Marai A. Effect of Water Bodies Lining on the Efficacy of Molluscicides Against Biomphalaria alexandrina Snails with Emphasis to their Integrated Control Measures. Egypt J of Aquatic Biolo and Fish. 2019;23(5):267–83. https://doi.org/10.21608/ejabf.2019.66051

46. Abou-El-Naga IF. Biomphalaria alexandrina in Egypt: past, present and future. J Biosci. 2013;38(3):665–72. https://doi.org/10.1007/s12038-013-9329-4 PMID: 23938396
47. Abd-Elaty I, Pugliese L, Bali KM, Grismer ME, Eltarabily MG. Modelling the impact of lining and covering irrigation canals on underlying groundwater stores in the Nile Delta, Egypt. Hydrol Process. 2022;36(1).
48. Giroud JP, Plusquellec H. Evaluation of concrete and geomembrane lining options for a canal in Egypt. Geosynthetics International. 2023;30(1):108–12. https://doi.org/10.1680/jgein.22.00013
49. Khater HF. Introductory Chapter: Back to the Future - Solutions for Parasitic Problems as Old as the Pyramids. In: Natural Remedies in the Fight Against Parasites. InTech; 2017.
50. Sarant L. Crayfish in the Nile: A threat to biodiversity with potential for a booming industry. 2011 [cited 2023 Apr 2]; Available from: https://egyptindependent.com/crayfish-nile-threat-biodiversity-potential-booming-industry/
51. Holdich DM. The negative effects of established crayfish introductions. Crayfish in Europe as alien species. Routledge; 2017. p. 31–47.
52. Laamrani H, Mahjour J, Madsen H, Khallaayoune K, Gryseels B. Schistosoma haematobium in Morocco: moving from control to elimination. Parasitol Today. 2000;16(6):257–60. https://doi.org/10.1016/s0169-4758(00)01665-3 PMID: 10827435
53. Tlamçani Z, Er-Rami M. Schistosomiasis control: moroccan experience compared to other endemic countries. Asian Pacific Journal of Tropical Disease. 2014;4(4):329–32. https://doi.org/10.1016/s2222-1808(14)60583-1
54. Balahbib A, Amarir F, Bouhout S, Rhajaoui M, Adlaoui E, Sadak A. Review of the Urinary Schistosomiasis Control in Morocco (1960-2018). Interdisciplinary Perspectives on Infectious Diseases. 2020;2020:3868970. https://doi.org/10.1155/2020/3868970
55. Amarir F, El Mansouri B, Fellah H, Sebti F, Mohammed L, Handali S, et al. National serologic survey of Haematobium schistosomiasis in Morocco: evidence for elimination. Am J Trop Med Hyg. 2011;84(1):15–9. https://doi.org/10.4269/ajtmh.2011.10-0378 PMID: 21212195
56. Barkia H, Barkia A, Yacoubi R, Alemad A, El Kharim K, Belghyti D. Contribution of mobile teams to efforts to eliminate schistosomiasis at Schistosoma haematobium in Morocco- narrative review article. Iran J Public Health. 2014;43(9):1167–75.
57. Boelee E. Irrigation ecology of schistosomiasis: environmental control options in Morocco. [external PhD, WU]. 199 p; 2000 [cited 2023 Mar 9]. Available from: https://edepot.wur.nl/196817
58. Khallaayoune K, Laamrani H, Madsen H. Distribution ofBulinus truncatus, the Intermediate Host ofSchistosoma haematobium, in an Irrigation System in Morocco. Journal of Freshwater Ecology. 1998;13(1):129–33. https://doi.org/10.1080/02705060.1998.9663598
59. King CH, Sutherland LJ, Bertsch D. Systematic review and meta-analysis of the impact of chemical-based molluscicide for control of Schistosoma mansoni and S. haematobium transmission. PLoS Negl Trop Dis. 2015;9(12):e0004290. https://doi.org/10.1371/journal.pntd.0004290
60. Khallaayoune K, Madsen H, Laamrani H. Evaluation of three methods to control Bulinus truncatus, the intermediate host of Schistosoma haematobium in an irrigation scheme, Tessaout-Amont, Morocco. Acta Trop. 1998;69(1):51–63. https://doi.org/10.1016/s0001-706x(97)00119-8 PMID: 9588241
61. De Leo G, Sokolow S. Supplemental Information. Stanford Digital Repository. 2015. Available from: http://purl.stanford.edu/yt060bn1019
62. Ghana Ministry of Health. Two-year Strategic Plan for Integrated Neglected Tropical Diseases Control in Ghana 2007-2008. 2016 [cited 2023 May 2]. Available from: https://www.moh.gov.gh/wp-content/uploads/2016/02/Plan-for-Pro-Poor-Diseases.pdf
63. Schur N, Hürlimann E, Garba A, Traoré MS, Ndir O, Ratard RC, et al. Geostatistical model-based estimates of Schistosomiasis prevalence among individuals aged ≤ 20 years in West Africa. PLoS Negl Trop Dis. 2011;5(6):e1194. https://doi.org/10.1371/journal.pntd.0001194 PMID: 21695107
64. Hunter JM. Inherited burden of disease: agricultural dams and the persistence of bloody urine (Schistosomiasis hematobium) in the Upper East Region of Ghana, 1959-1997. Soc Sci Med. 2003;56(2):219–34. https://doi.org/10.1016/s0277-9536(02)00021-7 PMID: 12473309
65. Hotez PJ, Biritwum N-K, Fenwick A, Molyneux DH, Sachs JD. Ghana: Accelerating neglected tropical disease control in a setting of economic development. PLoS Negl Trop Dis. 2019;13(1):e0007005. https://doi.org/10.1371/journal.pntd.0007005 PMID: 30653493
66. Global Health Burden. Comparison of prevalence and incidence of selected NTDs in Ghana in the years 2000 and 2017. 2023 [cited 2023 May 2]. Available from: https://vizhub.healthdata.org/gbd-results/
67. Bosompem K, Yirenya-Tawiah D, McCown M, Anyan W, Biritwum NK, Acquaah-Arhin D. Schistosomiasis Control Initiative Ghana (SCIG) National Schistosomiasis Control Forum Developing an Integrated National Plan for Sustainable Schistosomiasis Control. 2010.
68. Zakhary K. Factors Affecting the Prevalence of Schistosomiasis in the Volta Region of Ghana. MJM. 2020;3(2):93–101. https://doi.org/10.26443/mjm.v3i2.583
69. Kranjac-Berisavljevic G, Abagale FK. Siltation Of Dams And Reservoirs And Its Effect On Agricultural Production In Northern Ghana: A Case Study Of Chabchab Irrigation Project, Savelugu-Nanton District. 2004 [cited 2023 Mar 7]. Available from: http://www.udsspace.uds.edu.gh/handle/123456789/2169?mode=full
70. Nukpezah D, Sawyer LM, Twum-Barimah R, Ntiamoa-Baidu Y. Re-optimisation and re-operation study of Akosombo and Kpong dams: voices from the downstream communities. In Dams, Development and Downstream Communities: Implications for Re-Optimising the Operations of the Akosombo and Kpong Dams in Ghana. 2017;27–42.
71. Dankwa HR, Owiredu SA, Amevenku F, Amedorme E. Environmental flow requirements and impacts of the Akosombo and Kpong dams on the fish and fisheries of the Lower Volta River, Ghana. In Dams, Development and Downstream Communities: Implications for Re-Optimising the Operations of the Akosombo and Kpong Dams in Ghana. 2017;43–62.

72. Amatekpor J. Soils and land-use in the Volta basin, state of the art. The sustainable integrated development of the Volta basin in Ghana. In: Volta Basin Research Project, University of Ghana, Legon. Accra, Ghana: Gold Type Press; 1999.
73. Bray RN. Environmental Aspects of Dredging. CRC Press; 2008. https://doi.org/10.1201/9780203894897
74. Zume JT, Mariwah S, Boateng ENK. Evaluating the impacts of on-site sanitation facilities and saltwater intrusion on shallow groundwater quality in peri-urban communities of Cape Coast, Ghana. Environ Monit Assess. 2021;193(5):264. https://doi.org/10.1007/s10661-021-09059-1 PMID: 33847837
75. Mueller W, Zamrsky D, Essink GO, Fleming LE, Deshpande A, Makris KC, et al. Saltwater intrusion and human health risks for coastal populations under 2050 climate scenarios. Sci Rep. 2024;14(1):15881. https://doi.org/10.1038/s41598-024-66956-4 PMID: 38987576
76. Njunda AL, Ndzi EN, Assob JCN, Kamga H-LF, Kwenti ET. Prevalence and factors associated with urogenital schistosomiasis among primary school children in barrage, Magba sub-division of Cameroon. BMC Public Health. 2017;17(1):618. https://doi.org/10.1186/s12889-017-4539-6 PMID: 28673343
77. Tchuem Tchuenté LA, Dongmo Noumedem C, Ngassam P, Kenfack CM, Gipwe NF, Dankoni E. Mapping of schistosomiasis and soil-transmitted helminthiasis in the regions of Littoral, North-West, South and South-West Cameroon and recommendations for treatment. BMC Infect Dis. 2013;13:602.
78. Slootweg R, Kooyman M, de Koning P, van Schooten M. Water contact studies for the assessment of schistosomiasis infection risks in an irrigation scheme in Cameroon. Irrig Drainage Syst. 1993;7(2):113–30. https://doi.org/10.1007/bf00880871
79. Tsafack F. Ecology of schistosome intermediate hosts in the Benue Upper-Valley area. Denmark: University of Copenhagen; 1997.
80. Massenet D, Toukour A, Kamwa Ngassam RI, Djao R, Portal JL, Tchuenté LAT. Changes in the distribution of human schistosomiasis in Far North province, Cameroon, since 1986. Ann Trop Med Parasitol. 2011;105(4):325–8.
81. Aula OP, McManus DP, Jones MK, Gordon CA. Schistosomiasis with a Focus on Africa. Trop Med Infect Dis. 2021;6(3):109. https://doi.org/10.3390/tropicalmed6030109 PMID: 34206495
82. Slootweg R. Contrôle intégré de la schistosomiase à Gounougou: réussites et échecs. 1991 [cited 2023 Mar 12]. Available from: https://www.ircwash.org/sites/default/files/245.10-91RA-11817.pdf
83. Slootweg R, Keyzer R. Reducing schistosomiasis infection risks through improved drainage. Irrig Drainage Syst. 1993;7(2):99–112. https://doi.org/10.1007/bf00880870
84. Green AE, Anchang-Kimbi JK, Wepnje GB, Ndassi VD, Kimbi HK. Distribution and factors associated with urogenital schistosomiasis in the Tiko Health District, a semi-urban setting, South West Region, Cameroon. Infect Dis Poverty. 2021;10(1):49. https://doi.org/10.1186/s40249-021-00827-2 PMID: 33845904
85. Takougang I, Meli J, Fotso S, Angwafo F 3rd, Kamajeu R, Ndumbe PM. Some social determinants of urinary schistosomiasis in Northern Cameroon: implications for schistosomiasis control. Afr J Health Sci. 2004;11(3–4):111–20. https://doi.org/10.4314/ajhs.v11i3.30788 PMID: 17298128
86. M'Bra RK, Kone B, Yapi YG, Silué KD, Sy I, Vienneau D. Risk factors for schistosomiasis in an urban area in northern Côte d'Ivoire. Infect Dis Poverty. 2018;7(1):47.
87. Assaré RK, Tian-Bi Y-NT, Yao PK, N'Guessan NA, Ouattara M, Yapi A, et al. Sustaining Control of Schistosomiasis Mansoni in Western Côte d'Ivoire: Results from a SCORE Study, One Year after Initial Praziquantel Administration. PLoS Negl Trop Dis. 2016;10(1):e0004329. https://doi.org/10.1371/journal.pntd.0004329 PMID: 26789749
88. Assaré RK, Knopp S, N'Guessan NA, Yapi A, Tian-Bi YNT, Yao PK. Sustaining control of schistosomiasis mansoni in moderate endemicity areas in western Côte d'Ivoire: a SCORE study protocol. BMC Public Health. 2014;14:1290.
89. Fürst T, Silué KD, Ouattara M, N'Goran DN, Adiossan LG, N'Guessan Y, et al. Schistosomiasis, soil-transmitted helminthiasis, and sociodemographic factors influence quality of life of adults in Côte d'Ivoire. PLoS Negl Trop Dis. 2012;6(10):e1855. https://doi.org/10.1371/journal.pntd.0001855 PMID: 23056662
90. Mortey EM, Kouassi KL, Diedhiou A, Anquetin S, Genoud M, Hingray B, et al. Sustainable Hydroelectric Dam Management in the Context of Climate Change: Case of the Taabo Dam in Côte D'Ivoire, West Africa. Sustainability. 2019;11(18):4846. https://doi.org/10.3390/su11184846
91. N'Goran EK, Diabate S, Utzinger J, Sellin B. Changes in human schistosomiasis levels after the construction of two large hydroelectric dams in central Côte d'Ivoire. Bull World Health Organ. 1997;75(6):541–5. PMID: 9509626
92. Kouassi RM, Kone B, Yao EK, Silue B, Cisse G, Soro N. Approvisionnement en eau potable, qualité de la ressource et risques sanitaires associés à Korhogo (Nord-Côte d'Ivoire). Environnement, Risques & Santé. 2015;14(3):230–41.
93. Cissé G, Koné B, Bâ H, Mbaye I, Koba K, Utzinger J, et al. Ecohealth and climate change: adaptation to flooding events in riverside secondary cities, West Africa. Resilient Cities: Cities and Adaptation to Climate Change-Proceedings of the Global Forum 2010:55–67. 2011;55–67.
94. Assaré RK, N'Tamon RN, Bellai LG, Koffi JA, Mathieu TBI, Ouattara M. Characteristics of persistent hotspots of Schistosoma mansoni in western Côte d'Ivoire. Parasit Vectors. 2020;13(1):337.
95. Southgate VR. Schistosomiasis in the Senegal River Basin: before and after the construction of the dams at Diama, Senegal and Manantali, Mali and future prospects. J Helminthol. 1997;71(2):125–32. https://doi.org/10.1017/s0022149x00015790 PMID: 9192711
96. Talla I, Kongs A, Verlé P, Belot J, Sarr S, Coll AM. Outbreak of intestinal schistosomiasis in the Senegal River Basin. Ann Soc Belg Med Trop. 1990;70(3):173–80. PMID: 2122819

97. Sow S, de Vlas SJ, Engels D, Gryseels B. Water-related disease patterns before and after the construction of the Diama dam in northern Senegal. Ann Trop Med Parasitol. 2002;96(6):575–86. https://doi.org/10.1179/000349802125001636 PMID: 12396320

98. Sow S, de Vlas SJ, Stelma F, Vereecken K, Gryseels B, Polman K. The contribution of water contact behavior to the high Schistosoma mansoni infection rates observed in the Senegal River Basin. BMC Infect Dis. 2011;11:198.

99. Picquet M, Ernould JC, Vercruysse J, Southgate VR, Mbaye A, Sambou B, et al. Royal Society of Tropical Medicine and Hygiene meeting at Manson House, London, 18 May 1995. The epidemiology of human schistosomiasis in the Senegal river basin. Trans R Soc Trop Med Hyg. 1996;90(4):340–6. https://doi.org/10.1016/s0035-9203(96)90501-5 PMID: 8882173

100. Rohr JR, Sack A, Bakhoum S, Barrett CB, Lopez-Carr D, Chamberlin AJ, et al. A planetary health innovation for disease, food and water challenges in Africa. Nature. 2023;619(7971):782–7. https://doi.org/10.1038/s41586-023-06313-z PMID: 37438520

101. Wood CL, Sokolow SH, Jones IJ, Chamberlin AJ, Lafferty KD, Kuris AM, et al. Precision mapping of snail habitat provides a powerful indicator of human schistosomiasis transmission. Proc Natl Acad Sci U S A. 2019;116(46):23182–91. https://doi.org/10.1073/pnas.1903698116 PMID: 31659025

102. Savaya Alkalay A, Rosen O, Sokolow SH, Faye YPW, Faye DS, Aflalo ED, et al. The prawn Macrobrachium vollenhovenii in the Senegal River basin: towards sustainable restocking of all-male populations for biological control of schistosomiasis. PLoS Negl Trop Dis. 2014;8(8):e3060. https://doi.org/10.1371/journal.pntd.0003060 PMID: 25166746

103. Chaine JP, Malek EA. Urinary schistosomiasis in the Sahelian region of the Senegal River Basin. Trop Geogr Med. 1983;35(3):249–56. PMID: 6649050

104. Katz N. Schistosomiasis control in Brazil. Mem Inst Oswaldo Cruz. 1998;93(suppl 1):33–5. https://doi.org/10.1590/s0074-02761998000700005

105. Coura JR, Amaral RS. Epidemiological and control aspects of schistosomiasis in Brazilian endemic areas. Mem Inst Oswaldo Cruz. 2004;99(5 Suppl 1):13–9. https://doi.org/10.1590/s0074-02762004000900003 PMID: 15486629

106. Gordon CA, Kurscheid J, Williams GM, Clements ACA, Li Y, Zhou X-N, et al. Asian Schistosomiasis: Current Status and Prospects for Control Leading to Elimination. Trop Med Infect Dis. 2019;4(1):40. https://doi.org/10.3390/tropicalmed4010040 PMID: 30813615

107. Minai M, Hosaka Y, Ohta N. Historical view of schistosomiasis japonica in Japan: implementation and evaluation of disease-control strategies in Yamanashi Prefecture. Parasitol Int. 2003;52(4):321–6. https://doi.org/10.1016/s1383-5769(03)00047-3 PMID: 14665389

108. Tanaka H, Tsuji M. From discovery to eradication of schistosomiasis in Japan: 1847-1996. Int J Parasitol. 1997;27(12):1465–80. https://doi.org/10.1016/s0020-7519(97)00183-5 PMID: 9467732

109. Wang W, Bergquist R, King CH, Yang K. Elimination of schistosomiasis in China: Current status and future prospects. PLoS Negl Trop Dis. 2021;15(8):e0009578. https://doi.org/10.1371/journal.pntd.0009578 PMID: 34351907

110. Zhou Y, Chen Y, Jiang Q. History of Human Schistosomiasis (bilharziasis) in China: From Discovery to Elimination. Acta Parasitol. 2021;66(3):760–9. https://doi.org/10.1007/s11686-021-00357-9 PMID: 33713275

111. Qian M-B, Chen J, Bergquist R, Li Z-J, Li S-Z, Xiao N, et al. Neglected tropical diseases in the People's Republic of China: progress towards elimination. Infect Dis Poverty. 2019;8(1):86. https://doi.org/10.1186/s40249-019-0599-4 PMID: 31578147

112. Carmo EH, Barreto ML. Schistosomiasis mansoni in Bahia, Brazil: historical trends and control measures. Cad Saude Publica. 1994;10(4):425–39. https://doi.org/10.1590/s0102-311x1994000400002 PMID: 14676928

113. Ebisawa I. Epidemiology and eradication of Schistosomiasis japonica in Japan. J Travel Med. 1998;5(1):33–5. https://doi.org/10.1111/j.1708-8305.1998.tb00454.x PMID: 9772314

114. Tarjuelo JM, Rodriguez-Diaz JA, Abadía R, Camacho E, Rocamora C, Moreno MA. Efficient water and energy use in irrigation modernization: Lessons from Spanish case studies. Agricultural Water Management. 2015;162:67–77. https://doi.org/10.1016/j.agwat.2015.08.009

115. Komiya Y. Cementing ditches of the habitat of Oncomelania Nosphora, the intermediate host of Schistosoma Japonicum, as a preventive measure of schistosomiasis-a review. Jpn J Med Sci Biol. 1965;18(6):275–81. https://doi.org/10.7883/yoken1952.18.275

116. Sun L-P, Wang W, Zuo Y-P, Zhang Z-Q, Hong Q-B, Yang G-J, et al. An integrated environmental improvement of marshlands: impact on control and elimination of schistosomiasis in marshland regions along the Yangtze River, China. Infect Dis Poverty. 2017;6(1):72. https://doi.org/10.1186/s40249-017-0287-1 PMID: 28330510

117. Xianyi C, Liying W, Jiming C, Xiaonong Z, Jiang Z, Jiagang G. Schistosomiasis control in China: the impact of a 10-year World Bank loan project (1992-2001). Bull World Health Organ. 2005;83(1):43–8.

118. Spear R, Zhong B, Liang S. Low transmission to elimination: rural development as a key determinant of the end-game dynamics of Schistosoma japonicum in China. Trop Med Infect Dis. 2017;2(3):35.

119. Yokogawa M. Review of prevalence and distribution of schistosomiasis in Japan. Southeast Asian J Trop Med Public Health. 1976;7(2):137–43. PMID: 1025716

120. Gross MD. Chasing snails: anti-schistosomiasis campaigns in the People's Republic of China. University of California, San Diego; 2010. https://escholarship.org/uc/item/9kw3b0vc

121. Chen D, Webber M, Chen J, Luo Z. Emergy evaluation perspectives of an irrigation improvement project proposal in China. Ecological Economics. 2011;70(11):2154–62. https://doi.org/10.1016/j.ecolecon.2011.06.017

122. Martins-Melo FR, Pinheiro MCC, Ramos AN Jr, Alencar CH, Bezerra FS de M, Heukelbach J. Trends in schistosomiasis-related mortality in Brazil, 2000-2011. Int J Parasitol. 2014;44(14):1055–62. https://doi.org/10.1016/j.ijpara.2014.07.009 PMID: 25161102

123. Coura-Filho P. Participação popular no controle da esquistossomose através do Sistema Único de Saúde (SUS), em Taquaraçu de Minas, (Minas Gerais, Brasil), entre 1985-1995: construção de um modelo alternativo. Cad Saúde Pública. 1998;14(suppl 2):S111–22. https://doi.org/10.1590/s0102-311x1998000600010

124. Attayde JL, Brasil J, Menescal RA. Impacts of introducing Nile tilapia on the fisheries of a tropical reservoir in North-eastern Brazil. Fisheries Management Eco. 2011;18(6):437–43. https://doi.org/10.1111/j.1365-2400.2011.00796.x

125. da Silva Cacho JC, Teixeira de Moura RS, Henry-Silva GG. Influence of Nile tilapia (Oreochromis niloticus) fish farming in net cages on the nutrient and particulate matter sedimentation rates in Umari reservoir, Brazilian semi-arid. Aquaculture Reports. 2020;17:100358. https://doi.org/10.1016/j.aqrep.2020.100358

126. Bay AR. Total prevention: a history of schistosomiasis in Japan. Med Hist. 2022;66(2):95–115. https://doi.org/10.1017/mdh.2022.11

127. Zhang S, Wang T, Zhou Y, Cao Z, Zhang G, Wang N, et al. Influence of the Three Gorges Dam on schistosomiasis control in the middle and lower reaches of the Yangtze River. Global Health Journal. 2019;3(1):9–15. https://doi.org/10.1016/j.glohj.2019.03.003

128. Yoosefdoost A, Lubitz WD. Sluice Gate Design and Calibration: Simplified Models to Distinguish Flow Conditions and Estimate Discharge Coefficient and Flow Rate. Water. 2022;14(8):1215. https://doi.org/10.3390/w14081215

129. Xu J, Zhu H, Liu J, Lin J, Liu J, Liang Y. China's Experiences in the Combat of Schistosomiasis. In: Zhou, XN. editor. Tropical diseases in China. Public Health in China, vol 5. Springer, Singapore; 2022. p. 159–217. https://doi.org/10.1007/978-981-19-5707-9_5

130. Li Z, Wen Y, Lin D, Hu F, Wang Q, Li Y. Impact of the National Wetland Park in the Poyang Lake Area on Oncomelania hupensis, the Intermediate Host of Schistoma japonicum. Trop Med Infect Dis. 2023;8(4):194.

131. Chen H, Lin D. The prevalence and control of schistosomiasis in Poyang Lake region, China. Parasitol Int. 2004;53(2):115–25. https://doi.org/10.1016/j.parint.2004.01.002 PMID: 15081943

132. Sokolow SH, Wood CL, Jones IJ, Lafferty KD, Kuris AM, Hsieh MH, et al. To Reduce the Global Burden of Human Schistosomiasis, Use "Old Fashioned" Snail Control. Trends Parasitol. 2018;34(1):23–40. https://doi.org/10.1016/j.pt.2017.10.002 PMID: 29126819

133. Sokolow SH, Wood CL, Jones IJ, Swartz SJ, Lopez M, Hsieh MH, et al. Global Assessment of Schistosomiasis Control Over the Past Century Shows Targeting the Snail Intermediate Host Works Best. PLoS Negl Trop Dis. 2016;10(7):e0004794. https://doi.org/10.1371/journal.pntd.0004794 PMID: 27441556

134. Silva Brito R, João Bebianno M, Rocha TL. Plant-based silver nanoparticles ecotoxicity: Perspectives about green technologies in the One Health context. Critical Reviews in Environmental Science and Technology. 2024;54(16):1218–35. https://doi.org/10.1080/10643389.2024.2303298

135. Araújo PS, Caixeta MB, Canedo A, Nunes E da S, Monteiro C, Rocha TL. Toxicity of plant-based silver nanoparticles to vectors and intermediate hosts: Historical review and trends. Sci Total Environ. 2022;834:155299. https://doi.org/10.1016/j.scitotenv.2022.155299 PMID: 35439509

136. Sule MN, Mosha J, Soboka TE, Kinung'hi SM, Sfynia C, Rafiq K, et al. A novel theatre-based behaviour change approach for influencing community uptake of schistosomiasis control measures. Parasit Vectors. 2022;15(1):301. https://doi.org/10.1186/s13071-022-05421-5 PMID: 36008841

137. Torres-Vitolas CA, Trienekens SCM, Zaadnoordijk W, Gouvras AN. Behaviour change interventions for the control and elimination of schistosomiasis: A systematic review of evidence from low- and middle-income countries. PLoS Negl Trop Dis. 2023;17(5):e0011315. https://doi.org/10.1371/journal.pntd.0011315 PMID: 37163556



https://dspace.org/

Schistosomiasis and water resources development in Africa: a scoping review and multi-case evaluation of associated snail control

Sule, May N.; El Lahham, Ibrahim; Munkombwe, Mutinta N.; Nasike, Patricia; Gouvras, Anouk ...

2025-06-12
Public Library of Science (PLoS)
https://doi.org/10.1371/journal.pntd.0013180
Sule MN, El Lahham I, Munkombwe MN, et al., (2025) Schistosomiasis and water resources development in Africa: a scoping review and multi-case evaluation of associated snail control. PLOS Neglected Tropical Diseases, Volume 19, Issue 6, June 2025, Article number e0013180

Downloaded from a DSpace repository. https://dspace.org/