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A review of the current advances on the role of limnology in the epidemiology of schistosomiasis: The snail vector experience

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ABSTRACT: Schistosomiasis infection produces a degenerating effect on victims. The areas most affected are the intestinal blood vessels and organs (for *Schistosoma mansoni*) and the urinary blood vessels and tissues (for *S. haematobium*). Schistosomiasis, like other parasitic diseases, has pre-disposing factors which, if not avoided, lead to increase in the spread of the disease. The major point of interest in the case of schistosomiasis is its transmission-link with aquatic environment. The intermediate hosts of schistosomiasis are snails and these snails live in the freshwater habitats. The establishment, survival maturity and reproduction of these snails, and consequently schistosomes, are therefore dependent on the limnological characteristics of the water in which they find themselves. Some of these factors include water temperature, water level, calcium hardness, pH, water velocity and aquatic vegetation among other minor intrinsic and extrinsic factors. These limnological factors affect the snail vectors significantly ($P<0.05$)either positively, neutrally or negatively and the manipulation of these factors have been successfully applied in the control of the snails and subsequently, control of schistosomiasis.

Key words: Limnology, population, vectors, schistosomiasis.

Introduction

The epidemiology of schistosomiasis involves a vertebrate definitive and a molluscan intermediate hosts and their common presence in an aquatic environment in which transmission can take place (Jordan & Webbe 1982, Kabatereine et al 2004, Anto *et al* 2005). For many years now, health-workers all over the world have continued to place schistosomiasis among the priority research targets in the world with special attention to the tropics. It is in a bid to give schistosomiasis the required attention it deserves that the UNDP/WORLD BANK/WHO special programme for Tropical Diseases Research (TDR) included it among the eight “Target Diseases”of the TDR. The UNDP/WORLD BANK/WHO(1993) report stated that the TDR’s current disease-specific steering committee would be reorganized into three main areas: Strategic Research (SR), Product Research and Development (PRD) and Applied Field Research (AFR) and that there will be greater emphasis on AFR and that the budg*et al*location for this area will be increased.

This resolution depicts clearly the current need for investigation into TDR-target diseases (of which schistosomiasis is one) by a method that will involve AFR rather than pure laboratory or hospital based approach. These clarifications amplifies the importance of vector ecology as a major aspect of the AFR and which implies that the intervention of schistosomiasis disease depends more on the control of the vector rather than chemotherapy. Schistosomiasis is one of the most important public health problems in many developing countries(Kenawy and Rizk, 2004) and the most prevalent of the endemic tropical diseases (Umeh *et al* 2004).

Cases of co-infection for schistosomiasis and malaria are frequently encountered. Booth *et al* (2004) reported that *Schistosoma mansoni* and *Plasmodium falciparum* are common infections of school aged children in Kenya and that they both cause enlargement of the spleen and provided firm evidence that relatively high exposure to both infections exacerbates splenomegaly even outside the malaria transmission season. Legesse *et al* (2004) reported that co-infections with schistosome and malaria parasites aggravated malaria severity and prolonged parasite reduction or clearance after chemotherapy in humans. They therefore suggested the need for considering schistosome infection in clinical as well as therapeutic management of malaria patients in areas where the two diseases are co-endemic.

Mobidity and mortality attributable to schistosomiasis is significant especially when the progressive nature of the disease is considered. Utzinger and Keiser (2004) reported that schistosomiasis currently affects 200 million people living in tropical and subtropical environments. The report also stated that schistosomiasis is a chronic disease and the latest estimates for sub-Saharan Africa are that it kills >200,000 people every year.

Efforts on diagnosis and treatment as means of controlling the disease have been pursued by many countries and researchers, but no equivalent result has been achieved inspite of the high economic involvement (Montes *et al*, 2004, de-Vlas *et al* 2004, Mandong and Madaki 2005.)

This scenario makes it imperative for greater attention to be placed on the control of the snail vectors as a major component for the control of schistosomiasis. For a significantly effective result to be achieved in this direction, a clear understanding of the influence of limnological factors on the establishement, survival, reproduction and distribution of the snail vectors is essential.

This review, therefore, elucidates the effects of six limnological factors of the aquatic environment on the snail vectors of the infective stages of the schistosome parasites and the use of the manipulation of these factors to control the snail vectors and schistosomiasis. These factors are water velocity, water level (depth), water temperature, aquatic vegetation, water pH and water hardness.

Water Velocity

One of the characteristics of a water body is the flow rate or velocity and this varies from one aquatic habitat to the other. The physical and chemical characteristics of the aquatic habitat affect the establishement and distribution of the aquatic flora and fauna therein (Madsen and Monrad 1981). Water velocity is one of the physical factors that influence the establishment of snail vectors (Ezeugwu and Obiamiwe 2005) and slow-flowing habitats are preferred by the snails (Webbe 1967, Williams and Hunter, 1978).

Bulinus truncatus does not usually tolerate rapidly flowing water while *Biomphalaria alexandrina* is apparently even less able to withstand high rates of flow (Watson,1958) and water current velocity is the most important factor influencing the distribution of snails in lotic environment (Appleton 1978).

Williams and Hunter (1968), Mousa and El-Hassan (1972) while working on the effect of water velocity on the distribution of six species of snails including *Bulinus truncatus* and *Bulinus forskali* reported that microhabitats, where the water flow is nearly stagnant or slow-flowing, are preferred by snails for breeding. The snails and their egg masses are attached to logs and vegetations and increased water current dislodges them from their points of attachment. Paulinyi and Paulini (1967), Ezeugwu and Obiamiwe, (2005) reported that the deleterious effects of increased water velocity and turbulence manifest in dislodgement of the snails from their attachment and are subsequently washed away to unfavorable locations. The report stated that a greater number of *Biomphalaria glabrata* snails were dislodged and swept away by the water flow and that the percentage of the snails dislodged increased in proportion with the linear velocity of water flow.

The report by Ezeugwu and Obiamiwe (2005) showed that there were significant ($P< 0.05$) differences between the abundance of *Bulinus globosus* and *Bulinus forskali* in the aquatic habitats studied which also had significant differences in their velocities. They reported that the single regression analysis clearly showed a negative effect of water velocity an snail distribution with a single regression equation of:

$$Y = 105.016-3.017\,X \pm 8.85$$

(where Y = *B. globosus* and X = water velocity)

Using a scatter- diagram with regression line and 95% confidence belt of water velocity against the abundance of *B.globosus* ,the report showed that water velocity has a negative slope implying a probable deleterious effect of increase in water velocity on the snail biology. The two snail species, the report added, preferred habitat with stagnant and slow-flowing waters. Manipulation of the water velocities could therefore be used in the control of the snail vectors as increased velocities dislodge them from their points of attachments and wash them away to unfavorable environments where they may eventually die.

Water Level

Fluctuation of the levels of a water body is a product of the climatic and environmental changes around and within the water body. These fluctuations affect the biology of the aquatic flora and fauna. Snail vectors of schistosomiasis are positively or negatively affected by this fluctuation depending on the degree and duration of the fluctuation. Irrigation canals are examples of aquatic habitats that are constantly subjected to water level fluctuations.Ugonabo *et al* (1991) reported that snail intermediate hosts of schistosomiasis flourish in sluggish flowing water bodies such as irrigation canals and that high frequency of water level fluctuations tends to discourage the proliferation of the snail hosts.Ezeugwu & Mafe (1998) reported that the snails were more abundant when the aquatic habitats become stable in terms of water level and velocity.

According to Ezeugwu & Okaka (2001), the snails with egg mass were more abundant in Alau Dam from March to July which coincided with the period of low level of water in the dam during which period the water was stable both in level and stagnancy resulting in favourable conditions for snail breeding.

Another report by Ezeugwu and Obiamiwe (2003) stated that changing water levels had an adverse effect on *Bulinus globosus* as the snails are usually attached to and lay eggs on the under surface of floating leaves of the rooted plants and that a fall in the water level exposes the snails and egg masses to desiccation and possibly death. Using a scatter-diagram with regression line and 95% confidence belt of *B.globosus and B.forskali* against water level, the report stated that the water level they studied was deleterious to *B.globosus* but favoured *B.forskali* adding that while *B.globosus* occupied mostly the surface of the water *,B.forskali* was recovered mostly from the bottom or middle of the water. Fluctuation in water level could therefore be adequately applied in the control of the snail vectors and consequently reduce the transmission of schistosomiasis.

Water Temperarure

Snails are capable of tolerating different chemical and physical conditions with very wide limits and temperature plays a significant role in this regard. Profound diurnal temperature ranges occur in many of the habitats of snail intermediate hosts and the distribution and growth of snail populations in a given area depend upon temperature and other intrinsic and extrinsic factors (Jordan & Webbe 1982). A study done in Northeastern Nigeria (Ezeugwu and Obiamiwe 2003)revealed that higher water temperatures were deleterious to both *Bulinus globosus* and *B.forskali* with *B.globosus* being more tolerant to higher temperatures. By means of a scatter-diagram with regression line and 95% confidence belt and a regression equation ,the researchers extrapolated the upper critical water temperatures for *B.forskali* and *B.globosus* as 30.6ºC and 37.6ºC respectively.

Water temperature affects the abundance of freshwater snail vectors directly by influencing such biological activities as egg laying, incubation, hatching and rate of maturity. Mousa and El-Hassan (1972) observed that the incubation period of *Bulinus truncatus* and *Biomphalaria alexandrina* shortened as water temperature increased and an optimium temperature of 25ºC for most pronounced growth of the snail and 20ºC-25ºC as optimum for survival, sexual maturity and egg laying of both species.Guo *et al* (2004) while working in China reported that the warming climate phenomenon seen in winter was considered favorable to the living condition of snails which resulted in the increase of the northward spreading of the snails.

El-Gindy and Radhawy (1965), Sturrock and Sturrock (1972) working with different species of aquatic snails observed optimum temperature ranges of 20ºC to 34ºC and lethal extremes of temperature as below 10ºC and above 37ºC. Ezeugwu and Obiamiwe (2003) reported an optimum water temperature range of 25ºC-27ºC with probable maximum lethal temperature of about 37.6ºC and minimum lethal temperature of about 19ºC.Snail population can be controlled by making use of the two extremes of lethal temperatures and this practice will consequently reduce the transmission of schistosomiasis.

Aquatic Vegetation

Aquatic vegetation plays vital roles in the snail vector biology. Most aquatic habitats contain rich microflora which, in combination with decaying aquatic vegetable matter, provide the principal foods for the snails. Jordan and Webbe (1982) reported that while there may be no preference for any particular species of microflora, the quantitative composition of the diet is probably important in conditioning the habitats.

A positive correlation has, however, been found between the presence of a green algae and *Oncomelania quadrasi* and a negative correlation with blue-green algae (Dazo and Moreno 1962). The pulmonate snails have been reported to be essentially browsing animals which feed continuously as they move (Berrie 1970,Ezeugwu and Mafe 1998,Ezeugwu and Okaka,2001).

Aquatic weeds do not only serve as food, they also provide points of attachment for the snails. Ecological studies of *Bulinus truncatus rohlfsi* in Volta Lake have shown a correlation between the spread and proliferation of this species and floating masses of vegetation and in particular, *Ceratophyllum demersum* (Klumpp and Chu 1978).The report also revealed that the roots and hollow stems of *Polygonum sp* provide shelter and protected surfaces for oviposition while the rotting *Polygonum sp* serves as an ideal bottom substrate and snail food source.

Ezeugwu and Okaka (2002) in a comparative study on urinary schistosomiasis in Northern Borno,Nigeria reported the aquatic weeds that influence the biology of snail vectors as *Ipomoea aquatica,Pistia stratiotis,Cyperus escalentus,Sphenoclea zeylanica,Sorghum aethioipicum,Lactuca sp,Momordica charantia,Sida rhombidolia,Citrulus lunatus, Eichornia crassipes* and *Hibiscus cannibinus* in addition to microflora made up of mainly blue and blue-green algae. The report stated that the main functions of these weeds/vegetation were in the provision of attachment sites for the snails, direct consumption as food by the snails, provision of shade to the exposed water surface thereby reducing the effect of high temperature,evaportranspiration and solar radiation while the under surfaces of the leaves act as oviposition sites for the snails.

Certain species of snail exhibit localization in response to certain aquatic vegetation. Kariuki *et al* (2004) working on the distribution patterns of vector snails in Kenya reported that while rainfall was significantly associated with the temporal distribution of all snail species, water lily(*Nymphaea spp*) and several aquatic grass species appeared necessary for local colonization by *Bulinus (afrcanus) nasutus* or *Lanistes purpureus.* Localization therefore is a direct positive response to preferred aquatic vegetation.

Boelee and Laamrani (2004), while working in a Moroccan community, reported that the presence of aquatic vegetation, especially *Potamogeton sp*, was identified as a key factor determining snails occurrence and abundance in canals, impoundments and isolated small puddles and streamlets in the Akka riverbed and that the snails *Bulinus truncatus* and their egg mass densities showed significant reductions after repeated vegetation clearing by the community and also noted that this is an effective control measure for schistosomiasis.Coulibaly *et al* (2004)revealed that a key element in snail habitats is the abundance of the aquatic macrophytes,especially the submerged species and that snail control using environmental modification should focus on controlling these plants in human-water contact sites. Total clearance of aquatic weeds serves as an effective intervention strategy for the control of snail vectors with a resultant effect of reduction in the infection and transmssion of schistosomiasis.

pH (hydrogen ion concentration)

The pH status of an aquatic environment, in combination with other factors, affect the establishment, survival and distribution of snail vectors and the schistosome parasites.Schutte and Frank (1963) while working in S-E Transwaals and adjacent Northern Switzerland reported that very few habitats were found with pH below 6.7 and above 8.4 and that this range was suitable for the snail species .Jordan and Webbe (1982)observed that low pH may be harmful to molluscs,coagulating the mucus on exposed skin surfaces, but that there may be marked diurnal variation in the reaction of water depending upon the carbon dioxide concentration.According to Adewunmi *et al* (1989),the pH range of 6.4-7.0 was well within the reported optimum range for the survival of snails in their natural environment .

Ezeugwu and Okaka(2005) studied the effect of pH on *Bulinus globosus* in Northern Nigeria and reported that the resultant influence of pH on the adult snail vector was positive as against the negative effect it had on snail egg mass. The researchers illustrated the above statement with single regression equations of *B.globosus* and egg mass against pH (in Alau Dam) as follows:

$C_{12} = - 7.30 + 1.82C_2 \pm 3.827$ (positive effect)

$C_{14} = - 15.10 - 1.87C_2 \pm 11.358$ (negative effect)

(where C_2,C_{12} and C_{14} represent pH,*B.globosus* and egg mass respectively).

The report further stated that the pH values of the aquatic habitats studied fell within the range for most fresh waters and since the average mean pH level of 7.38 is on the right side of the neutral pH 7.00,the water are slightly basic which could mean the presence of carbonates and bicarbonates.

According to the report, pH exerted significant ($p \leq 0.05$) controlling effects on *B.globosus* probably through its (pH) roles in biochemical activities in aquatic ecosystems. The interplay of pH and temperature controls the composition and dissociation of complex compounds with the resultant effect of increase in ionized substances which consequently affect the distribution of the snails and their egg masses. The negative effect of pH on the snail egg masses could be applied in the effective control of snail vectors by lowering the pH level towards acidity to destroy the egg masses thereby reducing the number of eggs that could hatch into juvenile snails and this would subsequently lead to the control of urinary and intestinal schistosomiasis.

Water Hardness

The water chemistry and the totality of environmental factors in and around the aquatic habitats exert controlling effects on both the developmental stages of the snail vectors and the infective stages of the schistosome parasites. Water hardness (which is reflected in the form of total hardness ,calcium hardness or magnesium hardness) is an important factor that affects snail distribution. Observation on the distribution of molluscs in relation to water chemistry and effects of different concentrations of calcium and magnesium upon the natality rates of snails has been made. The concentrations of these variables in aquatic habitat determine the suitability of the water to encourage or discourage the establishment and subsequent development of the vectors (Schutte and Frank 1963, Ukoli 1986).

Rundle *et al* (2004) reported that calcium availability interacts with predation cues to modify snail shell growth and form. Small snails increased their growth and were heavier when exposed to fish chemical cues, but that this response was calcium limited.

According to the report, there was also an interactive effect of fish cues and calcium hardness levels on the shell growth of larger snails but shell strength and aperture narrowness were affected by calcium level alone. The authors therefore suggested that the expressions of defensive traits in molluscs can be constrained by calcium availability which has implication for molluscan ecology and evolution.

A study on polymeric release formulations of niclosamide for the control of *Biomphalaria alexandrina*, the vector snail of schistosomiasis by Kenawy and Rizk (2004) reported that the molluscicidal potency of the polymerized niclosamide was increased when the water hardness concentration ($CaC0_3$) was decreased. The report revealed that before embarking on an effective molluscicidal project, the water hardness status of the aquatic habitat must be ascertained as this factor affects the potency of the molluscicide and by implication the effective control of the snail vectors.

The effect of water hardness on two snail vectors has been extensively reported for northern Nigeria (Ezeugwu and Obiamiwe 2002, 2005). The report stated that calcium hardness had a direct positive significant ($P<0.05$) effect on the abundance of *Bulinus globosus* and *B. forskali.* Illustrating with a scatter-diagram with regression line and 95% confidence belt of *B.globosus* and *B.forskali* against calcium hardness, they reported the corresponding single regression equations as:

$Y^1 = -101.39 + 18.15X^1 \pm 7.10$ (positive effect) ------------point 1

$Y^2 = -21.87 + 3.41X^2 \pm 1.47$ (positive effect) -----------------point 2

(where Y^1, Y^2 = *B. globsous , B. forskali* and X^1 X^2 = calcium hardness).

According to the report, *B. globosus* was probably more tolerant to lower levels of calcium hardness than *B. forskali* adding that calcium hardness is a major factor in the snail biology as calcium ions are used in the formation of shells and other mechanical structures in aquatic invertebrates especially snails and clam shells and skeletal structures of vertebrates including fishes. An aquatic habitat deficient in calcium ion concentration would be ideal for the control and reduction in the population of snail vectors of schistosomiasis which would, implicitly, control the transmission of schistosomiasis.

Conclusion:

Schistosomiasis still constitutes a major cause of loss of lives in developing countries especially in tropical Africa.Within the integrated control scheme, snail vector control is still the hope and view of many researchers towards a successful control or reduction in schistosomiasis infection. The interfactorial relationship existing among the snail vectors, the aquatic environment and the micro- and- macro- flora and fauna could be successfully manipulated to produce a controlling effect on the snail vectors. The positive or negative effects reported for water velocity, water level, water temperature, aquatic vegetation, pH and water hardness are veritable tools in snail vector control and, by extension, schistosomiasis control.

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