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Some Physico-chemical Parameters of Atavu River that Influence Gastropod Density at Amagunze Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. Author OOI prepared the study design, coordinated the study, identified gastropods, analyzed the data, wrote the protocol and initial draft of the manuscript. Authors CGE, UCN and MEO sampled gastropods and water, determined water parameters and shed cercariae from gastropods. Authors MJN and AUU sampled aquatic plants in gastropods' habitats, identified human-water-contact activities and managed the literature searches. All authors read and approved the final manuscript submitted for publication.

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ABSTRACT

Aims: The study was focused on the influence of some physico-chemical parameters of water on gastropod density at Atavu River waterlines, Amagunze south-eastern Nigeria.
Study Design: Cross-sectional prospective field study.
Place and Duration of Study: The study was carried out in Atavu River Amagunze, south-eastern Nigeria, between November 2018 and July 2019.
Methodology: Three 20 m^2-quadrat stations were delineated from three respective communities on Atavu River water-lines for gastropod and water sampling for the determinations of some water parameters that could influence gastropod density. Gastropods were sampled with the scoop net for 9 months (November 2017-July 2018) while the species as well as cercariae shed in the laboratory were morphologically identified with Malacology Keys. Water was sampled for routine determination of water temperature, depth, current, electrical conductivity, dissolved oxygen (DO),

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total dissolved solids (TDS), calcium ions (Ca^{++}) and hydrogen ion concentration (pH). Data on gastropod abundance and water parameters were subjected to descriptive statistics. Regression and correlation analysis were employed to determine the nature and degree of relationships between gastropod density and variable physico-chemical parameters of Atavu River.
Results: A total of 197 gastropods were collected from all sampled stations in 9 months, giving an overall mean density of 0.12 snails.m^{-2}. The percentages of identified species were *Bulinus africanus* (45.7), *B. globosus* (33.0), and *B. truncatus* (21.7). About 9.5% of the gastropods recovered shed the characteristic fork-tailed cercariae of *Bulinus* species in the laboratory. Regression of variables on gastropod density indicated positive correlation with Ca^{++}, TDS, DO and electrical conductivity but negative with water current and depth. Water temperature and pH were not easily correlated with gastropod density. Human activities like bathing, swimming, washing, fetching of water for domestic use were observed at Atavu River-lines during the study period.
Conclusion: Fork-tailed cercariae-shedding *Bulinus* species have been recovered from Atavu river-lines where some water parameters influenced gastropod density. *Bulinus* species are known intermediate hosts of *Schistosoma* species that cause schistosomiasis. The on-going and unrestricted water-contact activities at Atavu river is a potential risk for schistosomiasis in Amagunze. This paper advocates for an innovative approach to schistosomiasis control in the study area and elsewhere in the country.

Keywords: Atavu River; Bulinus species; forked-tail cercariae; human activities; Schistosomiasis.

1. INTRODUCTION

Schistosomiasis has long been known to be endemic in more than 76 countries worldwide [1] and its socio–economic and public health importance has been felt in many African countries including Nigeria where substantial transmission occurs in all the states [2] especially among adolescent boys [3,4] who show symptoms of haematuria. *Schistosoma haematobium* is the Trematode blood fluke that causes urogenital schistosomiasis in adolescent boys but emphasis is also shifting on women. Female genital schistosomiasis results from an inflammatory reaction to schistosome eggs trapped in body tissue, leading to fibrosis and scarring of the female genital tract, with early signs of the disease manifesting as a burning sensation in the genitals, spot bleeding, abnormal discharge smell, bloody discharge, stress incontinence and lower abdominal pain [5]. It has also been linked to pain, bleeding and sub- or infertility, leading to social stigma, which is a common issue for women in schistosomiasis-endemic areas in sub-Saharan Africa [6].

Nigeria has about 366 schistosomiasis haematobium geo-referenced endemic foci [7] and part of *S haematobium* life cycle occurs in foci which are freshwater bodies frequently visited by man [8]. In its indirect life cycle, the sub-populations of *S. haematobium* are the adults in human, free-living miracidia, developing larval stages in snail, and free-living cercariae; all are found in freshwater environments (Image 1). The parasite sub-populations are regulated by birth, emigration, immigration and death processes. The free-living infective miracidia and cercariae have short life spans outside their hosts so that the rate of acquisition of infection is directly proportional to the frequency of contact between susceptible host and infective parasite [8]. Transmission-success of human schistosomiasis requires contact between susceptible host and infective cercariae. It means that schistosomiasis cannot be in the absence of snail intermediate host in freshwater bodies (Image 1), and these water bodies can be subject to rapid changes due to human interventions [9].

The endemicity, locality and seasonality of Schistosomiasis in Amagunze Eastern Nigeria where Atavu River provides suitable habitats for gastropods of public health importance has been reported in 1989 [10]. After nine years, this was followed by a school-based schistosomiasis control programme [11]. Although three gastropod species namely, *Bulinus truncatus*, *B. forskalii* and *Biomphalaria pfeifferi* were reported from Amagunze in 1989 [10], there was silence on the influence of physico-chemical parameters of Atavu River on gastropod abundance in the area. Since aquatic snails' habitats are subject to rapid changes due to human interventions [9] we revisited Amagunze 28 years later to study the relationships between physico-chemical parameters of Atavu River on gastropod density. This work was intended to report on the current endemic gastropod species, cercariae-shedding

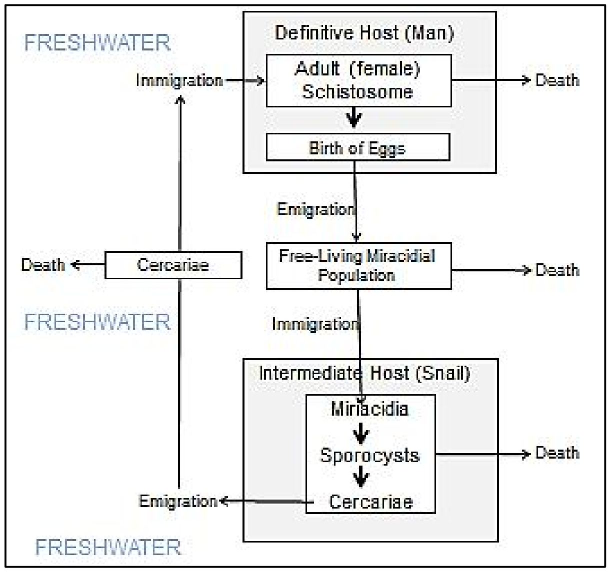

Image 1. Flow-chart of the indirect life-cycle of *Schistosoma haematobium* showing the importance of snail as an intermediate host for the larval stages of the parasite [Illustrated by Dr. OO Ikpeze, Department of Parasitology and Entomology, Nnamdi Azikiwe University Awka Nigeria. October 2020]

species, and the influence of physico-chemical water parameters on gastropod density, as well as on-going human activities at Atavu River and adjoining water bodies. The result from this study will add to the existing body of knowledge on schistosomiasis. It will also help in evidence-based policy decision for innovative schistosomiasis control programme because we have seen that water-contact activities, essential for transmission of schistosomiasis will continue in an area even after health education and treated portable water have been provided [12].

2. MATERIALS AND METHODS

2.1 Study Area

This cross-sectional prospective field study was carried out on the section of Atavu River that traverses Amagunze, the Headquarters of Nkanu East Local Government Area of Enugu State south-eastern Nigeria. The area has temperature of 25°C, 88% relative humidity, wind velocity of 02 ms^{-1}, and a population of 9598 [13]. The Atavu River is a major source of water for domestic purposes in the dry season, and generally for socio-economic purposes throughout the year. The river is also perceived to be the main source of schistosomiasis infection in the area where adolescents are more prone to schistosomiasis, followed by infants, who more frequently move and swim in the river [11].

2.2 Field Sampling Procedures

Three sample stations, namely, Station I (in Onueke community), Station II (in Umuokpara community), and Station III (in Amampkuno community) were chosen for the study. At each station, a 20 m^{-2} quadrat (10 m x 2 m) on the water-line was purposively selected and delineated for gastropod and water sampling because of their preference for water-related activities such as fetching water for domestic use (Plate 1).

Each quadrat was sampled for 9 months, from November 2017 to July 2018. No field activity took place between August and October 2018 due to unforeseen circumstances beyond human control. Gastropod sampling was done with scoop net. The scoop net has a 100 cm handle with a 3 to 4 mm mesh net while the researchers wore a pair of rubber boots and hand gloves for personal protective against infective water-contact (Plate 2).

Between 8.00 am and 10.00 am on each sampling-day monthly, 40 passes were thrown systematically at every 50 cm-interval along the quadrat to collect gastropods. Entrapped gastropods were retrieved from the scoop net with tissue forceps and gloved-hands. Supplemented manual-search for gastropods was also carried out over aquatic cover-plants and other suspended matters (Plate 3). We were also on the watch for human water-contact activities in the study area.

Plate 1. Human activity at Station I on Atavu River

Plate 2. Use of scoop net at Station II on Atavu River

Plate 3. Manual search for gastropods at Station III on Atavu River

Pre-labeled plastic containers were used to store collected gastropods without first clearing them of mud and other debris. Care was taken to cover the containers with perforated lids to maintain air circulation. The collected gastropods were later washed before species identification with standard Malacology Keys [14,15]. Representative samples of the identified species were placed alongside a meter-rule and photographed to obtain their relative sizes. The identified gastropod species were stimulated to shed cercariae in the laboratory after they were individually placed in clean 100 mL beakers containing little quantity of water. Each beaker was placed under a 100-watt shedding-light bulb (Plate 4) for 2 h before the snail was transferred into another beaker for observation of emergent cercariae [16]. The characteristic morphology of the shed-cercariae were observed under enhanced-staining with vital dyes of neutral red and Nile blue sulphate, prepared by addition of 2 drops of 0.1% dye to 50 mL of water. Cercariae identification was done with descriptive keys [17,14,18].

2.3 Determination of Physical Parameters of Water at the Sample Stations on Atavu River

Water Depth was measured monthly using a 100 cm wooden metric [19]. The metric rule was immersed vertically to the depth of waterline at each sample station at monthly intervals and the calibration at the water level was recorded.

Water current was calculated by measuring distance covered by a floating object directly on the river and divided by the time taken to cover 20 m distance [20].

Electrical conductivity was determined by the direct measurement method. Water samples collected in clean plastic containers were analyzed immediately after collection. The meter was immersed in a beaker containing the sample solution. The probe was moved up and down to free any bubbles from the electrode area. The meter was read after ensuring that it was in the COND mode. The results were read in micro Siemens per cm ($ms.cm^{-1}$) which is the reverse micro-ohm [21].

Water temperature was taken *in situ* with ordinary mercury-in-glass thermometer twice daily at 7.00 am and 6.00 pm to obtain the average daily temperature. Monthly temperature was computed by dividing the sum of daily temperatures by days in the particular month.

2.4 Determination of Chemical Parameters of Water from the Sample Stations on Atavu River

The pH was determined when digital pH meter was dipped in water and monitored for about five minutes until the reading on the digital meter fluctuated. The highest value on the scale was recorded as the water pH.

Plate 4. Stimulation of gastropods to shed cercariae

Total dissolved solids (TDS) was measured when the TDS meter was inserted directly into water samples from different stations and recorded when the reading was constant. An average of two readings was recorded.

Dissolved oxygen (DO) was measured using the modified Azide Winkler method when the dissolved oxygen in water sample was fixed by adding a series of reagents that formed an acid compound which was titrated with a neutralizing compound that resulted in a colour change. The point of colour change (i.e., the end point) coincided with dissolved oxygen concentration in the sample [22].

Calcium ion (Ca^{++}) concentration was determined when collected water sample was put into clean 50 mL beaker to which a hardness test strip was placed. The test strip reacted and the developed color which was matched with the printed color chart designed to represent color reactions at various concentrations. The closest color-match-reading was taken as the Ca^{++} concentration [23].

2.5 Aquatic Plants Associated with Gastropod Habitats at Sample Stations

Aquatic plants associated with gastropod habitats were sampled and taken to the Herbarium of Department of Botany, Nnamdi Azikiwe University Awka Anambra State, Nigeria for authentication and identification.

2.6 Data Analysis

Monthly data on gastropod abundance and water parameters were subjected to descriptive statistics. In addition, variable water parameters were regressed on gastropod density, and the probability levels of correlation determined [24].

3. RESULTS

Human water-contact activities like bathing, swimming, washing, and fetching of water for domestic use were regularly observed at Atavu River-lines during the study period (see Plate 1).

3.1 Mean Gastropod Density and Physico-chemical Parameters of Water at Three Sample Stations

A total of 197 freshwater gastropods were recovered from all quadrats in 9 months, giving an overall mean density of 0.12 snails.m^{-2} (Table 1). Station II contributed the highest percentage (48.7%, 0.18 snails.m^{-2}) of the gastropods, and had the highest concentrations of $Calcium^{++}$ ions and least water current. There were fluctuations in physicochemical parameters from station to station, except for temperature, pH and DO.

3.2 Gastropod Species Recovered from the Sample Stations

The three *Bulinus* species identified during the study were *B. africanus*, *B. globosus*, and *B. truncatus*. Their relative sizes at the time of collection (Plate 5) were also shown in centimeters while the relative abundance and density (Table 2) of the species were *B. africanus* (45.7%; 0.06 snails.m^{-2}), *B. globosus* (33.0%; 0.04 snails.m^{-2}), and *B. truncatus* (21.3%; 0.02 snails.m^{-2}). Stations I, II, and III contributed 14.2, 48.7, and 37.1% respectively to the total gastropods collected during the study period (Table 2). About 7.6% of all gastropods shed Furcocercous (fork-tailed) cercariae in the Laboratory (Fig. 1).

Table 1. Gastropod abundance and water physico-chemical parameters at the Sample Stations

Station	Gastropod			Temp	Depth	Current	Cond.	TDS	DO	Ca^{++}	pH
	No.	***%***	****snailsm^{-2}***	***°C***	***cm***	***cms^{-1}***	***σ***	***mgL^{-1}***	***mgL^{-1}***	***mgL^{-1}***	
I	28	14.2	0.05	31.2	8.2	4.1	54.3	27.6	3.6	5.7	7.3
II	96	48.7	0.18	30.9	7.5	2.9	61.9	31.8	3.8	6.3	7.2
III	73	37.1	0.14	30.7	8.1	3.1	79.4	42.8	3.9	6.2	7.1
Total	197		0.37								
Mean	65.7		0.12	31.0	7.9	3.4	65.2	34.1	3.8	6.1	7.2

**Mean monthly gastropod density=* $\frac{Mean\ gastrpod\ abundance\ (no.)}{(No.\ of\ sampled\ quadrats)x\ (Area\ of\ each\ quadrat)x(no.of\ months)}$

Mean monthly gastropod density at each station= $\frac{mean\ abundance}{3x20x9}=\frac{65.7}{540}$ *= 0.12 snailsm^{-2} [25]*

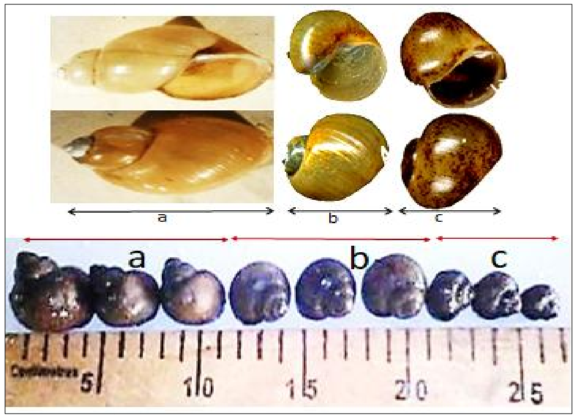

Plate 5. Scale measurements of identified [a] *B. africanus,* [b] *B. globosus, and* [c] *B. truncates*

**This measurement were not absolute but taken at a particular stage in the growth and development of the representative species at the time of collection*

Table 2. Abundance and density of *Bulinus* species at three sample stations

Stations	*B. africanus*		*B. globosus*		*B. truncatus*		Total abundance	
	no.	%	no.	%	no.	%	no.	%
I	14	50.0	8	28.6	6	21.4	28	14.2
II	45	46.9	28	29.2	23	23.9	96	48.7
III	31	42.5	29	39.7	13	17.8	73	37.1
Total	90	45.7	65	33.0	42	21.3	197	100.0
Mean	30		21.7		14		65.7	
Monthly density (snailm^{-2})	0.06		0.04		0.02		0.12	

**Mean monthly gastropod density=* $\frac{Mean\ gastrpod\ abundance\ (no.)}{(No.\ of\ sampled\ quadrats)x\ (Area\ of\ each\ quadrat)x(no.of\ months)}$

Mean monthly gastropod density at each station= $\frac{Mean\ abundance}{3x20x9}=\frac{65.7}{540}$ *= 0.12 snailsm*$^{-2}$ *[25]*

Table 3. *Bulinus* species that shed cercariae in the laboratory

Bulinus **species.**	**Recovered**	**Cercariae-shedding**	
	No.	***No.***	***%***
B. africanus	90	6	6.7
B. globosus	65	5	7.7
B. truncatus	42	4	9.5
Total	197	15	7.6

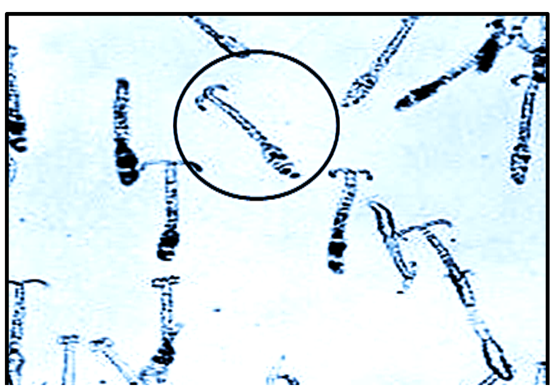

Fig. 1. *Furcocercous cercariae* shed by *Bulinus* species

3.3 Mean Monthly Gastropod Density and Water Parameters at Sample Stations

The overall mean monthly gastropod density (snails.m^{-2}) and water parameters at the three sample stations (Table 4) indicated that gastropod density began to increase with early rains in April, peaked in June and declined with heavy rains in July. Water depth also rose up to 9 cm towards the end of rainy season in November before receding about February. Water current ≥3 cm.s^{-1} was considered to be fast. There was no significant seasonal fluctuation in water temperature and pH as was the case with electrical conductivity, TDS, DO, and Ca^{++} concentrations.

Regression of variable water parameters on *Bulinus* density revealed strong and positive correlation with Ca^{++} (Fig. 2), TDS (Fig. 3), DO (Fig. 4) and electrical conductivity (Fig. 5).

Negative correlation was however observed between water current and *B*ulinus density (Fig. 6), and also between water depth and *Bulinus* density (Fig. 7).

The relationship between *Bulinus* density and water temperature (Fig. 8) and pH (Fig. 9) at the three sample stations were not strong as *Bulinus* species seemed to prefer limited ranges of temperature and pH.

Table 4. Mean monthly *Bulinus* density (snailsm^{-2}) and water parameters at sample stations

	***Bulinus* species**		***Temp***	***Depth***	***Current***	***Cond.***	***TDS***	***DO***	***Ca^{++}***	***pH***
	No.	***snailm^{-2}***	**°C**	***cm***	**cms^{-1}**	***σ***	**mgL^{-1}**	**mgL^{-1}**	**mgL^{-1}**	
Nov-2017	9	0.15	28.8	*9.6*	4.3	54	24	2.0	3.5	7
Dec	13	0.22	27.7	8.9	3.4	58	31	2.1	4	7.3
Jan-2018	1	0.02	31.7	8.5	4.2	64	31	2.1	4.3	7
Feb	0	0	31.8	7.8	4.4	68	35	2.1	4.8	7.1
Mar	2	0.03	31.8	7.6	3	70	35	2.6	5.5	7.3
Apr	10	0.17	29.1	7.5	3	55	37	3.5	7.3	7.1
May	31	0.52	32.7	7.4	2.7	68	36	4.2	8	7.1
Jun	70	1.17	33.4	6.8	2.7	73	40	7.3	9.2	7.5
Jul-2018	61	1.02	31.6	6.5	2.4	77	58	5.1	9.5	7.2
Total	197	3.3								
Monthly mean	21.9	0.12	31	7.8	3.3	65.2	36.3	3.4	6.2	7.2

Mean monthly gastropod density= $\frac{Mean\ gastrpod\ abundance\ (no.)}{(No.\ of\ sampled\ quadrats) x\ (Area\ of\ each\ quadrat) x (no. of\ stations)}$

Mean monthly gastropod density at each station = $\frac{Mean\ abundance}{3x20x3} = \frac{21.9}{180}$ = 0.12 snail.m^{-2} [25]

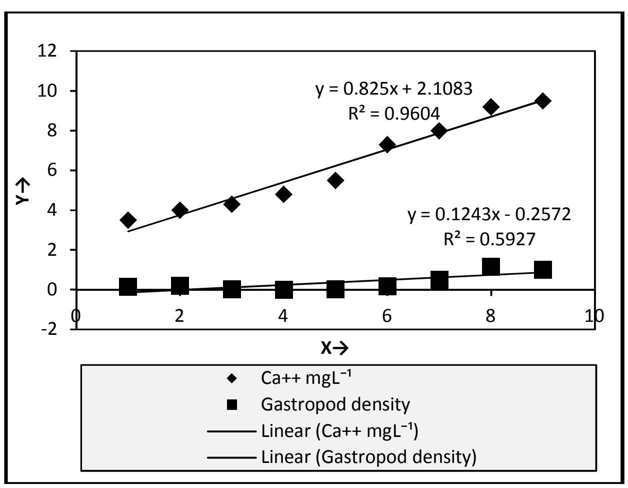

Fig. 2. *Bulinus* density versus Ca^{++} ions concentration

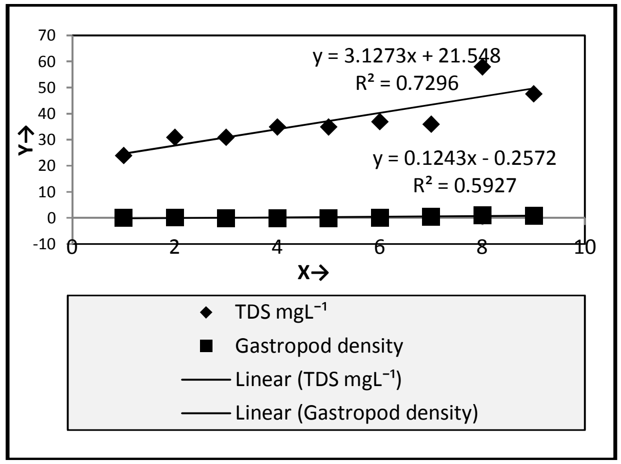

Fig. 3. *Bulinus* density versus concentrations of TDS

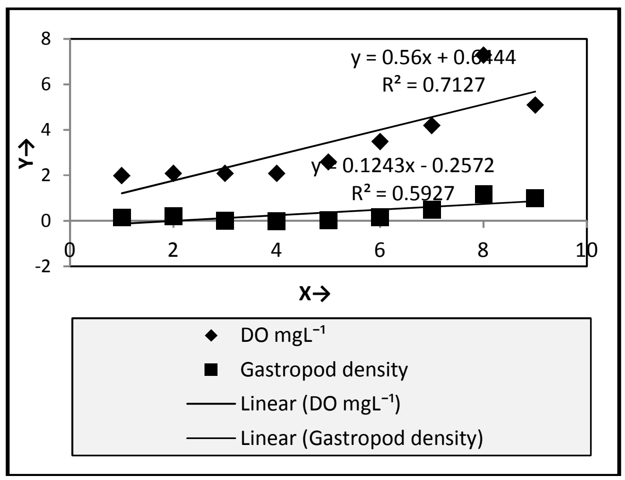

Fig. 4. *Bulinus* density versus DO concentration

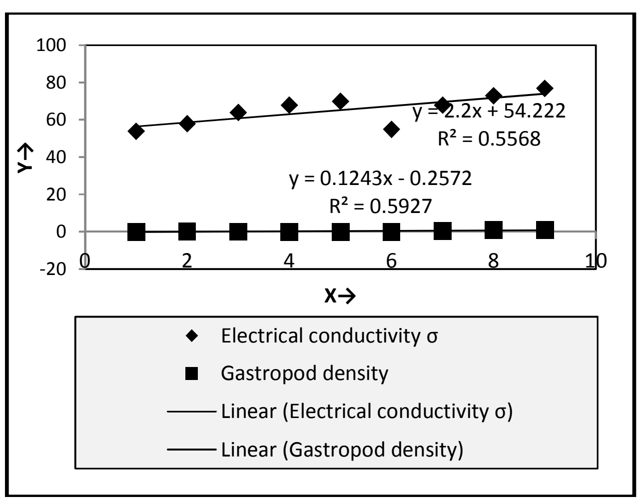

Fig. 5. *Bulinus* density versus electrical conductivity

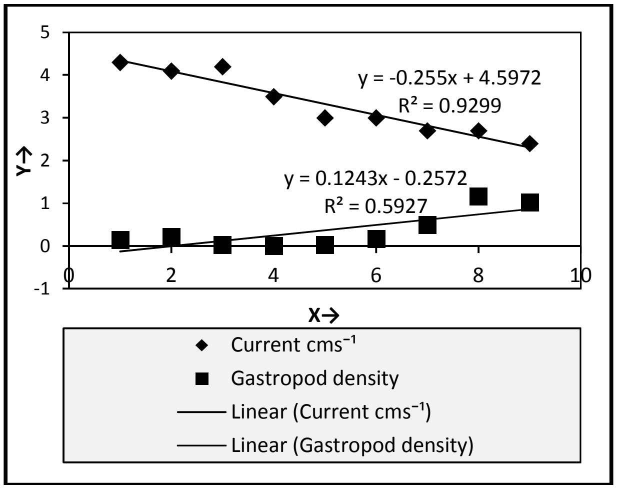

Fig. 6. *Bulinus* density versus water current

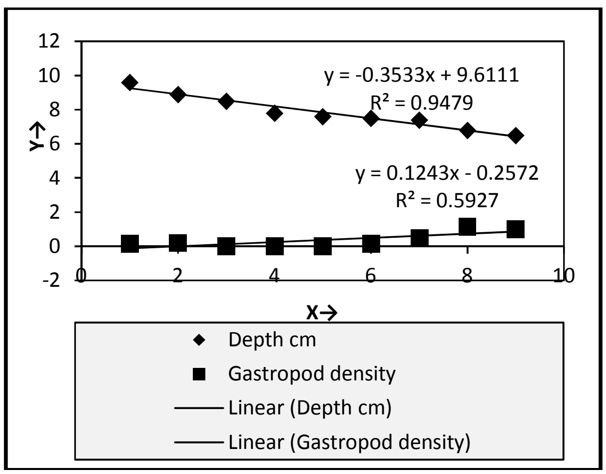

Fig. 7. *Bulinus* density versus water Depth

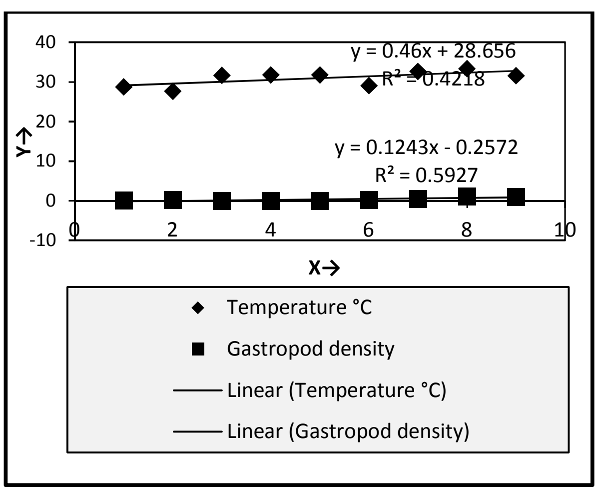

Fig. 8. *Bulinus* density versus water temperature

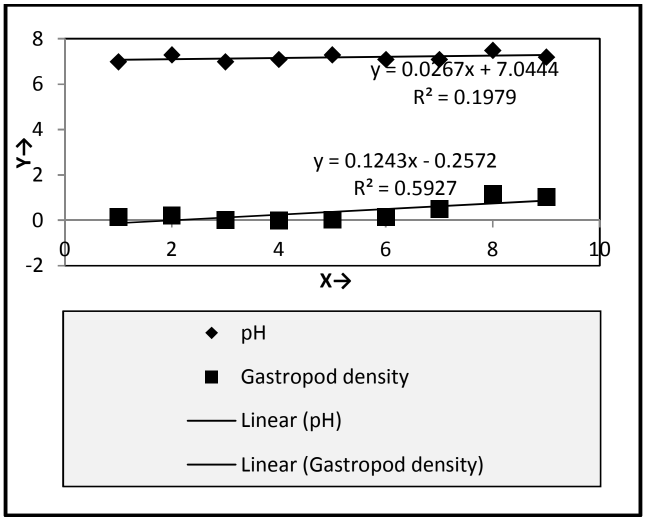

Fig. 9. *Bulinus* density versus water pH

Coefficients of determination (R^2) from regression of water variables on *Bulinus* density, and the corresponding correlation coefficients $r_{cal.}$ ($\sqrt{R^2} = r$) were used to determine the probability levels at which correlation was significant (Table 5). The degrees of freedom (*df*) for correlation is n-2 (i.e., 9-2=7*df*), and critical values $r_{crit.}$ for $r_{0.05\,(2),\,7df} = 0.666$, and $r_{0.01\,(2),\,7df} = 0.798$. When $r_{cal.} > r_{crit.}$ the correlation is significant at the specified level of probability [24]. With the exception of temperature and pH, the correlation between water parameters and Bulinid density were either strongly positive or strongly negative (*P*<.01); electrical conductivity was not strongly correlated (*P<.05*).

3.4 Aquatic Vegetation Associated with Gastropod Habitats

Eight aquatic plants identified from gastropod habitats (Plate 6) included *Axonopus compresus*, *Panicum maximum*, *Brachiaria falcifera*, *Brachiaria deflexa*, *Centrosema pubescens*, *Pteridium aquilinum*, *Paspalum serobisculatiun* (Farn poacae), and *Alchornea laxiflora.*

Table 5. Significant levels of correlation between variable physico-chemical parameters of water and *Bulinus* density

Regression			Correlation	
Variable (y) Vs. Density (x)	**R^2**	**$r_{cal.}$**	**$r_{0.05(2),7} = 0.666$**	**$r_{0.01(2),7} = 0.798$**
Ca++ Vs. Density	0.9604	0.9800	*Correlation was significant at both probability levels (*P*<.01)	
TDS Vs. Density	0.7296	0.8541	*Correlation was significant at both probability levels (*P*<.01)	
DO Vs. Density	0.7127	0.8442	*Correlation was significant at both probability levels (*P*<.01)	
Current Vs. Density	0.9299	0.9643	*Correlation was significant at both probability levels (*P*<.01)	
Depth Vs. Density	0.9497	0.9745	*Correlation was significant at both probability levels (*P*<.01)	
Conductivity Vs. Density	0.5568	0.7461	Correlation was significant at only one probability level (*P*<.05)	
Temperature Vs. Density	0.4218	0.6494	There was no correlation	
pH Vs. Density	0.1979	0.4448	There was no correlation	

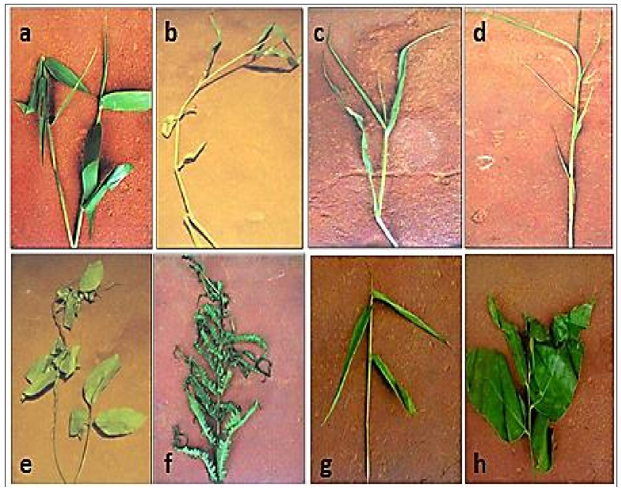

Plate 6. Dominant aquatic macrophytes from sampled gastropod habitats
[a] Axonopus compresus, [b] Panicum maximum, [c] Brachiaria falcifera, [d] Brachiaria deflexa, [e] Centrosema pubescens, [f] Pteridium aquilinum, [g] Paspalum serobisculatiun (Farn poacae), and [h] Alchornea laxiflora

4. DISCUSSION

The three *Bulinus* species recovered from Amagunze supported earlier reports on *Bulinus* species from different parts of Nigeria, including Man-made Oyan Reservoir in southwest [26], Agulu Lake in southeast [8], Vandeikya LGA in Benue State [27] and Kubanni reservoir in Zaria [28]. Moreover, molecular identification of *Bulinus* samples from 8 states of Nigeria showed that majority belonged to *B. truncatus* while only two were *B. globosus* [2]. It is interesting to note that *B. africanus* and *B. truncatus* are the less abundant species in Douv dam freshwater of Farth Nord region in nearby Cameroon [29]. Three Bulinus species we recovered at Amagunze did not include *Biomphalaria pfeifferi* reported in 1989 [10], perhaps anthropogenic activities in Atavu River might have negative impact leading to habitat change of freshwater gastropods as reported from mollusk-inhabited freshwater bodies in Northern Nigeria [30], and at Omo-Gibe river basin in Ethiopia [31].

Bulinus species recovered from Amagunze were induced to shed furcocercous cercariae in the laboratory but we could not establish the *Schistosoma* species involved. However, molecular sequencing of the partial schistosome from a small subset of *Bulinus* samples from Nigeria revealed that some snails were either penetrated by both *Schistosoma haematobium* and *S. bovis* miracidia or hybrid miracidia formed from the two species [2]. *Bulinus globosus* and *L. natalensis* were also observed to be infected by more than one and same type of cercariae in Ethiopia [31].

The variation in physicochemical parameters of water at the sample stations was not significantly different (p >.05) for temperature, pH and DO. With the exception of temperature and pH, the correlation between other parameters and Bulinid density were either strongly positive or strongly negative (P>.01) but electrical conductivity was weakly correlated (P>*.05*). Though some authors [26,32] maintain that pH is rarely a factor limiting snail distribution. Reports from Upper Egypt [33] and Brazil [34] indicated that pH ranges of 6.8-7.95 and 7.0-8.0 respectively are optimally normal for development of aquatic Molluscs. Water temperature beyond 30°C may be lethal to some gastropods' development but some can survive temperatures between 10 and 35°C [8].

Snails were expected to be more abundant in the hot dry season probably because aquatic habitat would be stable in terms of water level and velocity. This was so in Northern Nigeria where positive association was established between snail abundance and high water temperature [35]. However we recovered higher numbers of *Bulinus* species in the rainy season. Comparison of Freshwater Mollusc Assemblages between Dry and Rainy Season in freshwater pond systems in Bogor, Indonesia revealed that abundance of Molluscs were generally higher in rainy than dry season in all freshwater ponds [36]. These authors [36] pointed out that six dominant species including *Melanoides tuberculata and Pila scutata* (gastropods) were ubiquitous during dry season while the numbers of two gastropod species (*Pomacea canaliculata* and *Wattebledia crosseana*) were higher in the rainy season. It was reported from Farth Nord region Cameroon that the population of *Lymnaea natalensis* presents a single annual generation which starts to appear in September and the number peaks between the end of the dry season and the middle of the rainy season [29]. It appears that seasonal abundance would depend on the species of gastropods and the aquatic ecosystem.

Dissolved oxygen in water bodies tends to reduce with increased water temperature in the presence of decomposition of organic matter [8,37]. Low oxygen level has also been linked to slow flowing nature of waters which could limit dissolved oxygen level [22]. Dumping of refuse in or near Atavu River is prohibited, so there was no serious case of microbial putrefaction that would take-up DO meant for gastropods. High concentrations of calcium ions and TDS were expected in Atavu River because of the large deposit of limestone which provided the raw material for the large cement plant of the Nigerian Cement company at nearby Ebonyi State.

Aquatic vegetation maintained suitable substrates for ovipositor and feeding of snails as well as protecting the snails from high water velocities and predator fish and birds [38]. It was reported that abundance of freshwater snails in Benue tributaries was due to availability of food, shelter and ovipositor sites provided by aquatic plants to which snails were attached [39]. At least 8 aquatic plants associated with gastropod habitat were identified during the present study and *Bulinus* species were often seen clustering around aquatic vegetation or floating on submerged plant materials. Most gastropod species from streams of Moorea in French Polynesia were reported to have higher densities during Austral Fall than Austral Spring, with no observable relationship between substrate type and either species presence-abundance or shell size but a stepwise multiple regression indicated that velocity, depth, and substrate roughness were determinants of gastropod abundance for some species within these streams [40].

The Atavu River is a major source of water for domestic purposes in the dry season, and generally for socio-economic purposes which included swimming, washing, and vegetable gardening, throughout the year. The river is also perceived to be the main source of schistosomiasis infection in the area where adolescents are reported to be prone to schistosomiasis, followed by infants, who more frequently move and swim in the river [11].

5. CONCLUSION

Fork-tailed cercariae-shedding *Bulinus* species have been recovered from Atavu river-lines where the water parameters studied influenced gastropod density. *Bulinus* species are known intermediate hosts of *Schistosoma* species that cause schistosomiasis. On-going human activities at Atavu river and adjoin water bodies constituted potential risks for schistosomiasis in Amagunze. This paper advocates for an innovative approach to schistosomiasis control in the study area and elsewhere in the country because water-contact activities essential for transmission of schistosomiasis have continued in the area even after health education and portable water have been provided.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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